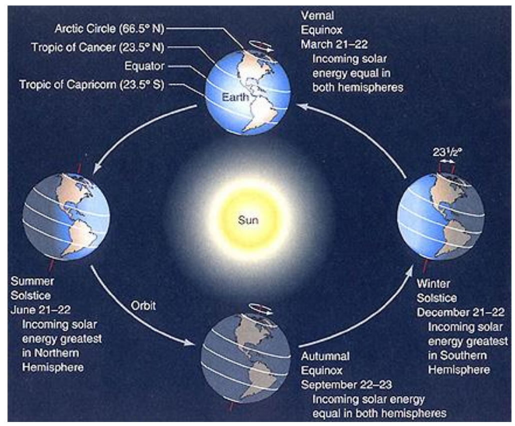
Astronomy

Astronomy: Earth

mass (kg)	radius (km)	average density (gm/cm^3)	standard atmosphere (pascals)
5.97×10^{24}	6,378	5.514	101,325
mean distance from Sun (km = 1 AU)	perihelion (km)	aphelion (km)	axial tilt
1.496×10^8	1.471×10^8	1.521×10^8	23.45^0
gravity (m/s^2)	average orbital speed (km/s)	escape velocity (km/s)	orbital eccentricity
9.81	29.78	11.186	0.0167

Astronomy: Equinoxes and Solstices



equinox: when the plane of Earth's equator passes through the center of the Sun, occurs around Mar. 20 and Sep. 23

solstice: when the Sun reaches its most northern or southern excursion relative to the celestial equator; occurs around Jun. 21 and Dec. 21

(Image source: NASA, public domain)

Astronomy: Milankovitch Cycles (1)

Milankovitch cycles: describes the collective effects of changes in the Earth's movements on climate; theory that variations in eccentricity, axial tilt, and precession of Earth's orbit strongly influenced climatic patterns

eccentricity: Earth's orbital eccentricity varies between nearly circular, with the lowest eccentricity of 0.000055, and mildly elliptical, highest eccentricity of 0.0679, with the mean eccentricity of 0.0019

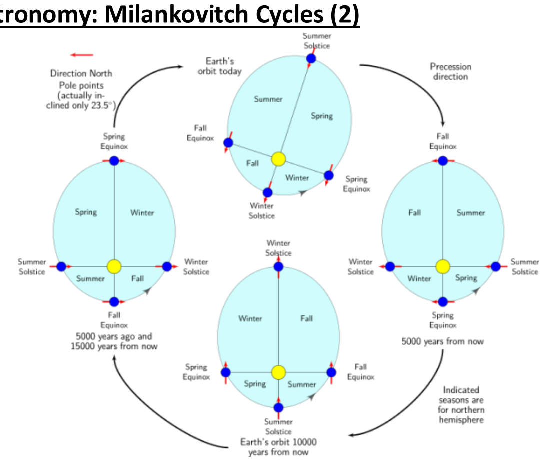
axial tilt: varies with respect to the plane of Earth's orbit; slow 2.4° obliquity variations take approximately 41,000 years to shift between 22.1° and 24.5° and back again; when obliquity increases, amplitude of the seasonal cycle in insolation increases, summers in both hemispheres receive more radiative solar flux, and less in winters; when the obliquity decreases, summers receive less and winters receive more

precession: trend in direction of Earth's axis of rotation relative to fixed stars, period of about 26,000 years; gyroscopic motion is due to tidal forces exerted by the Sun and the Moon on Earth; both contribute equally to this effect.

Astronomy: Milankovitch Cycles (2)

(Source of (1): https://en.wikipedia.org/wiki/Milankovitch_cycles)

(Image source: https://en.wikipedia.org/wiki/Milankovitch_cycles#/media/File:Precession_and_seasons.svg, Author: Krishnavedala, CC BY-SA 3.0)



Astronomy: Sidereal and Synodic Periods (1)

Earth		Moon	
sidereal rotation period in hours	sidereal orbital period in days	sidereal period in days	synodic period in days
23h 56m 4.099s	365.25636	27.32166	29.53059

sidereal period: amount of time that it takes an object to make a full orbit, relative to the stars; the sidereal day is 23h 56s

synodic period: amount of time that it takes for an object to reappear at the same point in relation to two or more other objects

synodic period between two bodies $\frac{1}{P_{syn}} = \frac{1}{P_1} + \frac{1}{P_2}$

P_1 and P_2 are the orbital periods of the two bodies

Astronomy: Sidereal and Synodic Periods (2)

prograde motion:

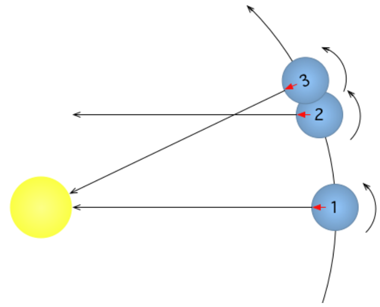
$$\text{length of solar day} = \frac{\text{length of sidereal day}}{1 - \dfrac{\text{length of sidereal day}}{\text{orbital period}}}$$

retrograde motion:

$$\text{length of solar day} = \frac{\text{length of sidereal day}}{1 + \dfrac{\text{length of sidereal day}}{\text{orbital period}}}$$

Astronomy: Sidereal and Synodic Periods (3)

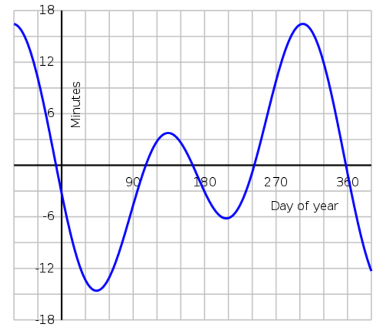
On a prograde planet like Earth, the stellar day is shorter than the solar day. At time 1, the Sun and a certain distant star are both overhead. At time 2, the planet has rotated 360° and the distant star is overhead again but the Sun is not (1→2 = one stellar day). It is not until a little later, at time 3, that the Sun is overhead again (1→3 = one solar day).



(Image source: https://en.wikipedia.org/wiki/Earth%27s_rotation#/media/File:Sidereal_day_(prograde).png, Author: Gdr, CC BY-SA 3.0)

Astronomy: Equation of Time

apparent solar time: time indicated by a sundial
mean solar time: average as indicated by well-regulated clocks
equation of time: difference between apparent solar time and mean solar time
above the axis: sundial will appear fast relative to a clock; below the axis sundial will appear slow



(Image source: https://en.wikipedia.org/wiki/Equation_of_time#/media/File:Equation_of_time.svg, Author: Drini, CC BY-SA 3.0)

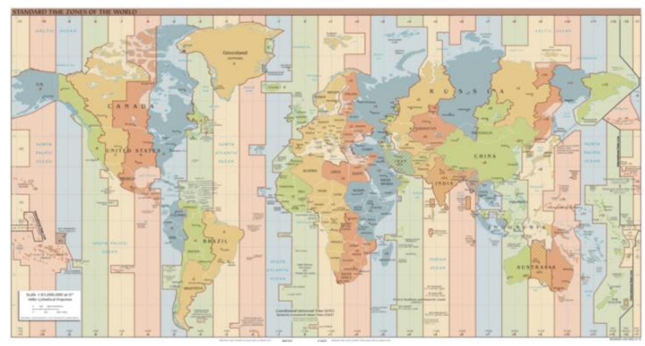
Astronomy: Universal Time and Coordinated Universal Time

universal time: time standard based on Earth's rotation; modern continuation of Greenwich Mean Time (GMT), the mean solar time on the Prime Meridian at Greenwich, London, UK

Coordinated Universal Time (UTC): primary time standard by which the world regulates clocks and time; is within about 1 second of mean solar time at 0° longitude; does not observe daylight saving time

(Sources: https://en.wikipedia.org/wiki/Universal_Time, https://en.wikipedia.org/wiki/Coordinated_Universal_Time)

Astronomy: Time Zones



(Image source: https://en.wikipedia.org/wiki/Time_zone#/media/File:Standard_World_Time_Zones.png, Author: TimeZonesBoy, CC BY-SA 4.0)

Astronomy: Orbits (1)

orbital speed $v = \sqrt{\frac{GM}{r}}$ escape speed $v = \sqrt{\frac{2GM}{r}}$

gravitational constant G = 6.67408 x 10^{-11} N m^2/kg^2

M = mass of body around which object is orbiting

r = distance of orbiting body from the center of mass M

gravitational potential energy $U = \frac{-GMm}{r}$

orbital period $T = \left(\frac{2\pi}{\sqrt{GM}}\right) r^{3/2}$ gravity $g = \frac{GM}{r^2}$

two massive bodies orbiting each other: $T = \left(\frac{2\pi}{\sqrt{G(M_1 + M_2)}}\right) r^{3/2}$

Astronomy: Orbits (2)

retrograde motion: motion backward from the norm
perigee: point in the orbit of the moon or a satellite at which it is nearest to Earth
apogee: point in the orbit of the moon or a satellite at which it is furthest from Earth
perihelion: point in the orbit of a planet, asteroid, or comet at which it is closest to the sun
aphelion: point in the orbit of a planet, asteroid, or comet at which it is furthest from the sun
periapsis: the point in the path of an orbiting body at which it is nearest to the body that it orbits
apoapsis: the point in the path of an orbiting body at which it is farthest from the body that it orbits

Astronomy: Orbit Classifications (1)

- altitude classifications
  - low Earth orbit (LEO): orbits ranging in altitude from 160 kilometers (100 statute miles) to 2,000 kilometers above mean sea level
  - medium Earth orbit (MEO): orbits with altitudes at apogee ranging between 2,000 kilometers and that of the geosynchronous orbit at 35,786 kilometers
  - geosynchronous orbit (GEO): circular orbit with an altitude of 35,786 kilometers; period equals one sidereal day, coinciding with the rotation period of the Earth
  - high Earth orbit (HEO): altitudes at apogee higher than that of the geosynchronous orbit

Astronomy: Orbit Classifications (2)

- eccentricity classifications
  - circular orbit: has an eccentricity of 0 and path traces a circle
  - elliptic orbit: eccentricity greater than 0 and less than 1 whose orbit traces the path of an ellipse
  - Hohmann transfer orbit: orbital maneuver that moves a spacecraft from one circular orbit to another using two engine impulses
  - geosynchronous transfer orbit: geocentric-elliptic orbit where perigee is at the altitude of a low Earth orbit (LEO) and apogee at altitude of a geosynchronous orbit
  - highly elliptical orbit (HEO):-geocentric orbit with apogee above 35,786 km and low perigee of about 1,000 km that result in long dwell times near apogee

(Source: https://en.wikipedia.org/wiki/Geocentric_orbit)

Astronomy: Orbital Elements (1)

- eccentricity (e): shape of the ellipse, describing how much it is elongated compared to a circle
- semimajor axis (a): sum of the periapsis and apoapsis distances divided by two
- inclination (i): vertical tilt of the ellipse with respect to the reference plane
- longitude of the ascending node (Ω): horizontally orients the ascending node of the ellipse with respect to the reference frame's vernal point
- argument of periapsis (ω): defines the orientation of the ellipse in the orbital plane, as an angle measured from the ascending node to the periapsis
- true anomaly (ν) at epoch(M_0): defines the position of the orbiting body along the ellipse at a specific time (the "epoch")

Astronomy: Orbital Elements (2)

$e = \dfrac{r_a - r_p}{r_a + r_p}$ r_p = perihelion distance r_a = aphelion distance

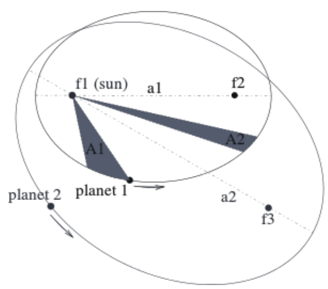
$a = \dfrac{r_p + r_a}{2}$ object circular velocity $v_c = \sqrt{\dfrac{GM}{a}}$

perihelion velocity $v_p = v_c\sqrt{\dfrac{1+e}{1-e}}$ aphelion velocity $v_a = v_c\sqrt{\dfrac{1-e}{1+e}}$

velocity at distance r $v_r = \sqrt{GM\left(\dfrac{2}{r} - \dfrac{1}{a}\right)}$

Astronomy: Kepler's Laws

1. The orbit of a planet is an ellipse with the Sun at one of the two foci.
2. A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.
3. The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit. $P^2 = a^3$



(Image source: https://en.wikipedia.org/wiki/Kepler%27s_laws_of_planetary_motion#/media/File:Kepler_laws_diagram.svg, Author: Hankwang, CC BY 2.5)

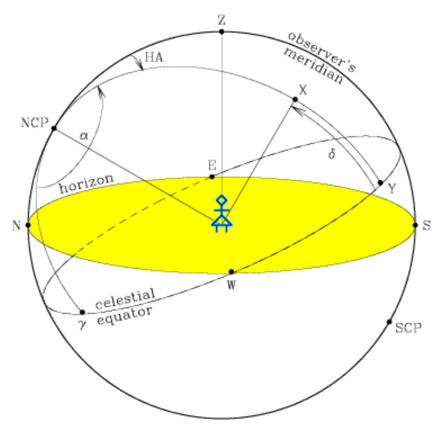
Astronomy: Right Ascension and Declination

right ascension: abbreviated ra, celestial equivalent of terrestrial longitude; measured from the vernal equinox, or the First Point of Aries, which is the place on the celestial sphere where the Sun crosses the celestial equator from south to north at the March equinox, currently located in the constellation Pisces; measured in hours (h), minutes (m), and seconds (s), with 24h equivalent to a full circle

declination: abbreviated dec; symbol δ; one of the two angles that locate a point on the celestial sphere in the equatorial coordinate system; measured north or south of the celestial equator, along the hour circle passing through the point in question

hour angle: measures the angular distance of an object westward along the celestial equator from the observer's meridian to the hour circle passing through the object; always increasing with Earth's rotation; may be considered a means of measuring the time since an object crossed the meridian; astar on the observer's celestial meridian has a zero hour angle

Astronomy: Right Ascension and Declination

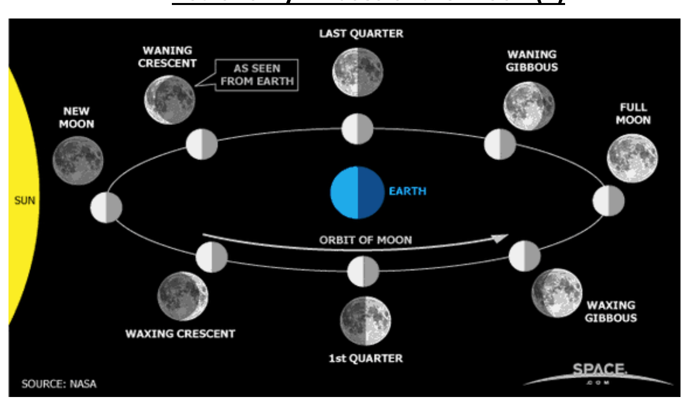


(Image source: http://astronomy.nmsu.edu/nicole/teaching/ASTR505/lectures/lecture08/slide05.html, Author: M. Vogt, New Mexico State University)

Astronomy: Phases of the Moon (1)

phase	moonrise	overhead time	moonset
new	6 am	noon	6 pm
waxing crescent	9 am	3 pm	9 pm
first quarter	noon	6 pm	midnight
waxing gibbous	3 pm	9 pm	3 am
full	6 pm	midnight	6 am
waning gibbous	9 pm	3 am	9 am
third quarter	midnight	6 am	noon
waning crescent	3 am	9 am	3 pm

Astronomy: Phases of the Moon (2)



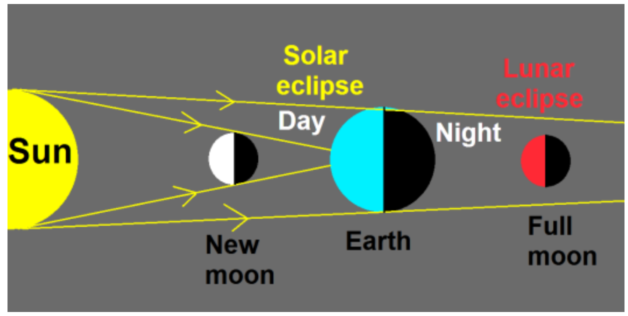
(Image source: NASA, public domain)

Astronomy: Lunar and Solar Eclipses (1)

lunar eclipse: occurs when the Moon passes directly behind the Earth into its umbra (shadow), can occur only when the sun, Earth, and moon are aligned ("syzygy"), with the Earth in the middle, a lunar eclipse can occur only the night of a full moon

solar eclipse: occurs when the Moon passes between the Sun and Earth, and the Moon fully or partially blocks ("occults") the Sun, can happen only at new moon when the Sun and the Moon are in conjunction as seen from Earth in an alignment ("syzygy"), in a total eclipse, the disk of the Sun is fully obscured by the Moon, in partial and annular eclipses, only part of the Sun is obscured

Astronomy: Lunar and Solar Eclipses (2)



(Image source: https://en.wikipedia.org/wiki/Lunar_eclipse#/media/File:Solar_lunar_eclipse_diagram.png, Author: Tomruen, CC BY-SA 4.0)

Bortle Dark Sky Scale (1)

class	title	NELM	
1	excellent dark sky	7.6 - 8.0	• zodiacal light, gegenschein, zodiacal band, airglow readily visible • many constellations, particularly fainter ones, barely recognizable due to large number of stars • many Messier and globular clusters are naked-eye objects • M33 is a direct vision naked-eye object
2	typical truly dark sky	7.1 – 7.5	• zodiacal light is distinctly yellowish, bright enough to cast shadows at dusk and dawn • airglow may be weakly visible near horizon • summer Milky Way highly structured • many Messier objects and globular clusters are naked-eye objects • M33 is easily seen with naked eye

NELM – naked eye limiting magnitude

Bortle Dark Sky Scale (2)

class	title	NELM	
3	rural sky	6.6 – 7.0	• zodiacal light is striking in spring and autumn, and color is still visible • some light pollution evident at the horizon, dark overhead • nearer surroundings are vaguely visible • the summer Milky Way still appears complex • M15, M4, M5, and M22 are naked-eye objects • M33 is easily visible with averted vision
4	rural/ surban transition	6.1 – 6.5	• zodiacal light still visible • light pollution domes visible in several directions • clouds illuminated in the directions of the light sources, dark overhead • surroundings clearly visible, even at a distance • Milky Way well above the horizon but lacks detail • M33 difficult, averted vision object, visible when high

Bortle Dark Sky Scale (3)

class	title	NELM	
5	sub-urban sky	5.6 – 6.0	• only hints of zodiacal light are seen on the best nights in autumn and spring • light pollution is visible in most, if not all, directions • clouds are noticeably brighter than the sky • Milky Way very weak or invisible near the horizon, looks washed out overhead
6	bright sub-urban sky	5.1 – 5.5	• zodiacal light is invisible • light pollution makes the sky within 35° of horizon grayish white • clouds anywhere in the sky appear fairly bright • surroundings are easily visible • Milky Way is only visible near the zenith • M33 is not visible, M31 is modestly apparent

Bortle Dark Sky Scale (4)

class	title	NELM	
7	sub-urban/ urban transition	4.6 – 5.0	• light pollution makes the entire sky light gray • Milky Way invisible • M31 and M44 may be glimpsed, but with no detail • brightest Messier objects are dim
8	city sky	4.1 – 4.5	• sky is light gray or orange, one can easily read • stars forming familiar constellations weak or invisible • M31 and M44 are barely glimpsed by experienced observer • only bright Messier objects detectable, with telescope
9	inner city sky	4.0	• sky is brilliantly lit • many constellations barely visible • aside from Pleiades, no Messier object naked eye visible • only observable objects are Moon, planets, a few bright star clusters

(Source: https://en.wikipedia.org/wiki/Bortle_scale)

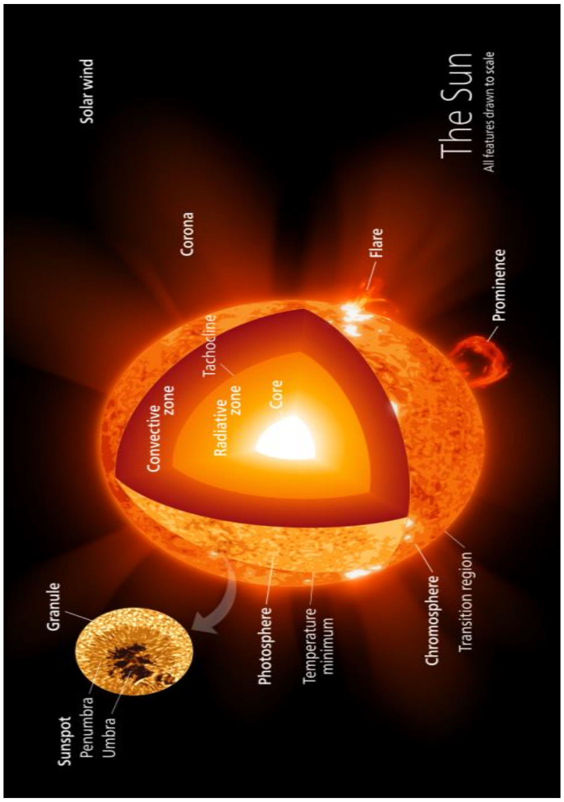
Observational Astronomy (1)

radio astronomy: uses radiation outside the visible range with wavelengths greater than approximately one mm; different from most other forms of observational astronomy in that the observed radio waves can be treated as waves rather than discrete photons
infrared astronomy: founded on the detection and analysis of infrared radiation, wavelengths longer than red light and outside the range of our vision; useful for studying objects that are too cold to radiate visible light, such as planets, circumstellar disks or nebulae
optical astronomy: modern images are made using digital detectors, particularly using charge-coupled devices (CCDs) and recorded on modern medium; visible light itself extends from approximately 4000 Å to 7000 Å that same equipment can be used to observe some near-ultraviolet and near-infrared radiation

Observational Astronomy (2)

ultraviolet astronomy: employs UV wavelengths between 100 and 3200 Å; light at those wavelengths absorbed by the Earth's atmosphere, requiring observations to be performed from upper atmosphere or space; suited to study of thermal radiation and spectral emission lines from blue stars, planetary nebulae, supernova remnants, active galactic nuclei
X-ray astronomy: X-rays absorbed by Earth's atmosphere; all X-ray observations must be performed from high-altitude balloons, rockets, or X-ray astronomy satellites; X-ray sources include X-ray binaries, pulsars, supernova remnants, elliptical galaxies, clusters of galaxies, active galactic nuclei
gamma ray astronomy: satellites observes astronomical objects at shortest wavelengths; most gamma-ray emitting sources are actually gamma-ray bursts, objects which only produce gamma radiation for a few milliseconds to thousands of seconds before fading away
(Source: https://en.wikipedia.org/wiki/Astronomy)

Astronomy: Structure of the Sun (1)



(Image source: https://en.wikipedia.org/wiki/Sun#/media/File:Sun_poster.svg, Author: Kelvinsong, CC BY-SA 3.0)

Astronomy: Structure of the Sun (2)

layer	description
core	extends from center to about 20–25% of the solar radius; density of up to 150 g/cm^3, temperature close to 15.7 million K
radiative zone	thermal radiation primary means of energy transfer; temperature drops from approximately 7 million to 2 million K; transfer of energy by radiation; convection; density drops from 20 g/cm^3 to only 0.2 g/cm^3
tacholine	region where uniform rotation of radiative zone and differential rotation of the convection zone results in a large shear
convective zone	extends from 0.7 solar radii (200,000 km) to near the surface; temperature drops to 5,700 K and the density to only 0.2 g/m^3

Astronomy: Structure of the Sun (3)

layer	description
photosphere	visible surface of the Sun, is the layer below which the Sun becomes opaque to visible light; about 6000 K
chromosphere	layer about 2,000 km thick, dominated by a spectrum of emission and absorption lines
transition region	temperature rises rapidly from around 20,000 K in the upper chromosphere to coronal temperatures closer to 1,000,000 K
corona	has a particle density around 10^{15} m^{-3} to 10^{16} m^{-3}; the average temperature of the corona and solar wind is about 1,000,000–2,000,000 K; in the hottest regions it is 8,000,000–20,000,000 K
heliosphere	tenuous outermost atmosphere of the Sun, filled with the solar wind plasma

Astronomy: Sun

mean distance from Earth (km)	mass (g)	radius (km)	average density gm/cm^3
1.496×10^8 km	1.99×10^{30}	695,600	1.408
escape velocity (km/s)	visual brightness	absolute magnitude	spectral classification
617.7	- 26.74	4.83	G2V
mean disance from Milky Way core	luminosity (watts)	photosphere temperature (K)	age
2.7×10^{17} km, 27,200 ly	3.828×10^{26}	5,772	4.6 billion years

Astronomy: Sunspots, Solar Flares, and Coronal Mass Ejections

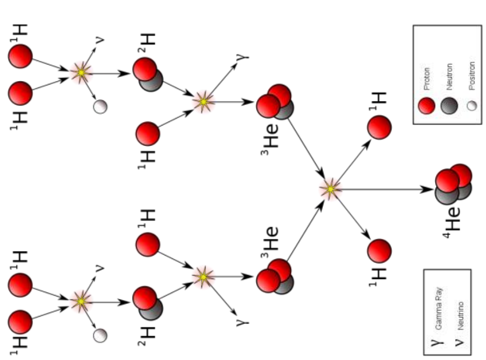
sunspot: temporary phenomena on solar photosphere; appear as dark spots; areas of reduced surface temperature caused by concentrations of magnetic field flux inhibiting convection; usually appear in pairs of opposite magnetic polarity; number varies according to approximately 11-year solar cycle

solar flare: sudden flash of brightness observed near the Sun's surface; involves a broad spectrum of emissions; energy release of typically 10^{20} joules of energy

coronal mass ejection: unusually large release of plasma and magnetic field from the solar corona; often follow solar flares and are normally present during a solar prominence eruption

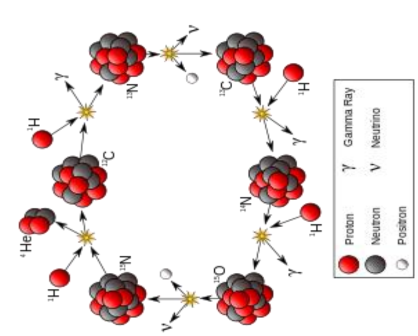
(Sources: https://en.wikipedia.org/wiki/Sunspot, https://en.wikipedia.org/wiki/Solar_flare, https://en.wikipedia.org/wiki/Coronal_mass_ejection)

Astronomy: Proton-Proton Chain



(Image source: https://en.wikipedia.org/wiki/Proton%E2%80%93proton_chain_reaction#/media/File:FusionintheSun.svg, Author: Borb, CC BY-SA 3.0)

Astronomy: CNO Cycle



(Image source: https://en.wikipedia.org/wiki/CNO_cycle#/media/File:CNO_Cycle.svg, Author: Borb, CC BY-SA 3.0)

Astronomy: Aurora Borealis and Aurora Australis (1)

aurora: natural light display in the sky, predominantly seen in the high latitude Arctic and Antarctic regions; produced when the magnetosphere is sufficiently disturbed by the solar wind that the trajectories of charged particles in both solar wind and magnetospheric plasma, mainly in the form of electrons and protons, precipitate them into the upper atmosphere (thermosphere/exosphere), where their energy is lost; the resulting ionization and excitation of atmospheric constituents emits light of various colors

Aurora Borealis: northern hemisphere aurora
Aurora Australis: southern hemisphere aurora

Astronomy: Aurora Borealis and Aurora Australis (2)

color	description
red	at highest altitudes, excited atomic oxygen emits at 630.0 nm; visible only under more intense solar activity; scarlet, crimson, and carmine are the most often-seen
green	at lower altitudes the 557.7 nm emission (green) dominates; most common color; from excited molecular nitrogen, which transfers energy by collision with oxygen atoms
blue	at lower altitudes, molecular nitrogen produces visible light in both red and blue parts of the spectrum, with 428 nm dominant
ultraviolet	has been observed; also seen on Mars, Jupiter and Saturn
infrared	part of many auroras
yellow, pink	mix of red, green, or blue; yellow-green common

(Source: https://en.wikipedia.org/wiki/Aurora)

Astronomy: Moon

mean distance from Earth (km)	mass (kg)	radius (km)	average density (gm/cm^3)
384,399	7.342×10^{22}	1737.1	3.344
escape velocity (km/s)	**albedo**	**axial tilt (to eclptic)**	**eccentricity**
2.38	0.136	1.5424^0	0.0549
apparent magnitude	**equator mean surface temperature (K)**	**equatorial rotation velocity (m/s)**	**sidereal rotation period (days)**
-2.5 to -12.9	220	4.627	27.321

Astronomy: Lunar Rotation and Revolution

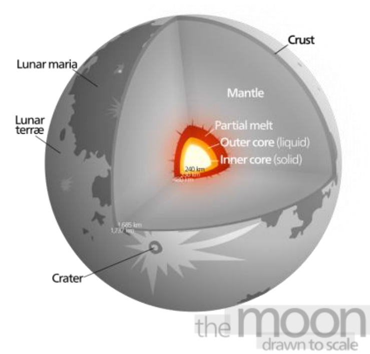
sidereal period in days	synodic period in days	saros cycle	metonic cycle
27.32166	29.53059	223 synodic months = 6,585.3211 days = 18 years, 11 days, 8 hours	6,940 days = 235 synodic months = 19 years

saros cycle: period that can be used to predict eclipses of the Sun and Moon
metonic cycle: nearly a common multiple of the solar year and the synodic lunar month

Astronomy: Structure of the Moon (1)

The Moon is differentiated, with a geochemically distinct crust, mantle, and core. It has a solid iron-rich inner core with a radius of 240 km and fluid outer core made of liquid iron with a radius of roughly 300 km. Around the core is a partially molten boundary layer with a radius of about 500 km, thought to have developed through fractional crystallization of a global magma ocean shortly after formation 4.5 billion years ago. Crystallization of this magma ocean would have created a mafic mantle from the precipitation and sinking of the minerals olivine, clinopyroxene, and orthopyroxene; after about three-quarters of the magma ocean had crystallized, lower-density plagioclase minerals could form and float into a crust atop.
(Source: https://en.wikipedia.org/wiki/Moon)

Astronomy: Structure of the Moon (2)



(Image source: https://en.wikipedia.org/wiki/Moon#/media/File:Moon_diagram.svg, Author: Kelvinsong, CC BY-3.0)

Astronomy: Lunar Geology (1)

The prevailing hypothesis is that the Earth–Moon system formed as a result of the impact of a Mars-sized body, named Theia, with the proto-Earth (giant impact), that blasted material into orbit about the Earth that then accreted to form the present Earth-Moon system. The Moon's gravitational influence produces the ocean tides, body tides, and the slight lengthening of the day. Its current orbital distance is about thirty times Earth's diameter, with its apparent size in the sky almost the same as that of the Sun, resulting in the Moon covering the Sun nearly precisely in total solar eclipse.

Astronomy: Lunar Geology (2)

Its most visible feature is the giant far-side South Pole, Aitken basin, 2,240 km in diameter, the largest crater on the Moon the second-largest confirmed impact crater in the Solar System. It is 13 km deep, the lowest point on the surface of the Moon. The highest elevations are located directly to the northeast. It might have been thickened by the oblique formation impact of the South Pole Aitken basin. Other large impact basins, include Imbrium, Serenitatis, Crisium, Smythii, and Orientale, which have regionally low elevations and elevated rims. The far side of the lunar surface is on average about 1.9 km higher than that of the near side. The discovery of fault scarp cliffs implies that the Moon has shrunk within the past billion years, by about 90 meters.

Astronomy: Lunar Geology (3)

The dark and relatively featureless lunar plains are called maria (Latin for "seas"; singular mare), and were once believed to be filled with water. They are large solidified pools of ancient basaltic lava. Although similar to terrestrial basalts, lunar basalts have more iron and no minerals altered by water. Most of these lavas erupted or flowed into the depressions associated with impact basins. Several geologic provinces containing shield volcanoes and volcanic domes are found within the near side "maria." Almost all maria are on the near side of the Moon, and cover 31% of the surface of the near side, compared with 2% of the far side.

Astronomy: Lunar Geology (4)

There are estimated to be about 300,000 craters wider than 1 km on the near side. The lunar geologic timescale is based on the most prominent impact events, including Nectaris, Imbrium, and Orientale, characterized by rings of uplifted material, between hundreds and thousands of kilometers in diameter. The lack of an atmosphere, weather and recent geological processes mean that many of these craters are well-preserved. Because impact craters accumulate at a nearly constant rate, counting the number of craters per unit area can be used to estimate the age of the surface.

(Source: https://en.wikipedia.org/wiki/Moon)

Astronomy: Brief Lunar Exploration History 1959-1972 (1)

date	spacecraft	country	date	spacecraft	country
Jan 4, 1959	Luna 1	USSR	Aug 27, 1966	Luna 11	USSR
Mar 4, 1959	Pioneer 4	USA	Oct 22, 1966	Luna 12	USSR
Sep 14, 1959	Luna 2	USSR	Nov 10, 1966	Lunar Orbiter 2	USA
Oct 6, 1959	Luna 3	USSR	Dec 24, 1966	Luna 13	USSR
Jul 31, 1964	Ranger 7	USA	Feb 8, 1967	Lunar Orbiter 3	USA
Feb 20, 1964	Ranger 8	USA	Apr 20, 1967	Surveyor 3	USA
Jul 20, 1965	Zond 3	USSR	May 8, 1967	Lunar Orbiter 4	USA
Feb 3, 1966	Luna 9	USSR	Aug 5, 1967	Lunar Orbiter 5	USA
April 3, 1966	Luna 10	USSR	Sep 11, 1967	Surveyor 5	USA
Jun 2, 1966	Surveyor 1	USA	Nov 10, 1967	Surveyor 6	USA
Aug 14, 1966	Lunar Orbiter 1	USA	Apr 10, 1968	Luna 14	USSR

Astronomy: Brief Lunar Exploration History 1959-1972 (2)

date	spacecraft	country	date	spacecraft	country
Sep 18, 1968	Zond 5	USSR	Nov 17, 1970	Luna 17	USSR
Nov 14, 1968	Zond 6	USSR	Nov 17, 1970	Lunokhod 1	USSR
Dec 24, 1968	Apollo 8	USA	Feb 5, 1971	Apollo 14	USA
May 21, 1969	Apollo 10	USA	Jul 30, 1971	Apollo 15	USA
Jul 20, 1969	Apollo 11	USA	Aug 4, 1971	PFS-1	USA
Aug 11, 1969	Zond 7	USSR	Oct 3, 1971	Luna 19	USSR
Nov 19, 1969	Apollo 12	USA	Feb 21, 1972	Luna 20	USSR
Apr 14, 1970	S-IV	USA	Apr 21, 1972	Apollo 16	USA
Sep 20, 1970	Luna 16	USSR	Apr 24, 1972	PFS-2	USA
Oct 24, 1970	Zond 8	USSR	Dec 11, 1972	Apollo 17	USA

(Source: https://en.wikipedia.org/wiki/Exploration_of_the_Moon)

Astronomy: Planet Types

terrestrial: planet that is composed primarily of silicate rocks or metals, have a solid planetary surface, all terrestrial planets may have the same basic type of structure, such as a central metallic core, mostly iron, with a surrounding silicate mantle

jovian: usually primarily composed of low-boiling-point materials, rather than rock or other solid matter, but massive solid planets can also exist, sometimes known as gas giants or ice giants, depending on composition

dwarf: a planetary-mass object that is neither a planet nor a natural satellite, it is in direct orbit of the Sun, and is massive enough for its gravity to crush it into a hydrostatic equilibrium shape (usually a spheroid), but it has not cleared the neighborhood of other material around its orbit

Astronomy: Terrestrial Planets

	Mercury	Venus	Earth	Mars
mean distance from Sun (AU)	0.387	0.723	1	1.524
light minutes from sun	3.2	6.0	8.3	12.7
mass (x Earth)	0.0553	0.815	1	0.107
radius (x Earth)	0.383	0.949	1	0.533
rotation period (Earth days)	175.942	– 116.75	1	1.027
orbit period (Earth years)	0.241	0.615	1	1.881
mean orbital velocity (km/s)	47.87	35.02	29.78	24.13
natural satellites	0	0	1	2
surface pressure (bars)	Near 0	92	1	.0069 to .009

Astronomy: Mercury and Venus

Mercury	Venus
smaller but more massive than Ganymede and Titan; consists of ~70% metallic and 30% silicate material; core occupies about 55% of its volume; extensive mare-like plains and heavy cratering similar to those on the Moon, indicating that it has been geologically inactive for billions of years	densest atmosphere of the four terrestrial planets, consisting of more than 96% carbon dioxide; atmospheric pressure at the surface is 92 times that of Earth; by far the hottest planet with a mean surface temperature of 735 K (462°C; 863°F); dense CO_2 clouds; has 167 large volcanoes that are over 100 km across

(Source: https://en.wikipedia.org/wiki/Mercury_(planet), https://en.wikipedia.org/wiki/Venus)

Astronomy: Mars

Mars
second smallest planet; rotational period and seasonal cycles likewise similar to Earth's; tilt produces the seasons; site of Olympus Mons, the largest volcano and second-highest known mountain in the Solar System, and of Valles Marineris, one of the largest canyons in the Solar System; has two moons, Phobos and Deimos, which may be captured asteroids; dense metallic core overlaid by less dense materials; core with radius of about 1,794 ± 65 km consisting primarily of iron and nickel with about 16–17% sulfur; core surrounded by a silicate mantle that formed many of the tectonic and dormant volcanic features; besides silicon and oxygen, the most abundant elements in the crust are iron, magnesium, aluminum, calcium, and potassium; average thickness of the planet's crust about 50 km

(Source: https://en.wikipedia.org/wiki/Mars)

Astronomy: Jovian Planets

	Jupiter	Saturn	Uranus	Neptune
mean distance from Sun (AU)	5.20	9.58	19.20	30.05
light hours from Sun	0.72	1.3	2.7	4.2
mass (x Earth)	317.8	95.2	14.5	17.1
radius (x Earth)	11.21	9.45	4.01	3.88
rotation period (hours)	9.9	10.7	17.2	16.1
orbit period (Earth years)	11.9	29.4	83.7	163.7
mean orbital velocity (km/s)	13.07	9.69	6.81	5.43
known natural satellites (January 2013)	67	62	27	13
rings	dust	extensive	thin, dark	ring arcs

Astronomy: Jupiter and Saturn

Jupiter	Saturn
gas giant; mass 1/1,000th of the Sun, 2 ½ times that of all the other planets in the Solar System combined; primarily hydrogen and helium; outer atmosphere segregated into several bands at different latitudes, resulting in turbulence and storms along their interacting boundaries; prominent result is the Great Red Spot; more than 60 moons	gas giant; only 1/8th average density of Earth, interior composed of core of iron–nickel and silicon and oxygen rocks; core is surrounded by deep layer of metallic hydrogen, intermediate layer of liquid hydrogen and liquid helium; prominent ring system of 9 continuous main rings; more than 60 moons

(Sources: https://en.wikipedia.org/wiki/Jupiter, https://en.wikipedia.org/wiki/Saturn)

Astronomy: Uranus and Neptune

Uranus	Neptune
ice giant, atmosphere primarily hydrogen and helium; contains ices including water, ammonia, and methane, traces of other hydrocarbons; coldest planetary atmosphere, minimum temperature of 49 K (−224.2°C); complex, layered cloud structure with water thought to make up the lowest clouds and methane the uppermost layer of clouds; interior is mainly composed of ices and rock	not visible to the unaided eye; similar in composition to Uranus; active, visible weather patterns; strongest sustained winds of any planet in the Solar System, recorded speeds as high as 2,100 km per hour (580 m/s; 1,300 mph); temperatures at cloud tops near 55 K (−218°C); temperatures at center approximately 5,400 K (5,100°C); faint and fragmented ring system called "arcs"

(Sources: https://en.wikipedia.org/wiki/Uranus, https://en.wikipedia.org/wiki/Neptune)

Astronomy: Largest Moons

	Ganymede	Titan	Callisto	Io	Moon	Europa	Triton
planet	Jupiter	Saturn	Jupiter	Jupiter	Earth	Jupiter	Neptune
radius (km)	2634	2576	2408	1818	1737	1561	1353
sem-major axis (km)	1,070,400	1,221,870	1,882,700	421,800	384,399	671,100	354,800
sidereal period (hr)	7.155	15.95	16.69	1.769	27.32	3.551	-5.877
discovery year	1610	1655	1610	1610	N/A	1610	1846
discovered	Galileo	Huygens	Galileo	Galileo	ancient	Galileo	Lassell

Astronomy: Dwarf Planets

	Ceres	Pluto	Haumea	Makemake	Eris
mean distance from sun (AU)	2.77	39.48	43.13	45.79	67.67
light hours from Sun	0.38	5.5	6.0	6.4	9.4
mass (x 10^{21} kg)	0.94	13.05	4.01	?	16.7
diameter (km)	946	2372	1240	1430	2326
rotation period (days)	0.38	-6.39	0.16	0.32	1
orbit period (Earth years)	4.60	248.09	283.28	309.9	557
mean orbital velocity (km/s)	17.882	4.666	?	4.419	3.436

Astronomy: Five Largest Asteroids

	1 Ceres	4 Vesta	2 Pallas	10 Hygiea	704 Interamnia
dimensions (km)	965 x 962 x 891	573 x 557 x 446	550 x 516 x 476	530 x 407 x 370	350 x 304
mean distance from Sun (AU)	2.766	2.362	2.773	3.139	3.062
date discovered	Jan 1, 1801	March 29, 1807	March 28, 1802	April 12, 1849	October 2, 1910
discoverer	Piazzi	Olbers	Olbers	de Gasparis	Cerulli
class	G	V	B	C	F

Astronomy: Asteroid Types (1)

- C-group dark carbonaceous objects
  - B-type (2 Pallas), primitive, volatile-rich remnants, found in the outer asteroid belt
  - F-type (704 Interamnia), have spectra generally similar to those of the B-type asteroids, but lack the "water" absorption feature around 3 µm
  - G-type(1 Ceres), similar to the C-type objects, but contain a strong ultraviolet absorption feature below 0.5 µm
  - C-type (10 Hygiea), remaining majority of 'standard' C-type asteroids, form around 75% of known asteroids, distinguished by a very low albedo, include a large amount of carbon, in addition to rocks and minerals, occur most frequently at the outer edge of the asteroid belt

Astronomy: Asteroid Types (2)

- X-group
  - M-type (16 Psyche) metallic, moderately bright, likely pieces of the metallic core of differentiated, fragmented asteroids, may be source of iron meteorites, third most common type
  - E-type (44 Nysa, 55 Pandora) differ from M-type mostly by high albedo, may have enstatite ($MgSiO_3$) achondrite surfaces, large proportion of asteroids inside the asteroid belt, may have originated from reduced mantle of a differentiated asteroid
  - P-type (259 Aletheia, 190 Ismene; CP: 324 Bamberga) differ from M-type mostly by low albedo and featureless reddish spectrum, may be composed of organic rich silicates, carbon, anhydrous silicates, possibly with interior water ice interior, found in the outer asteroid belt and beyond

Astronomy: Asteroid Types (3)

- S-type (15 Eunomia, 3 Juno) silicaceous (or "stony") objects, silicaceous asteroids, second most common type at 17%
- small classes
  - A-type (246 Asporina), relatively uncommon inner-belt asteroids, have strong, broad 1 µm olivine feature, very reddish spectrum shortwards of 0.7 µm, may come from the completely differentiated mantle of an asteroid
  - D-type (624 Hektor), low albedo, featureless reddish spectrum, may be composed of organic-rich silicates, carbon, anhydrous silicates, interior water ice, found in the outer belt and beyond
  - T-type (96 Aegle), rare inner-belt asteroids, unknown composition, dark, featureless and moderately red spectra, and a moderate absorption feature shortwards of 0.85 µm

Astronomy: Asteroid Types (4)

- Q-type (1862 Apollo), relatively uncommon inner-belt asteroids, strong, broad 1 µm olivine and pyroxene feature, spectral slope indicates presence of metal, absorption features around 0.7 µm, spectrum generally intermediate between V and S-type
- R-type (349 Dembowska), moderately bright, relatively uncommon inner-belt asteroids, spectrally intermediate between V and A-type asteroids, spectrum shows olivine and pyroxene features at 1 and 2 µm, possibility plagioclase, around 0.7 µm the spectrum is very reddish
- V-type (4 Vesta), relatively bright, similar to more common S-type, also made up of stony irons, ordinary chondrites, with V-types containing more pyroxene than S-types

(Source: https://en.wikipedia.org/wiki/Asteroid_spectral_types)

Astronomy: Meteors, Meteoroids, Meteorites

meteor: the visible passage of a glowing meteoroid, micrometeoroid, comet or asteroid through Earth's atmosphere, after being heated to incandescence by collisions with air molecules in the upper atmosphere
meteoroid: small rocky or metallic body in outer space, meteoroids are significantly smaller than asteroids, and range in size from small grains to 1 meter-wide objects
meteorite: a solid piece of debris from an object, such as a comet, asteroid, or meteoroid, that originates in outer space, survives its passage through the Earth's atmosphere, and impacts Earth's surface or that of another planet

Astronomy: Kuiper Belt, Oort Cloud

Kuiper belt: a circumstellar disc beyond the planets, extending from the orbit of Neptune at 30 AU to approximately 50 AU from the Sun; 20 times as wide and 20 to 200 times as massive as the asteroid belt; consists mainly of small bodies and remnants from Solar System formation; most of its objects are composed largely of frozen volatiles, called "ices," including methane, ammonia and water
Oort cloud: a theoretical cloud of predominantly icy planetesimals believed to surround the Sun as far as somewhere between 50,000 and 200,000 AU;divided into a disc-shaped inner Oort cloud and a spherical outer Oort cloud

Astronomy: Meteor Showers (1)

shower	time	parent object
Quadrantids	early January	
Lyrids	late April	Comet Thatcher
Pi Puppids	late April	Comet 26P/Grigg--Skjellerup
Eta Aquariids	early May	Comet 1P/Halley
Arietids	mid-June	Comet 96P/Machholz
June Bootids	late June	Comet 7P/Pons-Winnecke
Southern Delta Aquariids	late July	Comet 96P/Machholz
Alpha Capricornids	late July	Comet 169P/NEAT
Perseids	mid-August	Comet 109P/Swift-Tuttle
Kappa Cygnids	mid-August	Minor planet 2008 ED69
Aurigids	early September	Comet C/1911 N1

Astronomy: Meteor Showers (2)

shower	time	parent object
Draconids	early October	Comet 21P/Giacobini-Zinner
Orionids	late October	Comet 1P/Halley
Southern Taurids	early November	Comet 2P/Encke
Northern Taurids	mid-November	Minor planet 2004 TG_{10}
Andromedids	mid-November	Comet 3D/Bieta
Alpha Monocerotids	mid-November	unknown
Leonids	mid-November	Comet 55P/Tempel-Tuttle
Phoenicids	early December	Comet 289P/Blanpain
Geminids	mid-December	Minor planet 3200 Phaeton
Ursids	late December	Comet 8P/Tuttle

(Source: https://en.wikipedia.org/wiki/Meteor_shower)

Astronomy: Interesting Exoplanets (1)

exoplanet	description
Kepler-186f	first rocky planet to be found within the habitable zone; very close in size to Earth
HD 209458 b (nickname "Osiris")	first planet to be seen in transit and first planet to have it light directly detected; showed that transit observations were feasible
Kepler-11 system	first compact solar system discovered by Kepler telescope; revealed that a system can be tightly packed, with at least five planets within the orbit of Mercury
Kepler-16b	real-life "Tatooine," Kepler telescope's first discovery of a planet that orbits two stars, known as a circumbinary planet
51 Pegasi b	giant planet, about half the mass of Jupiter; orbits its star every 4 days, first confirmed exoplanet around sun-like star
CoRoT 7b	first super-Earth identified as a rocky exoplanet

Astronomy: Interesting Exoplanets (2)

exoplanet	description
Kepler-22b	A planet in the habitable zone and a possible water-world planet unlike any seen in our solar system
Kepler-10b	Kepler telescope's first rocky planet discovery is a scorched, Earth-size world that scientists believe may have a lava ocean on its surface
Kepler-444 system	oldest known planetary system has five terrestrial-sized planets, all in orbital resonance
55 Cancri e	toasty world that rushes around its star every 18 hours. It orbits so closely, about 25 times closer than Mercury to our sun, that it is tidally locked with one face forever blisters under the heat of its sun
HD 189733 b	about the size of Jupiter, is one of the most studied exoplanets and is the first caught passing in front of its parent star in X-rays

Astronomy: Interesting Exoplanets (3)

PSR B1257+12 system	**smallest planetary bodies known to exist outside our solar system, they orbit a neutron star**
K2-3	**three super-Earths discovered by the K2 mission orbiting a nearby star; their mass and radius are already known and soon they may reveal their atmospheric composition**
HR 8799	**first directly imaged multi-exoplanet system. This system contains a debris disk and at least four massive planets**
Kepler-36 system	**two known planets in this system have the most closely spaced orbits ever confirmed; the neighboring duo comes within about 1.2 million miles of each other, only five times the Earth-Moon distance**
HD 114762 b	**discovered in 1989, three years prior to the pulsar planets and six years prior to 51 Peg b, it is HD the first discovered planet around a sun-like star; its mass is 11 times that of Jupiter and was found in an orbit of 84 days; it was initially assumed (incorrectly) to be a brown dwarf**

Astronomy: Interesting Exoplanets (4)

Kepler-452b	**the first Earth-sized planet found in the habitable zone of a sun-like star; it is 60 percent larger than Earth and 5 percent farther from its parent star than Earth is from the sun**
HD 80606 b	**this world has the most eccentric orbit, and as one scientist put it, "wears its heart on its sleeve," with storms, rotation, atmospheric heating, and a crazy orbit all plainly visible**
WASP-47	**part of a compact multi-planet system, it's the only known hot Jupiter with close planetary companions**
OGLE-2005-BLG-390	**considered to be the first cold super Earth, this exoplanet began to form a Jupiter-like core of rock and ice, but couldn't grow fast enough in size; its final mass is five times that of Earth; its nickname is Hoth, after a planet from Star Wars**

(Source: https://www.nasa.gov/feature/jpl/20-intriguing-exoplanets, Author: NASA)

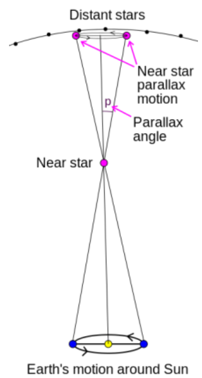
Astronomy: Stellar Parallax

distance in parsecs $d_{pc} = \dfrac{1}{p}$

p = parallax angle in arcseconds

1 parsec (pc) = 3.086×10^{16} meters

1 light year (ly) = 9.461×10^{15} meters



(Image source: https://commons.wikimedia.org/wiki/File:Stellarparallax_parsec1.svg, public domain)

Astronomy: Stefan-Boltzmann and Wein's Laws

Stefan-Boltzmann law: $P_{net} = e\sigma A(T^4 - T_s^4)$

σ = 5.67×10^{-8} W/m^2 K^4

P_{net} = net radiated power

e = emissivity — A = area

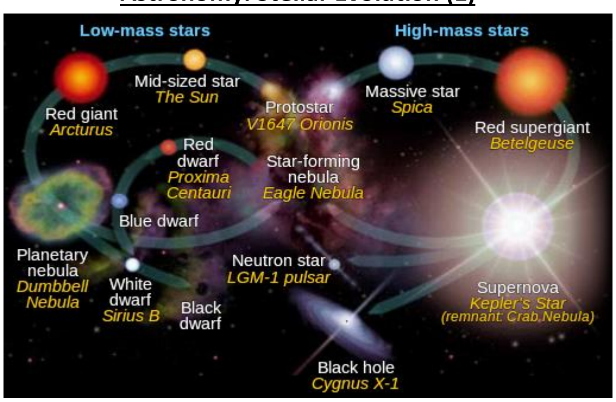
T = object temperature — T_s = temperature of surroundings

Wein's law: $\lambda_{\max} = \dfrac{b}{T}$

$b = 2.89776829$ nm K

temperatures in K

Astronomy: Stellar Evolution (1)



(Image source: http://scioly.org/wiki/index.php/Astronomy/Stellar_Evolution, Author : cmglee, NASA Spaceflight Center, CC BY-SA 4.0)

Astronomy: Stellar Evolution (2)

- stellar nebula: cloud of gas, mostly hydrogen and helium, and dust in space, that is the the birthplace of stars
- protostar: looks like a star but its core is not yet hot enough for fusion to take place; luminosity comes from the heating of the protostar as it contracts, usually surrounded by dust, which blocks light, difficult to observe in the visible spectrum
- T-Tauri star: very young, lightweight star, less than 10 million years old, that it still undergoing gravitational contraction; represents an intermediate stage between a protostar and a low-mass main sequence star like the Sun
- main sequence star: star that fuses hydrogen atoms to form helium atoms in their cores; 90 percent of stars are main sequence

Astronomy: Stellar Evolution (3)

- red giant: large bright star with a cool surface; formed during the later stages of the evolution as it runs out of hydrogen fuel at its center; have diameters between 10 and 100 times that of the Sun; very bright, with a surface temperature lower than that of the Sun; most common red giants are stars nearing the end but are still fusing hydrogen into helium in a shell surrounding a degenerate helium core
- planetary nebula: cloud of gas and dust; the outer layers of a star that are lost when the star changes from a red giant to a white dwarf

Astronomy: Stellar Evolution (4)

- supernova: explosive death of a star, and often results in the star obtaining the brightness of 100 million suns for a short time; extremely luminous burst of radiation expels much or all of a star's material at a great velocity, driving a shock wave into the surrounding interstellar medium; can be triggered by the sudden re-ignition of nuclear fusion in a degenerate star; or by the gravitational collapse of the core of a massive star
- nova: nuclear explosion of a white dwarf, causing sudden brightening; occurs on the surface of a white dwarf in a binary system; if the two stars of the system are sufficiently close material can be pulled from the companion star's surface onto the white dwarf; caused by the accretion of hydrogen onto the surface of the star, starting runaway fusion reaction

Astronomy: Stellar Evolution (5)

- white dwarf: very small, hot star, last stage in the life cycle of a star like the Sun; shrunken remains of normal stars, whose nuclear energy supplies have been used up; consist of degenerate matter with a very high density due to gravitational effects; one spoonful has a mass of several tons; gravity causes the star to collapse in on itself; great densities are only possible when electrons are displaced from their regular shells and pushed closer to the nucleus, allowing atoms to take up less space
- black dwarf: last stage of stellar evolution; is a white dwarf that has sufficiently cooled that it no longer emits significant heat or light.the time required for a white dwarf to reach this state is calculated to be longer than the current age of the universe (13.8 billion years), no black dwarfs are expected to exist yet

Astronomy: Stellar Evolution (6)

- brown dwarf: too large to be called a planet and too small to be a star; forms from a collapsing cloud of gas and dust, does not form an object which is dense enough at its core to trigger nuclear fusion; were first discovered in 1995
- neutron star: composed mainly of neutrons and produced after a supernova, forcing the protons and electrons to combine; typically have a mass of three times the Sun but a diameter of only 20 km
- black hole: form from massive stars at the end of their lifetimes; gravitational pull is so great that nothing can escape from it, not even light.; density inside it cannot be measured; distorts the space around it, and can often suck neighboring matter into them including stars

Astronomy: Stellar Lifetime

mass of star	
less than 10 solar masses	**10 or mor solar masses**
lifetime = $\frac{1}{(number\ of\ solar\ masses)^3} x10^{10}$	**lifetime =** $\frac{1}{(number\ of\ solar\ masses)^2} x10^{10}$

Astronomy: 25 Brightest Stars (1)

name	visual magnitude (m_V)	Bayer	distance (ly)	spectral class
Sirius	−1.46	α CMa	8.6	A1 V, DA2
Canopus	−0.74	α Car	310	A9 II
Rigil Kentaurus	−0.27 (0.01+1.33)	α Cen	4.4	G2 V, K1 V
Arcturus	−0.05	α Boo	37	K0 III
Vega	0.03 (−0.02-0.07var)	α Lyr	25	A0 Va
Capella	0.08 (0.03-0.16var)	α Aur	42	K0 III, G1 III
Rigel	0.13 (0.05-0.18var)	β Ori	860	B8 Ia
Procyon	0.34	α CMi	11	F5 IV-V
Achernar	0.46 (0.40-0.46var)	α Eri	140	B6 Vep
Betelgeuse	0.50 (0.2-1.2var)	α Ori	640	M2 Iab
Hadar	0.61	β Cen	350	B1 III
Altair	0.76	α Aql	17	A7 V
Acrux	0.76 (1.33+1.73)	α Cru	320	B0.5 IV, B1 V

Astronomy: 25 Brightest Stars (2)

name	visual magnitude (m_V)	Bayer	distance (ly)	spectral class
Aldebaran	0.86 (0.75-0.95var)	α Tau	65	K5 III
Antares	0.96 (0.6-1.6var)	α Sco	600	M1.5 Iab, B3 V
Spica	0.97 (0.97-1.04var)	α Vir	260	B1 III-IV, B2 V
Pollux	1.14	β Gem	34	K0 III
Fomalhaut	1.16	α PsA	25	A3 V
Deneb	1.25 (1.21-1.29var)	α Cyg	2,600	A2 Ia
Mimosa	1.25 (1.23-1.31var)	β Cru	350	B0.5 II, B2 V
Regulus	1.39	α Leo	77	B7 V
Adhara	1.50	ε CMa	430	B2 Iab:
Shaula	1.62	λ Sco	700	B2 IV
Castor	1.62 (1.98 + 2.97)	α Gem	52	Am, A1 V
Gacrux	1.64	γ Cru	88	M3.5 III

Astronomy: Binary Stars (1)

- visual binary: binary star for which the angular separation between the two components is great enough to permit them to be observed as a double star in a telescope or high-powered binoculars
- spectroscopic binary: the binary consists of a pair of stars where the spectral lines in the light emitted from each star shifts first towards the blue, then towards the red, as each moves first towards us, and then away from us, during its motion about their common center of mass, with the period of their common orbit; separation is very small
- eclipsing binary: binary star in which the orbit plane of the two stars lies so nearly in the line of sight of the observer that the components undergo mutual eclipses

Astronomy: Binary Stars (2)

- non-eclipsing binary: can be photometrically detected by observing how the stars affect each other; first is by observing extra light which the stars reflect from their companion; second by observing ellipsoidal light variations which are caused by deformation of the star's shape by their companions; third by looking at how relativistic beaming affects the apparent magnitude of the stars; detecting binaries with these methods requires accurate photometry
- astrometric binary: relatively nearby stars which can be seen to wobble around a point in space, with no visible companion; the visible star's position is detected to vary, due to the gravitational influence from its counterpart; the star’s position is measured relative to more distant stars, and checked for periodic shifts

(Source: https://en.wikipedia.org/wiki/Binary_star#Methods_of_observation)

Astronomy: Supernovae

<table>
<tr><td rowspan="3">Type I no hydrogen</td><td colspan="3">Type Ia presents a singly ionized silicon (Si II) line at 615.0 nm (nanometers), near peak light</td><td>thermal runaway</td></tr>
<tr><td rowspan="2">Type Ib/c weak or no silicon absorption feature</td><td colspan="2">Type Ib shows a non-ionized helium (He I) line at 587.6 nm</td><td rowspan="6">core collapse

(Source: https://en.wikipedia.org/wiki/Supernova#Classification)</td></tr>
<tr><td colspan="2">Type Ic weak or no helium</td></tr>
<tr><td rowspan="4">Type II shows hydrogen</td><td rowspan="3">Type II-P/L/N Type II spectrum throughout</td><td rowspan="2">Type II-P/L no narrow lines</td><td>Type II-P reaches a "plateau" in its light curve</td></tr>
<tr><td>Type II-L displays "linear" decrease in light curve</td></tr>
<tr><td colspan="2">Type IIn some narrow lines</td></tr>
<tr><td colspan="3">Type IIb spectrum changes to become like Type Ib</td></tr>
</table>

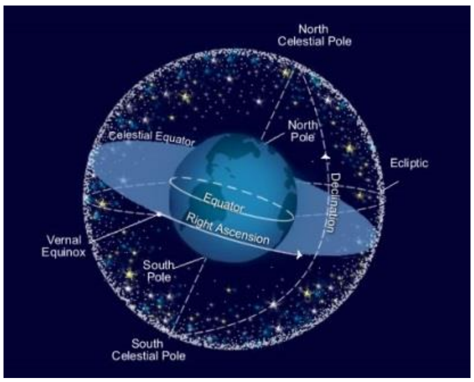
Astronomy: Black Holes

class	mass (solar masses)	size
supermassive	$\sim10^5$–10^{10}	~0.001–400 AU
intermediate	$\sim10^3$	$\sim10^3$ km $\approx R_{Earth}$
stellar	~10	~30 km
micro	up to $\sim M_{Moon}$	up to ~0.1 mm

black hole Schwarzschild radius $R = \dfrac{2MG}{c^2}$

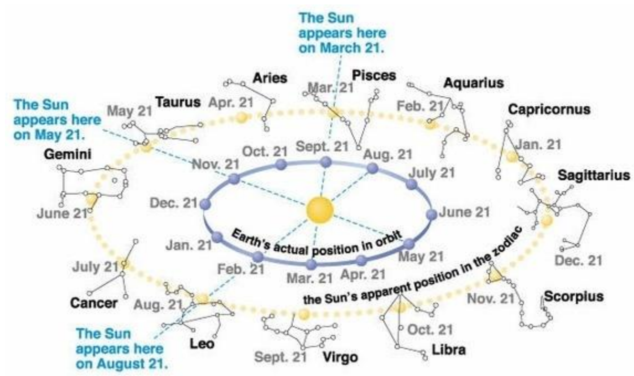
Astronomy: Celestial Sphere

celestial spere:
an imaginary sphere of arbitrarily large radius, concentric with Earth; all objects in the observer's sky can be thought of as projected upon the inside surface of the celestial sphere



(Source: https://en.wikipedia.org/wiki/Celestial_sphere; image source: Lunar and Planetary Institute)

Astronomy: Ecliptic



(Image source: https://www.quora.com/What-is-the-ecliptic)

Astronomy: Celestial Coordinate Systems

coordinate system	center point	fundamental plane (0° latitude)	poles	coordinates: latitude	coordinates: longitude	primary direction (0° longitude)
horizontal (also called Alt-Az)	observer	horizon	zenith, nadir	altitude (*a*) or elevation	azimuth (A)	north or south point of horizon
equatorial	center of the Earth (geocentric)/center of the Sun (heliocentric)	celestial equator	celestial poles	declination (δ)	right ascension (α) or hour angle (h)	vernal equinox
ecliptic		ecliptic	ecliptic poles	ecliptic latitude (β)	ecliptic longitude (λ)	
galactic	center of the Sun	galactic plane	galactic poles	galactic latitude (b)	galactic longitude (l)	galactic center
supergalactic		supergalactic plane	supergalactic poles	supergalactic latitude (SGB)	supergalactic longitude (SGL)	intersection of supergalactic plane and galactic plane

(Source: https://en.wikipedia.org/wiki/Celestial_coordinate_system)

Astronomy: Messier Objects (1)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M1	NGC 1952	Crab Nebula	supernova remnant	4.9–8.1	Taurus	8.4
M2	NGC 7089		cluster, globular	33	Aquarius	6.3
M3	NGC 5272		cluster, globular	33.9	Canes Venatici	6.2
M4	NGC 6121		cluster, globular	7.2	Scorpius	5.9
M5]	NGC 5904		cluster, globular	24.5	Serpens	6.7
M6	NGC 6405	Butterfly Cluster	cluster, open	1.6	Scorpius	4.2
M7	NGC 6475	Ptolemy Cluster	cluster, open	0.65–1.31	Scorpius	3.3
M8	NGC 6523	Lagoon Nebula	nebula with cluster	4.1	Sagittarius	6.0
M9	NGC 6333		cluster, globular	25.8	Ophiuchus	8.4
M10	NGC 6254		cluster, globular	14.3	Ophiuchus	6.4
M11	NGC 6705	Wild Duck Cluster	cluster, open	6.2	Scutum	6.3
M12	NGC 6218		cluster, globular	15.7	Ophiuchus	7.7

Astronomy: Messier Objects (2)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M13	NGC 6205	Great Globular	cluster, globular	22.2	Hercules	5.8
M14	NGC 6402		cluster, globular	30.3	Ophiuchus	8.3
M15	NGC 7078		cluster, globular	33	Pegasus	6.2
M16	NGC 6611	Eagle Nebula	nebula, H II region with cluster	7	Serpens	6.0
M17	NGC 6618	Omega, Swan, Horseshoe, or Lobster Nebula	nebula, H II region with cluster	5–6	Sagittarius	6.0
M18	NGC 6613		cluster, open	4.9	Sagittarius	7.5
M19	NGC 6273		cluster, globular	28.7	Ophiuchus	7.5
M20	NGC 6514	Trifid Nebula	nebula, H II region with cluster	5.2	Sagittarius	6.3

Astronomy: Messier Objects (3)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M22	NGC 6656	Sagittarius Cluster	cluster, globular	9.6–11.6	Sagittarius	5.1
M23	NGC 6494		cluster, open	2.15	Sagittarius	6.9
M24	IC 4715	Sagittarius Star Cloud	Milky Waystar cloud	~10	Sagittarius	4.6
M25	IC 4725		cluster, open	2.0	Sagittarius	4.6
M26	NGC 6694		cluster, open	5.0	Scutum	8.0
M27	NGC 6853	Dumbbell Nebula	nebula, planetary	1.148–1.52	Vulpecula	7.5
M28	NGC 6626		cluster, globular	17.9	Sagittarius	7.7
M29	NGC 6913		cluster, open	7.2	Cygnus	7.1
M30	NGC 7099		cluster, globular	27.8–31	Capricornus	7.7
M31	NGC 224	Andromeda Galaxy	galaxy, spiral	2,430–2,650	Andromeda	3.4
M32	NGC 221		galaxy, dwarf elliptical	2,410–2,570	Andromeda	8.1

Astronomy: Messier Objects (4)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M33	NGC 598	Triangulum Galaxy	galaxy, spiral	2,380–3,070	Triangulum	5.7
M34	NGC 1039		cluster, open	1.5	Perseus	5.5
M35	NGC 2168		cluster, open	2.8	Gemini	5.3
M36	NGC 1960		cluster, open	4.1	Auriga	6.3
M37	NGC 2099		cluster, open	4.511	Auriga	6.2
M38	NGC 1912		cluster, open	4.2	Auriga	7.4
M39	NGC 7092		cluster, open	0.8244	Cygnus	5.5
M40		Winnecke 4	double star WNC4	0.51	Ursa Major	9.7
M41	NGC 2287		cluster, open	2.3	Canis Major	4.5
M42	NGC 1976	Orion Nebula	nebula, H II region	1.324–1.364	Orion	4.0
M43	NGC 1982	De Mairan's Nebula	nebula, H II region (part of Orion Nebula)	1.6	Orion	9.0

Astronomy: Messier Objects (5)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M44	NGC 2632	Beehive Cluster	cluster, open	0.577	Cancer	3.7
M45		Pleiades	cluster, open	0.39–0.46	Taurus	1.6
M46	NGC 2437		cluster, open	5.4	Puppis	6.1
M47	NGC 2422		cluster, open	1.6	Puppis	4.2
M48	NGC 2548		cluster, open	1.5	Hydra	5.5
M49	NGC 4472		galaxy, elliptical	53,600–58,200	Virgo	9.4
M50	NGC 2323		cluster, open	3.2	Monoceros	5.9
M51	NGC 5194, NGC 5195	Whirlpool Galaxy	galaxy, spiral	19,000–27,000	Canes Venatici	8.4
M52	NGC 7654		cluster, open	5.0	Cassiopeia	5.0
M53	NGC 5024		cluster, globular	58	Coma Berenices	8.3
M54	NGC 6715		cluster, globular	87.4	Sagittarius	8.4

Astronomy: Messier Objects (6)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M55	NGC 6809		cluster, globular	17.6	Sagittarius	7.4
M56	NGC 6779		cluster, globular	32.9	Lyra	8.3
M57	NGC 6720	Ring Nebula	nebula, planetary	1.6–3.8	Lyra	8.8
M58	NGC 4579		galaxy, barred spiral	~63,000	Virgo	10.5
M59	NGC 4621		galaxy, elliptical	55,000–65,000	Virgo	10.6
M60	NGC 4649		galaxy, elliptical	51,000–59,000	Virgo	9.8
M61	NGC 4303		galaxy, spiral	50,200–54,800	Virgo	10.2
M62	NGC 6266		cluster, globular	22.2	Ophiuchus	7.4
M63	NGC 5055	Sunflower Galaxy	galaxy, spiral	37,000	Canes Venatici	9.3
M64	NGC 4826	Black Eye Galaxy	galaxy, spiral	22,000–26,000	Coma Berenices	9.4
M65	NGC 3623	Leo Triplet	galaxy, barred spiral	41,000–42,000	Leo	10.3
M66	NGC 3627	Leo Triplet	galaxy, barred spiral	31,000–41,000	Leo	8.9

Astronomy: Messier Objects (7)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M67	NGC 2682		cluster, open	2.61–2.93	Cancer	6.1
M68	NGC 4590		cluster, globular	33.6	Hydra	9.7
M69	NGC 6637		cluster, globular	29.7	Sagittarius	8.3
M70	NGC 6681		cluster, globular	29.4	Sagittarius	9.1
M71	NGC 6838		cluster, globular	13.0	Sagitta	6.1
M72	NGC 6981		cluster, globular	53.40–55.74	Aquarius	9.4
M73	NGC 6994		asterism	~2.5	Aquarius	9.0
M74	NGC 628		galaxy, spiral	24,000–36,000	Pisces	10.0
M75	NGC 6864		cluster, globular	67.5	Sagittarius	9.2
M76	NGC 650/651	Little Dumbbell Nebula	nebula, planetary	2.5	Perseus	10.1
M77	NGC 1068	Cetus A	galaxy, spiral	47,000	Cetus	9.6
M78	NGC 2068		nebula, diffuse	1.6	Orion	8.3

Astronomy: Messier Objects (8)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M79	NGC 1904		cluster, globular	41	Lepus	8.6
M80	NGC 6093		cluster, globular	32.6	Scorpius	7.9
M81	NGC 3031	Bode's Galaxy	galaxy, spiral	11,400–12,200	Ursa Major	6.9
M82	NGC 3034	Cigar Galaxy	galaxy, starburst	10,700–12,300	Ursa Major	8.4
M83	NGC 5236	Southern Pinwheel Galaxy	galaxy, barred spiral	14,700	Hydra	7.5
M84	NGC 4374		galaxy, lenticular	57,000–63,000	Virgo	10.1
M85	NGC 4382		galaxy, lenticular	56,000–64,000	Coma Berenices	10.0
M86	NGC 4406		galaxy, lenticular	49,000–55,000	Virgo	9.8
M87	NGC 4486	Virgo A	galaxy, elliptical	51,870–55,130	Virgo	9.6
M88	NGC 4501		galaxy, spiral	39,000–56,000	Coma Berenices	10.4
M89	NGC 4552		galaxy, elliptical	47,000–53,000	Virgo	10.7

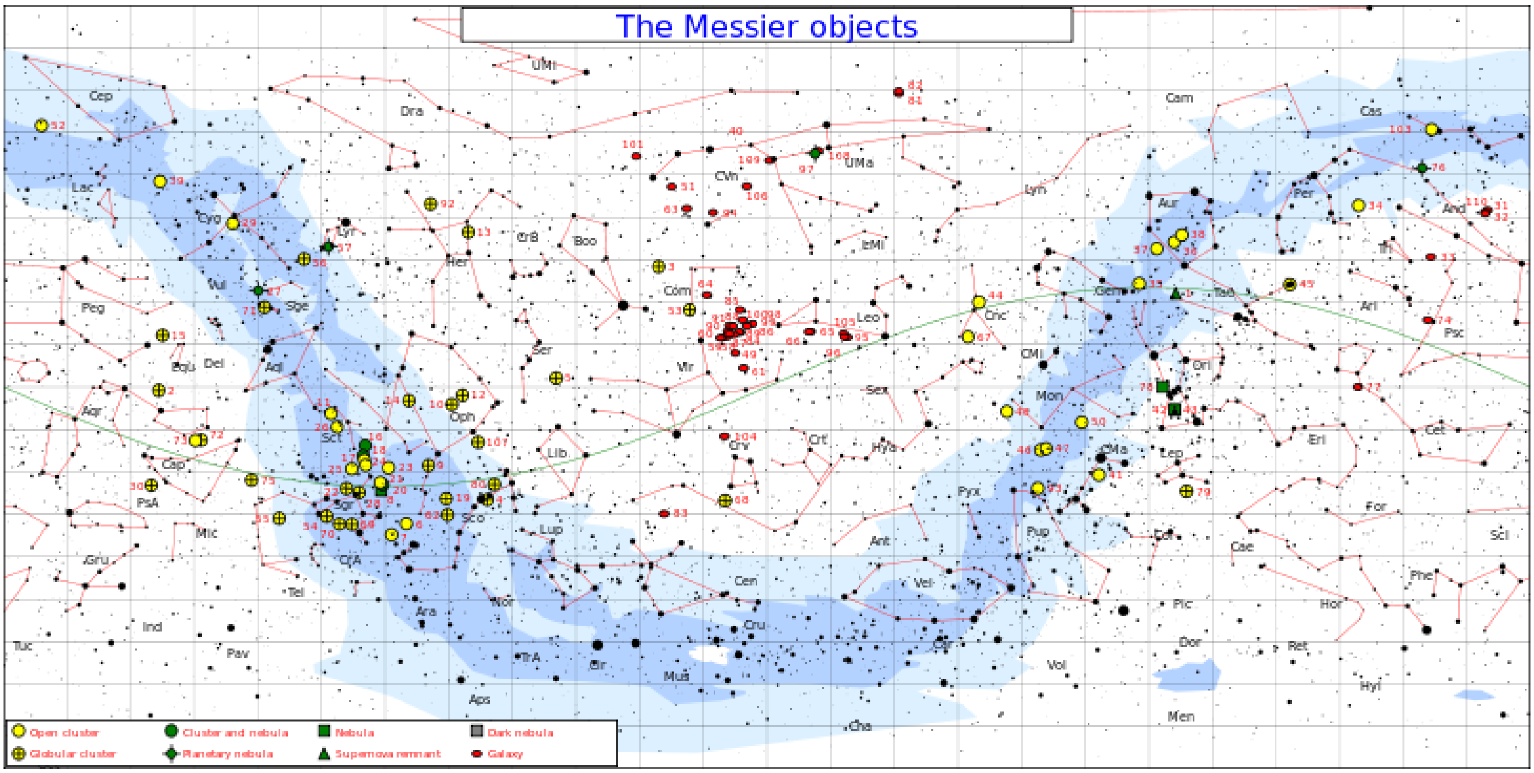
Astronomy: Messier Objects (9)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M90	NGC 4569		galaxy, spiral	55,900–61,500	Virgo	10.3
M91	NGC 4548		galaxy, barred spiral	47,000–79,000	Coma Berenices	11.0
M92	NGC 6341		cluster, globular	26.7	Hercules	6.3
M93	NGC 2447		cluster, open	3.6	Puppis	6.0
M94	NGC 4736		galaxy, spiral	14,700–17,300	Canes Venatici	9.0
M95	NGC 3351		galaxy, barred spiral	31,200–34,000	Leo	11.4
M96	NGC 3368		galaxy, spiral	28,000–34,000	Leo	10.1
M97	NGC 3587	Owl Nebula	nebula, planetary	2.03	Ursa Major	9.9
M98	NGC 4192		galaxy, spiral	44,400	Coma Berenices	11.0
M99	NGC 4254		galaxy, spiral	44,700–55,700	Coma Berenices	10.4
M100	NGC 4321		galaxy, spiral	55,000	Coma Berenices	10.1
M101	NGC 5457	Pinwheel Galaxy	galaxy, spiral	19,100–22,400	Ursa Major	7.9

Astronomy: Messier Objects (10)

Messier #	NGC/IC #	common name	object type	distance (kly)	constellation	apparent magnitude
M102	NGC 5866	Spindle Galaxy	galaxy, lenticular	50,000	Draco	10.7
M103	NGC 581		cluster, open	10	Cassiopeia	7.4
M104	NGC 4594	Sombrero Galaxy	galaxy, spiral	28,700–30,900	Virgo	9.0
M105	NGC 3379		galaxy, elliptical	30,400–33,600	Leo	10.2
M106	NGC 4258		galaxy, spiral	22,200–25,200	Canes Venatici	9.1
M107	NGC 6171		cluster, globular	20.9	Ophiuchus	8.9
M108	NGC 3556		galaxy, barred spiral	46,000	Ursa Major	10.7
M109	NGC 3992		galaxy, barred spiral	59,500–107,500	Ursa Major	10.6
M110	NGC 205		galaxy, dwarf elliptical	2,600–2,780	Andromeda	9.0

Astronomy: Messier Objects (11)



(Image source: https://commons.wikimedia.org/wiki/File:MessierStarChart.svg, Author: Jim Cornell, CC BY-SA 3.0)

Astronomy: Magnitude, Brightness and Luminosity (1)

apparent magnitude difference $m_2 - m_1 = -2.5\log\left(\frac{B_2}{B_1}\right)$

m_1 and m_2 = apparent magnitude B_1 and B_2 = brightness

$$\frac{B_{10}}{B_d} = \left(\frac{d}{10}\right)^2$$

B_{10} = brightness at a distance of 10 parsecs

B_d = brightness at a distance d parsecs

Astronomy: Magnitude, Brightness, and Luminosity (2)

absolute magnitude difference $M_2 - M_1 = -2.5\log\left(\frac{L_2}{L_1}\right)$

M_1 and M_2 = apparent magnitude L_1 and L_2 = brightness

absolute magnitude $M_V = m_V + 5 - 5\log d_{pc}$

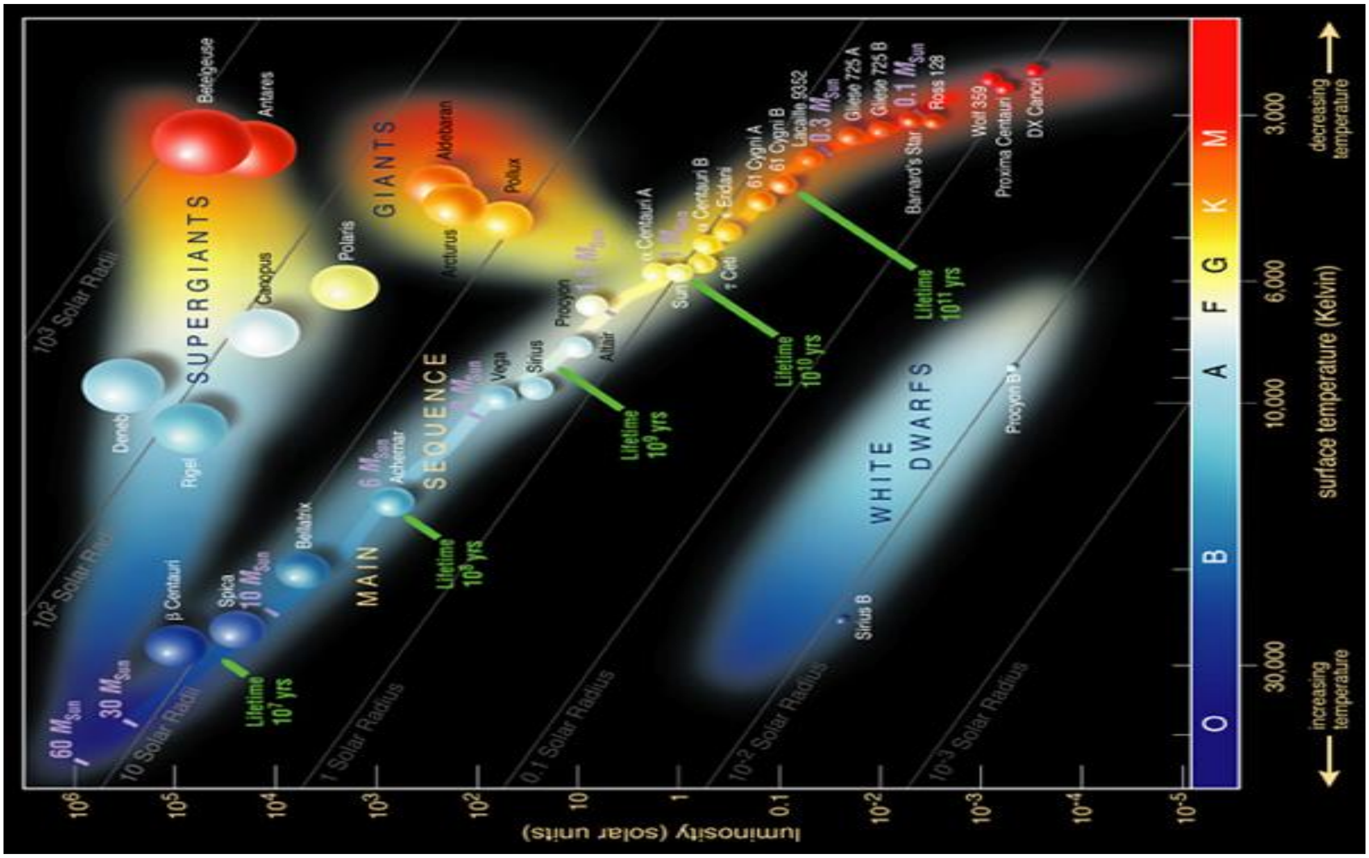
m_V = apparent magnitude d_{pc} = distance in parsecs

$$d_{pc} = (10\,pc)(10^{(m_V - M_V)/5})$$

$B = \frac{L}{4\pi d^2}$ L = luminosity in watts d = distance in meter

B = brightness in watts/meter^2

Hertzsprung-Russell Diagram (1)



Astronomy: Hertzsprung-Russell Diagram (2)

class	temperature	Vega-relative "color label"	mass (solar masses)	radius (solar radii)	luminosity (solar luminosity; bolometric)	% of main-sequence stars
O	≥ 30,000 K	blue	≥ 16	≥ 6.6	≥ 30,000	~0.00003
B	10,000–30,000 K	blue white	2.1–16	1.8–6.6	25–30,000	0.13
A	7,500–10,000 K	white	1.4–2.1	1.4–1.8	5–25	0.6
F	6,000–7,500 K	yellow white	1.04–1.4	1.15–1.4	1.5–5	3%
G	5,200–6,000 K	yellow	0.8–1.04	0.96–1.15	0.6–1.5	7.6%
K	3,700–5,200 K	orange	0.45–0.8	0.7–0.96	0.08–0.6	12.1%
M	2,400–3,700 K	red	0.08–0.45	≤ 0.7	≤ 0.08	76.45%

(Source: https://en.wikipedia.org/wiki/Stellar_classification#cite_note-m.C3.B6re-6)

Astronomy: Constellations (1)

constellation	abbr	family	origin	meaning	brightest star
Andromeda	And	Perseus	ancient*	princess	Alpheratz
Antlia	Ant	La Caille	1763+*	air pump	α Antliae
Apus	Aps	Bayer	1603**	bird of paradise	α Apodis
Aquarius	Aqr	Zodiac	ancient*	water-bearer	Sadalsuud
Aquila	Aql	Hercules	ancient*	eagle	Altair
Ara	Ara	Hercules	ancient*	altar	β Arae
Aries	Ari	Zodiac	ancient*	ram	Hamal
Auriga	Aur	Perseus	ancient*	charioteer	Capella
Boötes	Boo	Ursa Major	ancient*	herdsman	Arcturus
Caelum	Cae	La Caille	1763+*	chisel	α Caeli
Camelopardalis	Cam	Ursa Major	1613++*	giraffe	β Camelopardalis
Cancer	Cnc	Zodiac	ancient*	crab	Tarf

Astronomy: Constellations (2)

constellation	abbr	family	origin	meaning	brightest star
Canes Venatici	CVn	Ursa Major	1690***	hunting dogs	Cor Caroli
Canis Major	CMa	Orion	ancient*	greater dog	Sirius
Canis Minor	CMi	Orion	ancient*	lesser dog	Procyon
Capricornus	Cap	Zodiac	ancient*	sea goat	Deneb Algiedi
Carina	Car	Heavenly Waters	1763+*	keel	Canopus
Cassiopeia	Cas	Perseus	ancient*	queen	Shedir
Centaurus	Cen	Hercules	ancient*	centaur	Alpha Centauri
Cepheus	Cep	Perseus	ancient*	king	Alderamin
Cetus	Cet	Perseus	ancient*	whale	Deneb Kaitos
Chamaeleon	Cha	Bayer	1603**	chameleon	α Chamaeleontis
Circinus	Cir	La Caille	1763+*	compasses	α Circini
Columba	Col	Heavenly Waters	1592++*	dove	Phact

Astronomy: Constellations (3)

constellation	abbr	family	origin	meaning	brightest star
Coma Berenices	Com	Ursa Major	1603**	Berenice's hair	β Comae Berenices
Corona Australis	CrA	Hercules	ancient*	southern crown	Alphekka Meridiana
Corona Borealis	CrB	Ursa Major	ancient*	northern crown	Alphecca
Corvus	Crv	Hercules	ancient*	crow	Gienah
Crater	Crt	Hercules	ancient*	cup	Labrum
Crux	Cru	Hercules	1603**	southern cross	Acrux
Cygnus	Cyg	Hercules	ancient*	swan	Deneb
Delphinus	Del	Heavenly Waters	ancient*	dolphin	Rotanev
Dorado	Dor	Bayer	1603**	dolphinfish	α Doradus
Draco	Dra	Ursa Major	ancient*	dragon	Etamin
Equuleus	Equ	Heavenly Waters	ancient*	pony	Kitalpha
Eridanus	Eri	Heavenly Waters	ancient*	river	Achernar

Astronomy: Constellations (4)

constellation	abbr	family	origin	meaning	brightest star
Fornax	For	La Caille	1763+*	chemical furnace	Fornacis
Gemini	Gem	Zodiac	ancient*	twins	Pollux
Grus	Gru	Bayer	1603**	crane	Alnair
Hercules	Her	Hercules	ancient*	strong man	Kornephoros
Horologium	Hor	La Caille	1763+*	pendulum clock	α Horologii
Hydra	Hya	Hercules	ancient*	monster	Alphard
Hydrus	Hyi	Bayer	1603**	lesser water snake	β Hydri
Indus	Ind	Bayer	1603**	Indian	The Persian
Lacerta	Lac	Perseus	1690***	lizard	α Lacertae
Leo	Leo	Zodiac	ancient*	lion	Regulus
Leo Minor	LMi	Ursa Major	1690***	lesser lion	Praecipua
Lepus	Lep	Orion	ancient*	hare	Arneb

Astronomy: Constellations (5)

constellation	abbr	family	origin	meaning	brightest star
Libra	Lib	Zodiac	ancient*	balance	Zubeneshamali
Lupus	Lup	Hercules	ancient*	wolf	Men
Lynx	Lyn	Ursa Major	1690***	lynx	Elvashak
Lyra	Lyr	Hercules	ancient*	lyre	Vega
Mensa	Men	La Caille	1763+*	Table Mountain	α Mensae
Microscopium	Mic	La Caille	1763+*	microscope	γ Microscopii
Monoceros	Mon	Orion	1613++*	unicorn	β Monocerotis
Musca	Mus	Bayer	1603**	fly	α Muscae
Norma	Nor	La Caille	1763+*	carpenter's level	γ_2 Normae
Octans	Oct	La Caille	1763+*	octant	ν Oct
Ophiuchus	Oph	Hercules	ancient*	serpent-bearer	Rasalhague
Orion	Ori	Orion	ancient*	hunter	Rigel

Astronomy: Constellations (6)

constellation	abbr	family	origin	meaning	brightest star
Pavo	Pav	Bayer	1603**	peacock	Peacock
Pegasus	Peg	Perseus	ancient*	winged horse	Enif
Perseus	Per	Perseus	ancient*	hero	Mirfak
Phoenix	Phe	Bayer	1603**	phoenix	Ankaa
Pictor	Pic	La Caille	1763+*	easel	α Pictoris
Pisces	Psc	Zodiac	ancient*	fishes	Alpherg
Piscis Austrinus	PsA	Heavenly Waters	ancient*	southern fish	Fomalhaut
Puppis	Pup	Heavenly Waters	1763+*	poop deck	Naos
Pyxis	Pyx	Heavenly Waters	1763+*	mariner's compass	α Pyxidis
Reticulum	Ret	La Caille	1763+*	eyepiece graticule	α Reticuli
Sagitta	Sge	Hercules	ancient*	arrow	γ Sagittae
Sagittarius	Sgr	Zodiac	ancient*	archer	Kaus Australis

Astronomy: Constellations (7)

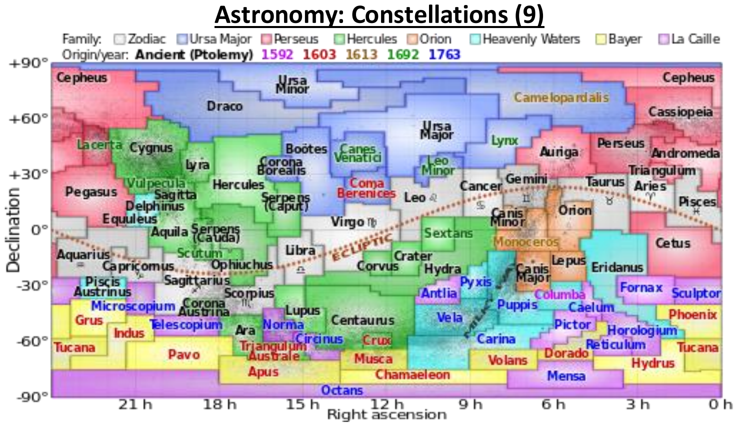
constellation	abbr	family	origin	meaning	brightest star
Scorpius	Sco	Zodiac	ancient*	scorpion	Antares
Sculptor	Scl	La Caille	1763+*	sculptor	α Sculptoris
Scutum	Sct	Hercules	1690***	shield	α Scuti
Serpens	Ser	Hercules	ancient*	snake	Unukalhai
Sextans	Sex	Hercules	1690***	sextant	α Sextantis
Taurus	Tau	Zodiac	ancient*	bull	Aldebaran
Telescopium	Tel	La Caille	1763+*	telescope	α Telescopii
Triangulum	Tri	Perseus	ancient*	triangle	β Trianguli
Triangulum Australe	TrA	Hercules	1603**	southern triangle	Atria
Tucana	Tuc	Bayer	1603**	toucan	α Tucanae
Ursa Major	UMa	Ursa Major	ancient*	great bear	Alioth
Ursa Minor	UMi	Ursa Major	ancient*	lesser bear	Polaris

Astronomy: Constellations (8)

constellation	abbr	family	origin	meaning	brightest star
Vela	Vel	Heavenly Waters	1763+*	sails	Regor
Virgo	Vir	Zodiac	ancient*	maiden	Spica
Volans	Vol	Bayer	1603**	flying fish	β Volantis
Vulpecula	Vul	Hercules	1690***	fox	Anser

*Ptolemy
**_Uranometria_, created by Keyser and de Houtman
***_Firmamentum Sobiescianum_, Hevelius
+*Lacaille
++*Plancius

Astronomy: Constellations (9)



(Image source: https://en.wikipedia.org/wiki/88_modern_constellations#/media/File:Constellations_ecliptic_equirectangular_plot.svg, Author: Cmglee, Timwe, NASA, public domain)

Astronomy: Milky Way Galaxy (1)

Milky Way: barred spiral galaxy, diameter about 100,000–120,000 light-years, containing about 100–400 billion stars, more than 100 billion planets

solar System location: about 27,000 light-years from the galactic center, on the inner edge of the Orion Arm

center: marked by an intense radio source, Sagittarius A*, likely a supermassive black hole

orbits: stars and gases orbit at approximately 220 km/s; constant rotation suggests that much mass of the Milky Way does not emit or absorb electromagnetic radiation; mass termed "dark matter"

Astronomy: Milky Way Galaxy (2)

rotational period: about 240 million years at the position of the Sun, galaxy is moving at approximately 600 km/s with respect to extragalactic frames of reference.

oldest stars: nearly as old as the Universe itself and thus likely formed shortly after the Big Bang.

related galaxies: satellite galaxies and part of the Local Group of galaxies, a component of the Virgo Supercluster, which is itself a component of the Laniakea Supercluster

(Source: https://en.wikipedia.org/wiki/Milky_Way)

Astronomy: Galaxy Classification (1)

- elliptical galaxies: smooth, featureless light distributions and appear as ellipses in images, designated "E", followed by an integer n representing degree of ellipticity on the sky
- spiral galaxies: consist of a flattened disk, with stars forming a (usually two-armed) spiral structure, and a central concentration of stars known as the bulge, similar in appearance to an elliptical galaxy, designated "S," roughly half of all spirals are also observed to have a bar-like structure, extending from the central bulge, designated "SB"
- lenticular galaxies: designated S0, consist of a bright central bulge surrounded by an extended, disk-like structure, the disks of lenticular galaxies have no visible spiral structure and are not actively forming stars in any significant quantity

Astronomy: Galaxy Classification (2)

- bars: SA designates spiral galaxies without bars, SAB denotes weakly barred spirals, lenticular galaxies classified as unbarred (SA0) or barred (SB0), with notation S0 reserved for galaxies for which it is impossible to tell if a bar is present or not
- rings: those possessing ring-like structures (denoted '(r)') and those without rings (denoted '(s)'), "transition" galaxies designated by (rs)
- spiral arms: spiral galaxies are assigned to a class based primarily on the tightness of their spiral arms
  - Sd (SBd): diffuse, broken arms made up of individual stellar clusters and nebulae; very faint central bulge
  - Sm (SBm): irregular in appearance; no bulge component
  - Im: highly irregular galaxy

(Source: https://en.wikipedia.org/wiki/Galaxy_morphological_classification)

Astronomy: Hubble's Law (1)

Hubble's law:

1. Objects more than 10 megaparsecs have a Doppler shift as relative velocity away from Earth;
2. This Doppler-shift-measured velocity is approximately proportional to their distance from the Earth for galaxies up to a few hundred megaparsecs away.

(Source: https://en.wikipedia.org/wiki/Hubble%27s_law)

Astronomy: Hubble's Law (2)

redshift $z = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}}$

λ_{obs} = wavelength, due to movement, of a line in the object's spectrum

λ_{rest} = wavelength of the same line if the object were not moving

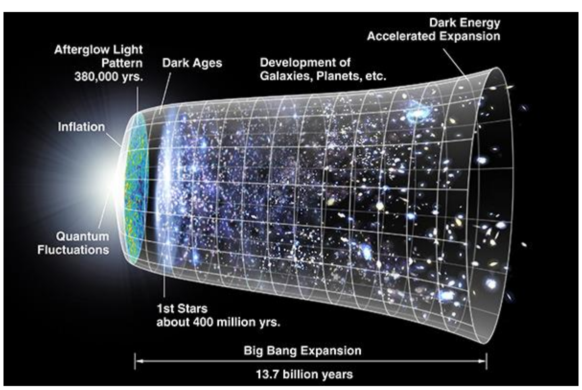
lookback time $T_{LB} = \frac{z}{H_0(1+z)}$

Hubble constant H_0 = 67.6 kilometers/second/megaparsec

(Source: https://en.wikipedia.org/wiki/Hubble%27s_law)

Astronomy: Cosmology

cosmology: study of the origin, evolution, and eventual fate of the universe



(Image source: https://astrosociety.org/wp-content/uploads/2012/10/1-CMB_Timeline300_no_WMAP.jpg, Author : Astronomical Society of the Pacific)

Astonomy: Chemical Abundance of the Universe

Atomic number	Element	Mass fraction ppm
1	hydrogen	739,000
2	helium	240,000
8	oxygen	10,400
6	carbon	4,600
10	neon	1,340
26	iron	1,090
7	nitrogen	960
14	silicon	650
12	magnesium	580
16	sulfur	440

Astronomy: History of the Universe (1)

epoch/era	time	redshift	temperature	description
Planck	$<10^{-43}$ s		$>10^{32}$ K 10^{19} GeV	quantum effects dominate
Grand unification	$<10^{-36}$ s		10^{16} GeV	3 forces of standard model unified
Inflation/ electroweak			10^{28} K - 10^{22} K	cosmic inflation expands space
Quark	$>10^{12}$ s		10^{12} K	forces of standard model have separated
Hadron	10^{-6} - 1 s		10^{10} K – 10^{9} K	quarks bound to hadrons
Lepton	1 s - 10 s		10^{9} K	neutrino decoupling

Astronomy: History of the Universe (2)

epoch/era	time	redshift	temperature	description
Photon	10 s - 10^{13} s		10^{9} K – 10^{3} K	universe consists of plasma of nuclei, electrons, and photons
Big Bang nucleo-synthesis	10 s – 10^{3} s		10 MeV – 100 KeV 10^{11} K – 10^{9} K	protons and neutrons bound
Matter-dominated era	47 ka – 10 Ga	3600 – 0.4	10^{4} K – 4 K	decelerated expansion of space

Astronomy: History of the Universe (3)

epoch/era	time	redshift	temperature	description
Recombination	380 ka	1100	4000 K	electrons and atomic nuclei form neutral atoms
Dark Ages	380 ka - 150 Ma	1100 - 20	4000 K – 60 K	formation of first stars
Stelliferous	150 Ma – 100 Ga	20 - -0.99	60 K – 0.03 K	first formation of Population III stars
Reionization	150 Ma – 1 Ga	20 - 6	60 K – 19 K	most distant astronomical objects date to this period

Astronomy: History of the Universe (4)

epoch/era	time	redshift	temperature	description
Galaxy formation and evolution	1 Ga – 10 Ga	6 – 0.4	19 K – 4 K	galaxy clusters form
Dark-energy dominated	>10 Ga	< 0.4	< 4 K	matter density falls below dark energy density
Present	13.8 Ga	0	2.7 K	
Far future	>100 Ga	< -0.99	< 0.1 K	may become Dark Era, Big Crunch, or Big Rip

(Source: https://en.wikipedia.org/wiki/Chronology_of_the_universe)

Astronomy: Drake Equation

Drake equation: argument used to arrive at an estimate of the number of active, communicative extraterrestrial civilizations, N, in the Milky Way

$$N = R^* * f_p * n_e * f_\ell * f_i * f_c * L$$

R^* = average rate of star formation in our galaxy

f_P = fraction of formed stars that have planets

n_e = average number of planets per star that can potentially support life

f_ℓ = fraction of those planets that actually develop life

f_i = fraction of planets bearing life on which intelligent, civilized life has developed

f_c = fraction of civilizations that have developed communications

L = length of time over which such civilizations release detectable signals

Astronomy: Rocket Equation

change in velocity Δv is a measure of the impulse that is needed to perform a maneuver such as launch from, or landing on a planet or moon, or in-space orbital maneuver; it is a scalar with the units of speed

$$\Delta v = I_{sp} g_0 \ln \frac{m_0}{m_f}$$

I_{sp} = specific impulse in seconds

g_0 = 9.81 m/s^2

m_0 = initial mass

m_f = final mass

Astronomy: Special Relativity (1)

Special relativity is based on:

1. The laws of physics are invariant (i.e. identical) in all inertial systems (non-accelerating frames of reference).
2. The speed of light in a vacuum is the same for all observers, regardless of the motion of the light source.

Originally proposed in 1905 by Albert Einstein in the paper "On the Electrodynamics of Moving Bodies,." it explains length contraction, time dilation, relativistic mass, a universal speed limit and relativity of simultaneity, and mass-energy equivalence, E = mc^2, where c is the speed of light, m is mass, and E is energy.

(Source: https://en.wikipedia.org/wiki/Special_relativity)

Astronomy: Special Relativity (2)

time dilation $\frac{t'}{t} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ length contraction $\frac{l'}{l} = \sqrt{1-\frac{v^2}{c^2}}$

mass increase $\frac{m'}{m} = \sqrt{1-\frac{v^2}{c^2}}$

t ′ = time measured by moving object

t = time measured by objects at rest compared to moving object

l ′ = length of moving object *l* = length of object at rest

m ′ = mass of moving object *m* = mass of object at rest

v = velocity of moving object in units of *c* *c* = velocity of light

Astronomy: Special Relativity (3)

relativistic velocity addition $v_{12} = \dfrac{v_1 + v_2}{1 + \dfrac{v_1 v_2}{c^2}}$

v_1 = velocity of object 1
v_2 = velocity of object 2
v_{12} = relative velocity of objects 1 and 2 moving toward each other

speed of light c = 299,792,458 meters/second (approximately 3.00×10^8 meters/second = 186,282 miles/second)

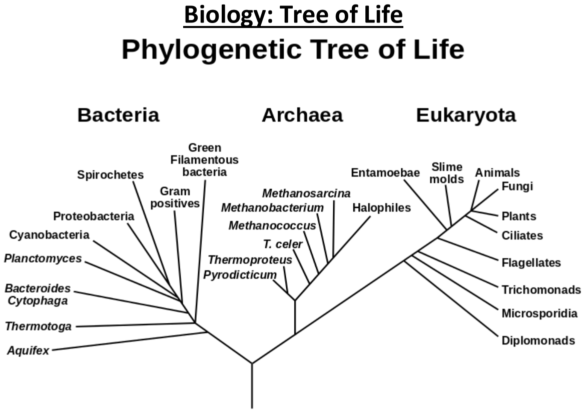
Astronomy: General Relativity

General relativity is the geometric theory of gravitation published by Albert Einstein in 1915. It generalizes special relativity and Newton's law of universal gravitation, providing a unified description of gravity as a geometric property of spacetime. Some predictions include gravitational time dilation, gravitational lensing, the gravitational redshift of light, and gravitational time delay. The theory implies the existence of black holes, supported by observations of intense radiation emitted by microquasars and active galactic nuclei.

(Source: https://en.wikipedia.org/wiki/General_relativity)

Biology

Biology: Tree of Life



(Image source: https://en.wikipedia.org/wiki/File:Phylogenetic_tree.svg, Author : NASA Astrobiology Institute, public domain)

Biology: Subdivisions of Biological Organisms

domain	cell structure	properties	kingdom
eukaryotes	eurkariotic	multicellular, extensive differentiation of cells and tissues unicellular, coenocytic or mycellal, little or no tissue differentiation	• plants • animals • protists • fungi
eubacteria	prokaryotic	cell chemistry similar to eucaryotes	eubacteria
archaebacteria	prokaryotic	distinctive cell chemistry	archaea

Biology: Prokariotic Cell Structure (1)

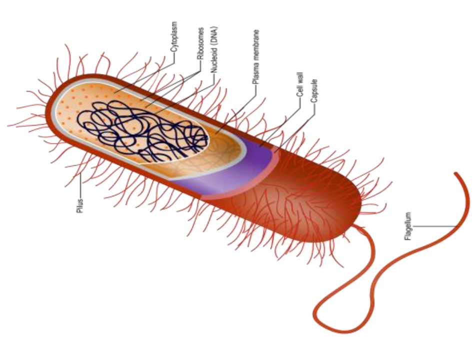


Image source: https://commons.wikimedia.org/wiki/File:Prokaryote_cell.svg, Author Ali Zifan, CC BY-SA 4.0)

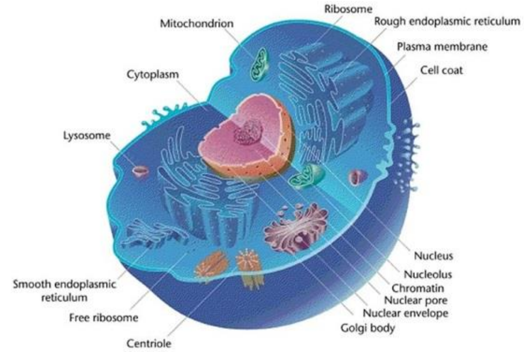
Biology: Prokaryotic Cell Structure (2)

capsule: slimy outer coating of the cell wall. It is composed of the polypeptide. The main function of the capsule is to protect the cell from getting dry and also helps in protecting cells from external pressures
cell wall: protects the plasma membrane, plays a vital role in supporting and protecting the cells, thick outer layer made of cellulose
cell membrane: double layered, thin barrier, surrounds the cell to control the entry and exit of certain substances
cytoplasm: membrane which protects the cell by keeping organelles separate, helps keep cell stable, where many vital biochemical reactions take place
nucleiod: cytoplasm region containing genetic material, DNA of a prokaryotic organism is one big loop or a circular, located inside the nucleoid, plays a vital role in cell division

Biology: Prokaryotic Cell Structure (3)

ribosome: plays a vital role in protein synthesis
plasmids: smallest membrane of a cell with double stranded DNA, rarely present in prokaryotic organisms, main role of plasmids is it helps in DNA exchanging between the bacterial cells
pilli: thinnest membrane of a prokaryotic cell, composed of protein complex called pilin and are mainly involved in sticking to the objects especially during sexual reproduction
flagella: helical shaped membrane, whose sizes ranges from 19-20nm in diameter and plays a vital role in motility of an organism from one place to another place, also helps in swimming, gliding, spinning and rotating both in clockwise and counterclockwise directions
(Source: https://en.wikipedia.org/wiki/Prokaryote)

Biology: Eukariotic Cell Structure (1)



(Image source: https://commons.wikimedia.org/wiki/File:Eukaryotic_Cell_(animal).jpg, Author: Mediran, CC BY-SA 3.0)

Biology: Eukariotic Cell Structure (2)

plasma membrane: semi-permeable membrane, acts as boundary of a cell, protects and separates the cell from the external environment
nucleus: membrane bound organelles, found in all eukaryotic cells, important organelle, controls the complete activity and plays a vital role in reproduction
nuclear membrane: bilayer membrane, acts as a barrier between cell nucleus and other organs of a cell
nucleolus: important membrane found inside the nucleus, plays a vital role in the production of cell's ribosome
mitochondria: double membrane, filamentous organelles, which play vital role in generating and transforming the energy and in various functions of the cell metabolisms including oxidative phosphorylation

Biology: Eukariotic Cell Structure (3)

endoplasmic reticulum: helps in the movement of materials around the cell, contains an enzyme that helps in building molecules and in manufacturing of proteins, main function is storage and secretion
ribosome: plays a vital role in protein synthesis
golgi bodies: help in the movement of materials within the cell
lysosomes: help in cell renewal and break down of old cell parts
cytoplasm: membrane which protects the cell by keeping organelles separate, helps keep cell stable, where many vital biochemical reactions take place
chromosomes: made up of DNA and stored in the nucleus, which contains the instructions for traits and characteristics
(Source: https://en.wikipedia.org/wiki/Eukaryote)

Biology: DNA and RNA

nucleic acids: high molar mass polymers that play an essential role in protein synthesis
deoxyribonucleic acid (DNA): among the largest molecules known, can have molar masses of up to tens of billions of grams; has two strands
nucleotides: consist of a base, a deoxyribose, and a phosphate group linked together
ribonucleic acid (RNA): molecules vary greatly in size, some having a molar mass of about 25,000 grams

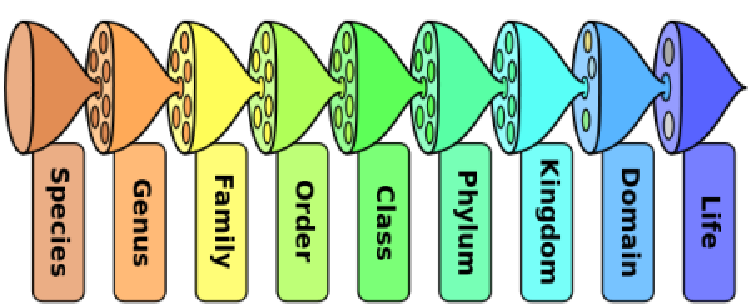
Biology: Gene, Chromosome, Chargaff's Rules

gene: locus or region of DNA which is made up of nucleotides and is the molecular unit of heredity
chromosome: a packaged and organized structure containing most of the DNA of a living organism

Chargaff's rules:
1. the amount of adenine (a purine) is equal to that of thymine (a pyrimidine), A = T
2. the amount of cytosine (a pyrimidine) is equal to that of guanine (a purine), C = G
3. the total number of purine bases is equal to the total number of pyrimidine bases, A + G = C + T

(Source: https://en.wikipedia.org/wiki/Chargaff%27s_rules)

Biology: Classification of Organisms



(Image source: https://en.wikipedia.org/wiki/File:Biological_classification_L_Pengo_vflip.svg, Author: Pengo, public domain)

Biology: Classification of Marine Organisms (1)

kingdom	phylum	class	organism
monera	cyanophytra		blue-green algae
	schizophyta		bacteria
protista	chrysophyta		diatoms, coccolithophores
	protozoa		foraminifera, radiolaria, flagellates
	pyrrophyta		dinoflagellates, zooxanthellae
	ciliophora		cilates
fungi	mycophyta		fungi, lichens
plantae	rhodophyta		red algae
	phaeophyta		brown algae
	chlorophyta		green algae
	tracheophyta		salt-marsh grasses, eel grasses, mangroves

(Source: Oceanography, Paul R. Pinet, 1992, p. 293)

Biology: Classification of Marine Organisms (2)

kingdom	phylum	class	organism
animalia	ctenophora		comb jellies
	cnidaria	hydrazoa	hydras
		schyphozoa	jellyfishes
		anthozoa	corals, sea anemones
	porifera		sponges
	bryzoa		moss animals
	platyhelminthes		flatworms
	chaetognatha		arrow worms
	annelida		polychaete worms
	brachyiopoda		lamp shells

Biology: Classification of Marine Organisms (3)

kingdom	phylum	class	organisms
animalia	mollusca	amphineura	chitons
		gastropoda	snails, limpets
		bivalvia	clams, oysters, mussels, scallops
		scaphopoda	
		cephalopoda	
	arthropoda	merostomata	horseshoe crabs
		arachnida	marine mites
		pycnogonida	sea spiders
		crustacea	copepods, barnacles, krill, shrimp, crabs, lobsters, isopods, amphipods

Biology: Classification of Marine Organisms (4)

kingdom	phylum	class	organisms
animalia	echinodermata	asteroidea	starfish
		echinoidea	sea urchins, sand dollars
		holothuroidea	sea cucumbers
		ophiuroidea	brittle stars
		crinoidea	sea lillies
	protochordata		pterobranches, acorn worms
	chordata	urochordata	tunicates, salps
		cephalochordata	lancelets
		pisces	cartilaginous, bony, jawless fish
		reptilia	sea turtles, sea snakes
		aves	sea birds
		mammalia	seals, sea otters, manatees, whales, porpoises, dolphins, walruses

Biology: Light Penetration in the Ocean

color	depth in m
ultraviolet	50
red	100
yellow	200
green	300
blue	450

Biology: Osmosis

osmosis: selective passage of solvent molecules through a porous membrane from a dliute solution to a more concentrated one

semipermeable membrane: allows the passage of solvent molecules but blocks the passage of solute molecules

osmotic pressure: pressure required to stop osmosis $\pi = MRT$

M = molarity R = gas constant T = absolute temperature

Biology:

Biology: Respiration

enzyme: biological catalyst

photosynthesis: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

aerobic respiration:

glucose + oxygen → carbon dioxide + water + energy

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + 2900 kJ/mol

anaerobic respiration in animals:

glucose → lactic acid + energy

$C_6H_{12}O_6 \rightarrow 2C_3H_6O_3$ + 120 kJ/mol

anaerobic respiration in plants:

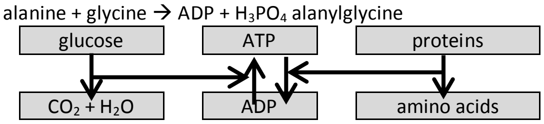
glucose → ethanol + carbon dioxide + energy

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ + Energy

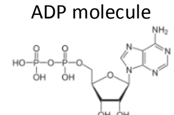
Biology: ADP and ATP

$ADP + H_3PO_4 \rightarrow ATP + H_2O$ alanine + glycine → alanylgycine

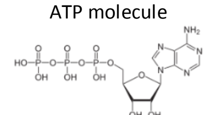
ATP + H_2O + alanine + glycine → ADP + H_3PO_4 alanylglycine



ADP molecule



ATP molecule



(Image sources:
https://en.wikipedia.org/wiki/Adenosine_diphosphate#/media/File:Adenosindiphosphat_protoniert.svg,
https://en.wikipedia.org/wiki/Adenosine_triphosphate#/media/File:Adenosintriphosphat_protoniert.svg, Author: NEUROtiker, public domain)

Biology: Chemical Abundance in Humans

Symbol	Element	Percent
O	oxygen	65
C	carbon	18
H	hydrogen	10
N	nitrogen	3
Ca	calcium	1.5
P	phosphorus	1
K	potassium	0.35
S	sulfur	0.25
Na	sodium	0.15
Mg	magnesium	0.05

Biology: Logistic Growth–Batch Growth

$$\frac{dx}{dt} = kx\left(1 - \frac{x}{x_\infty}\right) \qquad x = \frac{x_0 e^{kt}}{1 - \frac{x_0}{x_\infty}(1 - e^{kt})}$$

k = logistic growth constant (h^{-1})

x_0 = initial concentration (g/L)

x_∞ = carrying capacity (g/L)

Biology: Levels of Organization of Living Things

- cell: basic unit of structure and function of all living things
- tissue: group of cells of the same kind
- organ: structure composed of one or more types of tissues, the tissues of an organ work together to perfume a specific function, human organs include the brain, stomach, kidney, and liver, plant organs include roots, stems, and leaves
- organ system: group of organs that work together to perform a certain function, examples of organ systems in a human include the skeletal, nervous, and reproductive systems
- organism: individual living thing that may be made up of one or more organ systems

Biology: Characteristics of Organisms

sexual
asexual
unicellular
multicellular

Biology: Body Systems (1)

- circulatory: pumping and channeling blood to and from the body and lungs with heart, blood and blood vessels
- integumentary: skin, hair, fat, and nails
- skeletal: structural support and protection with bones, cartilage, ligaments and tendons
- reproductive: sex organs, such as ovaries, fallopian tubes, uterus, vagina, mammary glands, testes, vas deferens, seminal vesicles and prostate
- digestive: digestion and processing food with salivary glands, oesophagus, stomach, liver, gallbladder, pancreas, intestines, rectum and anus
- urinary: kidneys, ureters, bladder and urethra involved in fluid balance, electrolyte balance and excretion of urine
- respiratory: organs used for breathing, the pharynx, larynx, bronchi, lungs and diaphragm

Biology: Body Systems (2)

- endocrine: communication within the body using hormones made by endocrine glands such as the hypothalamus, pituitary gland, pineal gland, thyroid, parathyroid and adrenal glands
- immune: protects the organism from foreign bodies
  - lymphatic: structures involved in the transfer of lymph between tissues and the blood stream; includes the lymph and the nodes and vessels; the lymphatic system includes functions including immune responses and development of antibodies
- muscular: allows for manipulation of the environment, provides locomotion, maintains posture, and produces heat. Include skeletal muscles, smooth muscles and cardiac muscle
- nervous: collecting, transferring and processing information with brain, spinal cord and peripheral nervous system.

(Source: https://en.wikipedia.org/wiki/Biological_system)

Biology: Organism Relationships

parasite: organism that has sustained contact with another organism to the detriment of the host organism
host: an organism that harbors a parasitic, a mutual, or
a commensal symbiont, typically providing nourishment and shelter
niche: describes how an organism or population responds to the distribution of resources and competitors
ecosystem:
predator: an organism that is hunting and feeds on prey
prey: the organism that is attacked
consumer: heterotrophic organism that feeds on other organisms in a food chain
producer: autotrophic organism that serves as a source of food for other organisms in a food chain
decomposer: an organism, especially a soil bacterium, fungus, or invertebrate, that decomposes organic material

Biology: Levels of Organization

- organism: basic living system, a functional grouping of the lower-level components, including at least one
- population: groups of organisms of the same species
- community: interspecific groups of interacting populations
- ecosystem: groups of organisms from all biological domains in conjunction with the physical environment
- terrestrial biome: continental scale, climatically and geographically contiguous areas with similar climatic conditions, grouping of ecosystems
- biosphere: all life on Earth or all life plus the physical environment

(Source: https://en.wikipedia.org/wiki/Biological_organisation)

Biology: Whittaker Biome Classification System (1)

1. Tropical rainforest
2. Tropical seasonal rainforest
   deciduous
   semideciduous
3. Temperate giant rainforest
4. Montane rainforest
5. Temperate deciduous forest
6. Temperate evergreen forest
   needleleaf
   sclerophyll
7. Subarctic-subalpin needle-leaved forests (taiga)
8. Elfin woodland
9. Thorn forests and woodlands

Biology: Whittaker Biome Classification System (2)

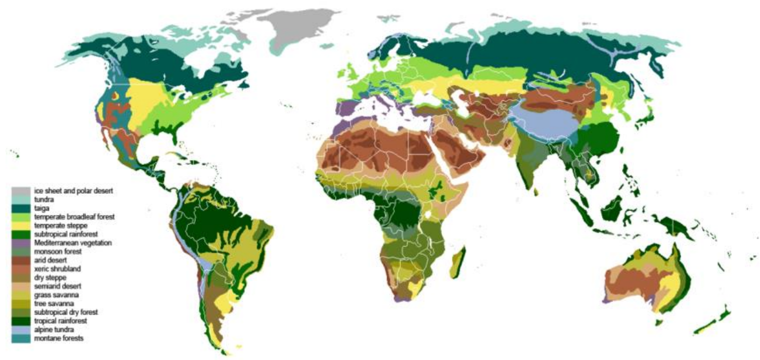
10. Thorn scrub
11. Temperate woodland
12. Temperate shrublands
    deciduous
    heath
    sclerophyll
    subalpine-needleleaf
    subalpine-broadleaf
13. Savanna
14. Temperate grassland
15. Alpine grassland
16. Tundra
17. Tropical desert

Biology: Whittaker Biome Classification System (3)

18. Warm-temperate desert
19. Cool temperate desert scrub
20. Arctic-alpine desert
21. Bog
22. Tropical fresh-water swamp forest
23. Temperate fresh-water swamp forest
24. Mangrove swamp
25. Salt marsh
26. Wetland

(Source: https://en.wikipedia.org/wiki/Biome#Whittaker_.281962.2C_1970.2C_1975.29_biome-types)

Biology: Terrestrial Biomes



(Image source: https://en.wikipedia.org/wiki/Biome#/media/File:Vegetation.png, Author : Ville Koistinen, CC BY-SA 3.0)

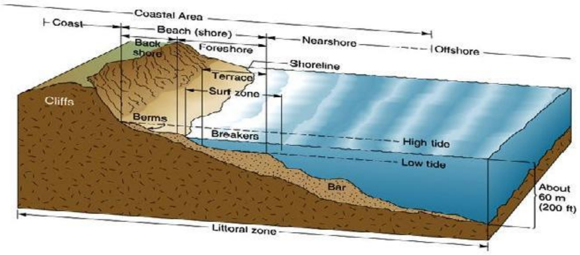
Biology: Walter Aquatic Ecosystems (1)

A. Inland Aquatic Ecosystems
   River and Stream Ecosystems
   Lakes and Reservoirs
B. Marine Ecosystems
   Intertidal and Littoral Ecosystems
   Coral Reefs
   Estuaries and Enclosed Seas
   Ecosystems of the Continental Shelves
   Ecosystems of the Deep Ocean
C. Managed Aquatic Ecosystems
   Managed Aquatic Ecosystems

(Source: https://en.wikipedia.org/wiki/Biome#Whittaker_.281962.2C_1970.2C_1975.29_biome-types)

Biology: Marine Habitats (1)

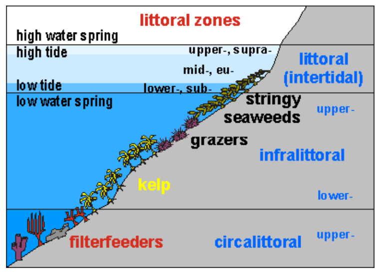
littoral zone: part of a sea, lake or river that is close to the shore; extends from the high water mark to shoreline areas that are permanently submerged; always includes the intertidal zone and is often used to mean the same as the intertidal zone, but can extend. beyond the intertidal zone



(Image source: https://en.wikipedia.org/wiki/Littoral_zone#/media/File:Littoral_Zones.jpg, public domain)

Biology: Marine Habitats (2)

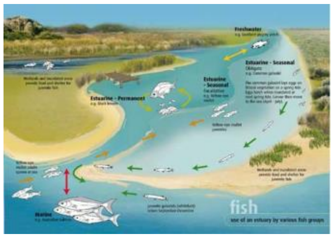
intertidal zone: also known as the seashore; sometimes referred to as the littoral zone,; area that is above water at low tide and under water at high tide;. can many habitats, with starfish, sea urchins, and coral; includes steep rocky cliffs, sandy beaches, wetlands, mudflats



(Image source: https://sites.google.com/site/islandecology2011/intertidal-zone, Island Ecology 2011)

Biology: Marine Habitats (3)

estuaries: partially enclosed coastal body of brackish water with one or more rivers or streams flowing into it, and a free connection to the open sea; form a transition zone between river environments and maritime environments;. subject to marine influences, such as tides, waves, and influx of saline water,

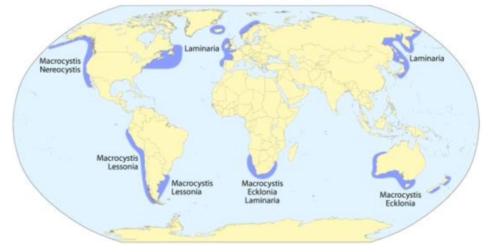


and riverine influences, such as fresh water flows and sediment; among the most productive natural habitats in the world

(Image source: http://www.estuarywatch.org.au/cb_pages/victorias_estuaries.php, Author: Victoria State Government)

Biology: Marine Habitats (4)

kelp forests: underwater areas with a high density of kelp; recognized as one of the most productive and dynamic ecosystems on Earth; smaller areas of anchored kelp are called kelp beds; physically formed by brown macroalgae, the order Laminariales, kelp forests provide a unique, three-dimensional



habitat for marine organisms and are a source for understanding many ecological processes (Image source: https://en.wikipedia.org/wiki/Kelp_forest#/media/File:Kelp_forest_distribution_map.png, Author: Maximilian Dörrbecker, CC BY-SA 2.0)

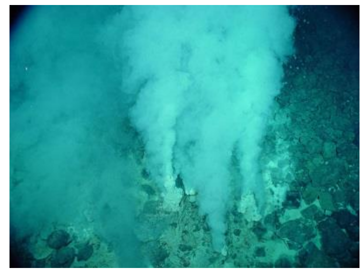
Biology: Marine Habitats (5)

coral reefs: diverse underwater ecosystems held together by calcium carbonate structures secreted by corals; built by colonies of tiny animals found in marine waters that contain few nutrients; built from stony corals, which in consist of polyps that cluster in groups; polyps belong to a group of animals known as Cnidaria, which includes sea anemones and jellyfish; .corals secrete hard carbonate exoskeletons which support and protect the coral polyps; most reefs grow best in warm, shallow, clear, sunny and agitated waters

(Image source: https://en.wikipedia.org/wiki/Coral_reef#/media/File:Blue_Linckia_Starfish.JPG, Author: Richard Ling, CC BY-SA 3.0)

Biology: Marine Habitats (6)

hydrothermal vents: fissures in a planet's surface from which geothermally heated water spews; commonly found near volcanically active locations, areas where tectonic plates are moving apart, ocean basins, and hotspots; common land types include hot springs, fumaroles and geysers; may form features called black smokers; areas around submarine hydrothermal vents are biologically productive, hosting complex communities fueled by the chemicals dissolved in the vent fluids



(Image source: https://en.wikipedia.org/wiki/Hydrothermal_vent#/media/File:Champagne_vent_white_smokers.jpg, Author : NOAA, public domain)

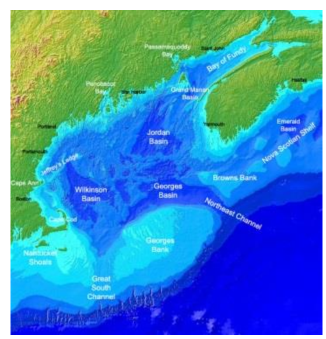
Biology: Marine Habitats (7)

cold seeps: areas of the ocean floor where hydrogen sulfide, methane and other hydrocarbon-rich fluid seepage occurs, often in the form of a brine pool; the temperature of the seepage is often slightly higher than the surrounding ocean; constitute a biome supporting several endemic species; develop unique topography over time, where reactions between methane and seawater create carbonate rock formations and reefs

(Image source: https://en.wikipedia.org/wiki/Cold_seep#/media/File:Lamellibrachia_luymesi1.png, Author: Charles Fisher, CC BY 2.5)

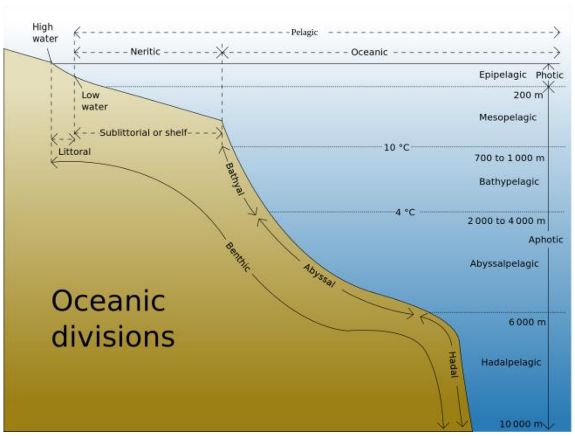
Biology: Marine Habitats (8)

ocean banks: part of the sea which is shallow compared to its surrounding area, such as a shoal or the top of an underwater hill; similar to .continental slopes, ocean banks slopes can upwell as tidal and other flows intercept them, resulting sometimes in nutrient rich currents; rich fishing sites



(Image source: https://en.wikipedia.org/wiki/Ocean_bank#/media/File:GulfofMaine.jpg, Author: NOAA, public domain)
(Source: https://en.wikipedia.org/wiki/Marine_habitats)

Biology: Ocean Zones (1)



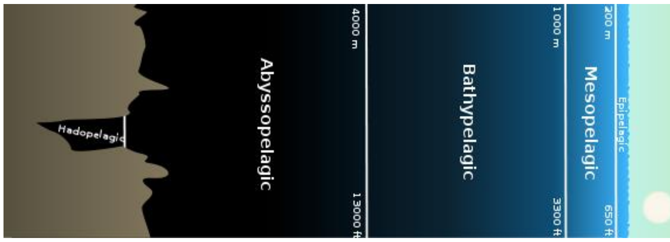
(Image source: https://en.wikipedia.org/wiki/Oceanic_zone#/media/File:Oceanic_divisions.svg, Author: K. Aainsqatsi , public domain)

Biology: Ocean Zones (2)

neritic zone: water above the continental shelf; relatively shallow part of the ocean above the drop-off of the continental shelf, approximately 200 meters deep; forms a relatively stable and well-illuminated environment for marine life, from plankton up to large fish and corals; where the oceanic system interacts with the coast; permanently covered with generally well-oxygenated water; receives a lot of sunlight and has low water pressure; relatively stable temperature, pressure, light and salinity levels; suitable for photosynthetic life
demersal zone: part of the ocean or deep lake comprising the water column near to and affected by the seabed and benthos; just above the benthic zone, it forms a layer of the larger profundal zone; is variable in depth and can be part of the photic zone where light can penetrate and photosynthetic organisms grow, or the aphotic zone, which begins between depths of roughly 200 and 1,000 m and extends to the ocean depths, where no light penetrates
(Source: https://en.wikipedia.org/wiki/Oceanic_zone)

Biology: Pelagic Zone (1)

pelagic zone: any water in a sea or lake that is neither close to the bottom nor near the shore; can be thought of as an imaginary cylinder or water column extending from the sea surface almost to the bottom; pressure increases with depth, temperature drops and less light penetrates; depending on the depth, water column, may be divided into different layer



(Image source: https://commons.wikimedia.org/wiki/File:Pelagiczone.svg, Author: omCatX, public domain)

Biology: Pelagic Zone (2)

layer	depth (m)	volume (%)	description
epipelagic	0-200	3	sunlit zone, supports photosynthesis; temperatures range from 40 to −3°C
mesopelagic	200-1,000	28	small amounts of light penetrate; referred to as Twilight Zone; temperatures from 5 to 4°C; pressure up to 10,100,000 Pa and increases with depth
bathypelagic	1,000-2,000	15	no light penetrates; also called the midnight zone; high water pressures and the temperatures near freezing, range 0 to 6°C
abyssopelagic	2,000-6,000	54	remains in perpetual darkness
hadalpelagic	>6,000	<1	deepest trenches in the ocean

(Source: Oceanography, Paul R. Pinet, 1992, p. 291)

Biology: Benthic Zone (1)

benthic zone: ecological region at the lowest level of a body of water such as an ocean or a lake, including the sediment surface and some sub-surface layers; organisms living in this zone are called benthos, and include crustaceans and polychaetes; organisms generally live in close relationship with the substrate bottom and many are permanently attached to the bottom; the superficial layer of the soil lining the given body of water, the benthic boundary layer, is an integral part of the benthic zone greatly influences biological activity; contact soil layers include sand bottoms, rocky outcrops, coral, and bay mud.

Biology: Benthic Zone (2)

layer	depth (m)	area (%)	description
littoral	intertidal		close to the shore; extends from high water mark, which is rarely inundated, to shoreline areas permanently submerged
sublittoral	0-200	8	red and brown algae characteristic; typical animals include sea anemones and corals on rocky shores, shrimps, crabs, and flounders on sandy shores; also called subtidal zone
bathyl	200-2,000	16	seaward of shallower neritic zone, landward of deeper abyssal zone; upper limit marked by the edge of continental shelf; may include trenches and submarine canyons
abyssal	2,000-6,000	75	no light, high pressure
hadal	>6,000	1	no light, high pressure

(Source: Oceanography, Paul R. Pinet, 1992, p. 291; http://encyclopedia.com)

Biology: Natural Selection (1)

natural selection: differential survival and reproduction of individuals due to differences in phenotype

variation: exists due to random mutations in the genome of an individual organism that can be inherited by offspring

species: the basic unit of biological classification and a taxonomic rank; often defined as the largest group of organisms in which two individuals can produce fertile offspring

biological diversity: refers to the variety and variability of life on Earth

Biology: Natural Selection (2)

phenotype: composite of an organism's observable characteristics or traits, including morphology, development, biochemical or physiological properties, behavior, products of behavior; results from expression of an organism's genetic code, genotype, and as the influence of environmental factors and their interactions

genotype: the part (DNA sequence) of the genetic makeup of a cell, and an organism or individual, which determines a specific phenotype of that cell/organism/individual

polymorphism: occurrence of two or more different forms, referred to as alternative phenotypes, in the population of a species;morphs must occupy the same habitat at the same time and belong to a panmictic population

panmictic population: a population without mating restrictions

Biology: Food Web Categories

- source - one or more node(s), all of their predators, all the food these predators eat, etc.
- sink - one or more node(s), all of their prey, all the food that these prey eat, etc.
- community (or connectedness) - a group of nodes and all the connections of who eats whom
- energy flow - quantified fluxes of energy between nodes along links between a resource and a consumer
- paleoecological - reconstructs ecosystems from the fossil record
- functional - emphasizes the functional significance of certain connections having strong interaction strength and greater bearing on community organization, more so than energy flow pathways, has compartments, which are sub-groups in the larger network where there are different densities and strengths of interaction

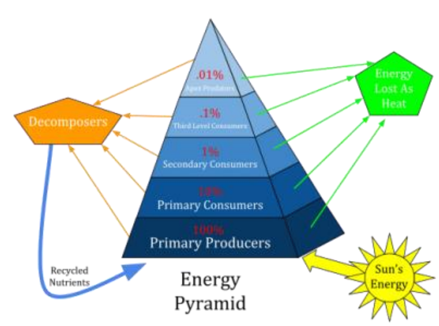
Biology: Ecological/Energy Pyramid

producers: bring energy from non-living sources into the community

primary consumers: eat producers, making them herbivores

secondary consumers: eat the primary consumers, making them carnivores

tertiary consumers: eat the secondary consumers



(Image source: https://commons.wikimedia.org/wiki/File:Ecological_Pyramid.svg, Author: Swiggity.Swag.YOLO.Bro, CC BY-SA 4.0)

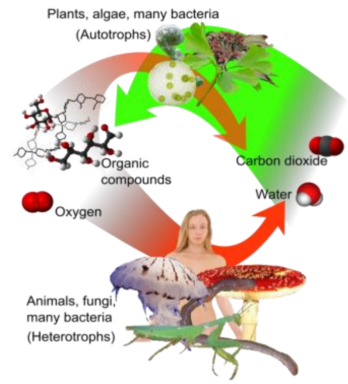
Biology: Food Chain (1)

food chain: linear network of links in a food web starting from producer organisms, ending at apex predator species, detritivores, or decomposers; shows how organisms are related with each other by the food they eat; each level represents a different trophic level; differs from a food web, because the complex network of different animals' feeding relations are aggregated and the chain only follows a direct, linear pathway of one animal at a time

food chain length: the length of a chain is the number of links between a trophic consumer and the base of the web and the
mean chain length of an entire web: the arithmetic average of the lengths of all chains in a food web

Biology: Food Chain (2)

detrivore: heterotrophs that obtain nutrients by consuming detritus
detritus: decomposing plant and animal parts and feces
trophic level: position an organism occupies in a food chain



(Image source: https://en.wikipedia.org/wiki/Heterotroph#/media/File:Auto-and_heterotrophs.png, Author: Mikael Häggström, CC BY-SA 3.0)

Biology: Autotroph (1)

autotroph: organism producing complex organic compounds, such as carbohydrates, fats, and proteins, from simple substances present in its surroundings, generally using energy from light (photosynthesis) or inorganic chemical reactions (chemosynthesis)

- chemoautotroph: synthesize organic compounds from carbon dioxide, use inorganic energy sources, such as hydrogen sulfide, elemental sulfur, ferrous iron, and molecular hydrogen, and ammonia; most are bacteria or archaea in hostile environments

Biology: Autotroph (2)

- lithotroph: diverse group of organisms using inorganic substrate (usually of mineral origin) to obtain reducing equivalents for use in biosynthesis (e.g., carbon dioxide fixation) or energy conservation (i.e., ATP production) via aerobic or anaerobic respiration
- photoautotroph: synthesizes food from inorganic substances using light as an energy source; includes green plants and photosynthetic bacteria are photoautotrophs; capable of using carbon dioxide as their principal carbon source

(Source: https://en.wikipedia.org/wiki/Autotroph)

Biology: Heterotroph (1)

- heterotroph: an organism that cannot fix carbon from inorganic sources (such as carbon dioxide) but uses organic carbon for growth
- chemoheterotroph: unable to fix carbon to form their own organic compounds, can be chemolithoheterotrophs, utilizing inorganic energy sources such as sulfur or chemoorgano-heterotrophs, utilizing organic energy sources such as carbohydrates, lipids, and proteins
- lithotroph: diverse group of organisms using inorganic substrate (usually of mineral origin) to obtain reducing equivalents for use in biosynthesis (e.g., carbon dioxide fixation) or energy conservation (i.e., ATP production) via aerobic or anaerobic respiration

Biology: Heterotroph (2)

- photoheterotroph: organisms that use light for energy, but cannot use carbon dioxide as their sole carbon source; they use organic compounds from the environment to satisfy carbon requirements, including carbohydrates, fatty acids, and alcohols; examples include purple non-sulfur bacteria, green non-sulfur bacteria, and heliobacteria
- organotroph: organism that obtains hydrogen or electrons from organic substrates, describes organisms based on how they obtain electrons for their respiration processes; some are also heterotrophs; can be either anaerobic or aerobic

(Source: https://en.wikipedia.org/wiki/Heterotroph)

Biology: Abiotic Factors

abiotic factors: non-living chemical and physical parts of the environment that affect living organisms and the functioning of ecosystems; include physical conditions and non-living resources that affect living organisms in terms of growth, maintenance, and reproduction; resources are distinguished as substances or objects in the environment required by one organism and consumed or otherwise made unavailable for use by other organisms; include water, light, radiation, temperature, humidity, atmosphere, and soil; pressure and sound waves in marine or sub-terrestrial environments

Biology: Biotic Factors

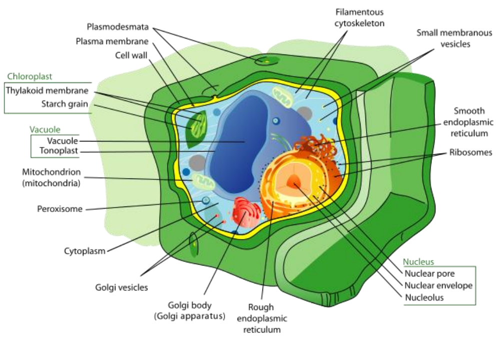
biotic factors: any living component that affects the population of another organism, or environment, including animals that consume the organism, and living food that the organism consumes; also include human influence, pathogens and disease outbreaks.

Biology: Plants

name(s)	scope	description
land plants, also known as Embryophyta	Plantae *sensu strictissimo*	plants in a strictest sense, includes liverworts, hornworts, mosses, and vascular plants, fossil plants similar to these surviving groups
green plants, also known as Viridiplantae, Viridiphyta or Chlorobionta	Plantae *sensu stricto*	plants in a strict sense, includes green algae, and land plants that emerged within them, stoneworts
Archaeplastida, also known as Plastida or Primoplantae	Plantae *sensu lato*	plants in a broad sense, green plants plus Rhodophyta, Glaucophyta, includes organisms that eons ago acquired chloroplasts by engulfing cyanobacteria
Old definitions of plant (obsolete)	Plantae *sensu amplo*	plants in an ample sense, old classifications, now obsolete

(Source: https://en.wikipedia.org/wiki/Plant)

Biology: Plant Cell Structure (1)



(Image source: https://en.wikipedia.org/wiki/Plant#/media/File:Plant_cell_structure-en.svg, Author: LadyofHats, public domain)

Biology: Plant Cell Structure (2)

chloroplast:
vacuole:
mitochondrion:
peroxisome:
cytoplasm:
golgi vesicles:

Biology: Plant Cell Structure (3)

golgi body:
rough endoplasmic reticulum:
nucleus:
ribosomes:
smooth endoplasmic reticulum:
small membrane vesicles:

Biology: Plant Cell Structure (4)

filamentous cytoskeleton:
plasmodesmata:
plasma membrane:
cell wall:

Biology: Extremophiles (1)

acidophile: organism with optimal growth at pH levels of 3 or below
alkaliphile: organism with optimal growth at pH levels of 9 or above
anaerobe: organism that does not require oxygen for growth; two sub-types exist: facultative anaerobe and obligate anaerobe: a facultative anaerobe can tolerate anaerobic and aerobic conditions; an obligate anaerobe would die in the presence of even trace levels of oxygen
cryptoendolith: organism that lives in microscopic spaces within rocks, such as pores between aggregate grains and in fissures, aquifers, and faults filled with groundwater in the deep subsurface
halophile: organism requiring at least 0.2M concentrations of salt for growth
hyperthermophile: organism that can thrive at temperatures above 80 °C, such as those found in hydrothermal systems
hypolith: organism that lives underneath rocks in cold deserts

Biology: Extremophiles (2)

lithoautotroph: organism whose sole source of carbon is carbon dioxide; capable of deriving energy from reduced mineral compounds; active in geochemical cycling and weathering of bedrock to form soil
metallotolerant: capable of tolerating high levels of dissolved heavy metals in solution, such as copper, cadmium, arsenic, and zinc
oligotroph: organism capable of growth in nutritionally limited environments
osmophile: organism capable of growth in environments with a high sugar concentration
piezophile: organism that lives optimally at high pressures such as those deep in the ocean or underground; common in the deep terrestrial subsurface, as well as in oceanic trenches

Biology: Extremophiles (3)

polyextremophile: organism that qualifies under more than one category
psychrophile/cryophile: organism capable of survival, growth or reproduction at temperatures of -15°C or lower for extended periods; common in cold soils, permafrost, polar ice, cold ocean water, and in or under alpine snowpack
radioresistant: organisms resistant to high levels of ionizing radiation, most commonly ultraviolet radiation, but also including organisms capable of resisting nuclear radiation
thermophile: organism that can thrive at temperatures between 45–122°C
thermoacidophile: combination of thermophile and acidophile; prefer temperatures of 70–80°C and pH between 2 and 3
xerophile: organism that can grow in extremely dry, desiccating conditions; exemplified by the soil microbes of the Atacama Desert
(Source: https://en.wikipedia.org/wiki/Extremophile)

Chemistry

Chemistry: Plasma, Gas, Liquid, and Solid

state of matter	plasma	gas	liquid	solid
volume/ shape	variable	assumes container shape	definite volume; assumes container shape	definite volume and shape
density	low	low	high	high
compressibility	varies	very compress-ible	slightly compressible	virtually incompress-ible
molecular motion	very free motion	very free motion	freely slide past each other	vibrate about a fixed position

Chemistry: Matter (1)

Avogadro's number N_A = 6.022×10^{23}/mol
atomic mass unit = 1/12 the mass of an atom of carbon-12 = approximately 1.66 x 10^{-27} kg

elementary charge e = 1.6022 x 10^{-19} C
electron mass m_e = 9.109 x 10^{-31} kilograms
proton mass m_p = 1.673 x 10^{-27} kilograms
neutron mass m_n = 1.675 x 10^{-27} kilograms
Boltzmann's constant k = 1.381 x 10^{-23} joules/K
gas constant R = 8.314 joules/mol K

Chemistry: Matter (2)

atom: basic unit of a chemical element
isotope: each of two or more forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei
proton: stable subatomic particle occurring in all atomic nuclei, with positive electric charge to that of an electron, but of opposite sign
neutron: subatomic chargeless particle about the same mass as a proton, present in all atomic nuclei except ordinary hydrogen
electron: stable subatomic particle with a charge of negative electricity, acts as the primary carrier of electricity in solids
element: distinguished by its atomic number, the number of protons in the nuclei of its atoms

Chemistry: Matter (3)

molecule: group of atoms bonded together, representing the smallest fundamental unit of a chemical compound that can take part in a chemical reaction
compound: substance consisting of atoms or ions of two or more different elements in definite proportions joined by chemical bonds
isomer: different arrangements of the same atoms
atomic number: number of protons in an atomic nucleus
atomic weight: average mass of a chemical element, expressed in atomic mass units; the atomic weight of an element having more than one principal isotope is calculated both from the atomic masses of the isotopes and from the relative abundance of each isotope in nature
law of conservation of mass: matter can't be created or destroyed

Chemistry: Matter (4)

anion: negatively charged ion
cation: positively charged ion
complex ion: an ion containing a central metal cation bonded to one or more molecules or ions
physical property: can be measured and observed without changing the identity of a substance
chemical property: requires a chemical changes
law of definite proportions: different samples of the same compound always contain its constituent elements in the same proportion by mass
law of multiple proportions: masses of one element that combine with another are in ratios of small whole numbers

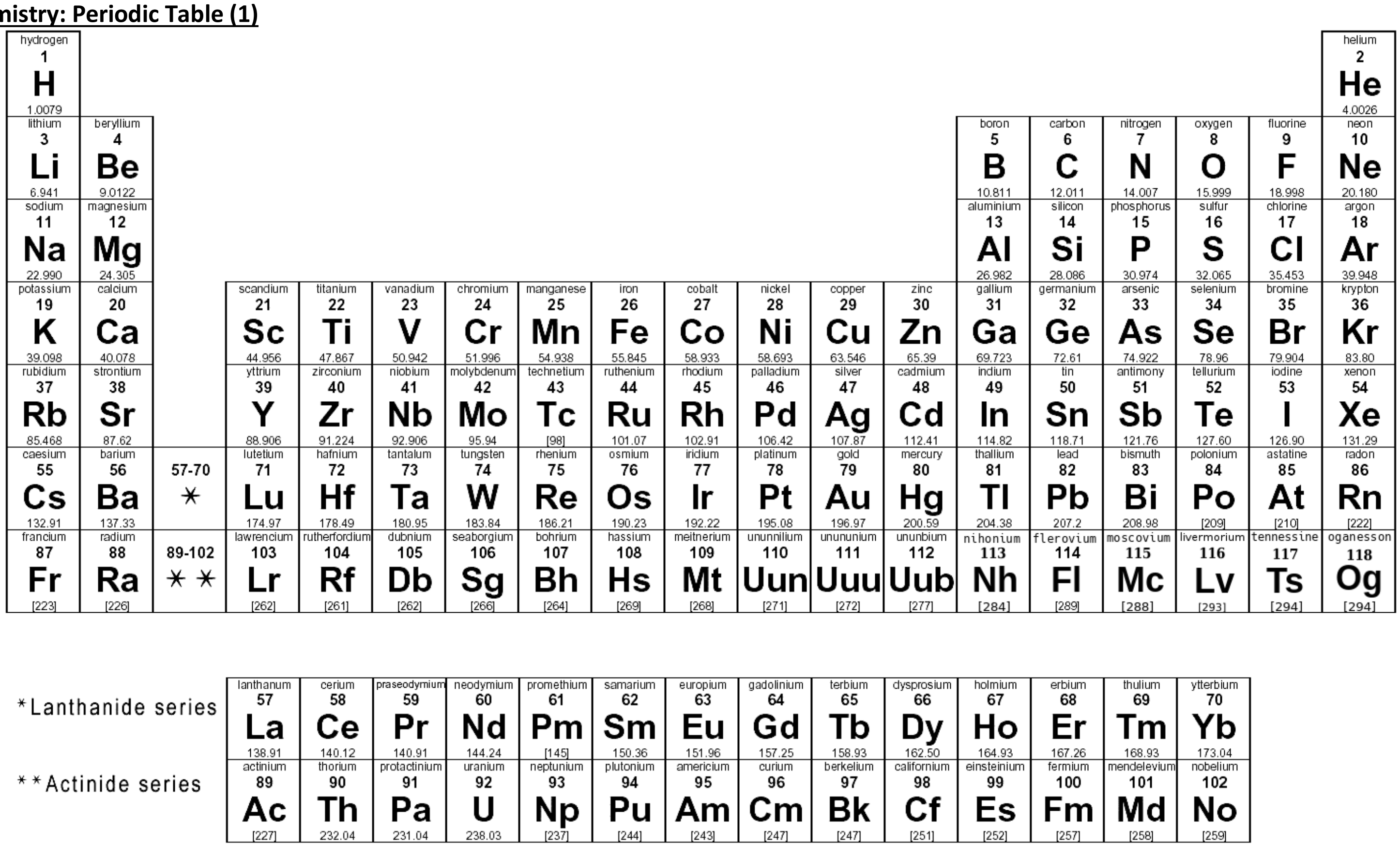
Chemistry: Matter (5)

atomic mass unit (amu): a mass exactly equal to 1/12th the mass of on carbon-12 atom
average atomic mass: sum of the masses of its isotopes, each multiplied by its natural abundance (the decimal associated with percent of atoms of that element that are of a given isotope)
mole: the amount of a substance that contains as many elementary entities (atoms, molecules, or other particles) as there are atoms in 12 grams of the carbon-12 isotope
atomic radius: ½ the distance between two nuclei of adjacent metal atoms
ionic radius: the radius of a cation or anion
ionization energy: the minimum energy in kJ/mol required to remove an electron from a gaseous atom in its ground state

Chemistry: Matter (6)

diagonal relationships: similarities between pairs of elements in different groups and periods of the periodic table
lattice energy: the energy required to completely separate one mole of a solid ionic compound into gaseous ions
electronegativity: ability of an atom to attract toward itself the electrons in a chemical bond

Chemistry: Periodic Table (1)



(Image source: http://www.wpclipart.com/science/atoms_molecules/periodic_tables/periodic_table_of_elements_BW.png.html, public domain)

Chemistry: Periodic Table (2)

Group 1, 1A: Alkali Metals, Lithium Group, H, Li, Na, K, Rb, Cs, Fr, most electropositive, soft, can be sliced with a knife, oxidation, low ionization energies, number in their compounds is +1, low melting points, low densities, very reactive, never found in the pure state in nature
Group 2, 2A: Alkali Earth Metals, Beryllium Group, Be, Mg, Ca, Sr, Ba, Ra, oxidation number in the combined form is almost always +2, react with water
Group 3, 3B: Scandium Group, Sc, Y, Lu, Lr,
Group 4, 4B: Titanium Group, Ti, Zr, Hf, Rf
Group 5, 5B: Vanadium Group, V, Nb, Ta, Db
Group 6, 6B: Chromium Group, Cr, Mo, W, Sg

Chemistry: Periodic Table (3)

Group 7, 7B: Manganese Group, Mn, Tc, Re, Bh
Group 8, 8B: Iron Group, Fe, Ru, Os, Hs
Group 9, 8B: Cobalt Group, Co, Rh, Ir, Mt
Group 10, 8B: Nickel Group, Ni, Pd, Pt, Ds
Group 11, 1B: Coinage Metals, Copper Group, Cu, Ag, Au, Rg, less reactive than group 1A, usually found in uncombined natural state
Group 12, 2B: Volatile Metals, Zinc Group, Zn, Cd, Hg, Cn
Group 13, 3A: Icosagens, Boron Group, B, Al, Ga, In, Tl, Nh, boron is a metalloid, the rest are metals, these elements form many molecular compounds
Group 14, 4A: Crystallogens, Carbon group, C, Si, Ge, Sn, Pb, Fl, form compounds in both the +2 and +4 oxidation states

Chemistry: Periodic Table (4)

Group 15, 5A: Pnictogens, Nitrogen Group, N, P, As, Sb, Bi, Mc, nitrogen forms many compounds
Group 16, 6A: Chalcogens, Oxygen Group, O, S, Se, Te, Po, Lv, these elements form a large number of compounds with nonmetals
Group 17, 7A: Halogens, Fluorine Group, F, Cl, Br, I, At, Ts, nonmetals, very reactive, high ionization energies, positive electron affinities, form many molecular compounds among themselves
Group 18, 8A: Noble gases, Helium or Neon Group, He, Ne, Ar, Kr, Xe, Rn, Og, exist as monatomic species, very stable, no tendency to accept extra electrons, not involved in natural biological processes

Chemistry: Liquid and Gas Elements at Atmospheric Conditions

gas		liquid
2 He helium	1 H hydrogen H_2	35 Br bromine
8 Ne neon	7 nitrogen N_2	80 Hg mercury
18 Ar argon	8 oxygen O_2	87 Fr francium
36 Kr krypton	9 fluorine F_2	
54 Xe xenon	17 chlorine Cl_2	
86 Rn radon		

Chemistry: Properties of Non-Metals (1)

hydrogen: simplest element, atomic form consists only at very high temperatures, diatomic molecule, colorless, odorless, nonpoisonous gas, at 1 atm liquid hydrogen has a boiling point of 20.3 K, three important isotopes are atomic hydogen, deuterium, and tritium
carbon: found free in the form of diamond and graphite, is a component of natural gas, petroleum, and coal, combines with oxygen to form carbon dioxide and carbonate in limestone and chalk, forms carbides, cyanides, and oxides
nitrogen: 78% of air by volume, essential element of life, a component of proteins and nucleic acids, ammonia and hydrazine are important compounds

Chemistry : Properties of Non-Metals (2)

phosphorus: occurs most commonly in nature as phosphate rocks which are mostly calcium phosphate, forms hydrides, halides, and oxides
oxygen: most abundant element in Earth's crust, 21% of air by volume, diatomic molecule, building block of almost all biomolecules, forms oxides, peroxides, superoxides, and ozone
sulfur: occurs commonly in nature in elemental form, largest known reserves are found in sedimentary deposits, occurs in sulfide minerals, forms oxides and acids
halogens: toxic, reactive nonmetals, strong oxidizing agents, form halides and oxides

Chemistry: Properties of Transition Metals

iron: after aluminum, is the most abundant metal in Earth's crust, found in many ores
copper: rare element, found in nature in the uncombined state as well as in many ores

Chemistry: Chemical Reactions and Nuclear Reactions

chemical reactions	nuclear reactions
1. Atoms rearranged by breaking and forming of chemical bonds.	**1. Elements or isotopes of same element converted from one to another.**
2. Only electrons in atomic or molecular orbitals involved in the breaking and forming of bonds.	**2. Protons, neutrons, electrons, and other elementary particles may be involved.**
3. Reactions accompanied by absorption or release of relatively small amounts of energy.	**3. Reactions accompanied by absorption or release of tremendous amounts of energy.**
4. Rates of reaction influenced by temperature, pressure, concentrations, and catalysts.	**4. Rates of reaction normally are not affected by temperature, pressure, and catalysts.**

(Source: p. 910)

Chemistry: Nuclear Stability

- nuclei that contain 2, 8, 20, 50, 82, or 126 protons or neutrons are generally more stable than other nuclei
- nuclei with even numbers of both protons and neutrons are generally more stable
- all isotopes of the elements with atomic numbers higher than 83 are radioactive; all isotopes of technetium and promethium are also radioactive

protons	neutrons	number of stable isotopes
odd	odd	4
odd	even	50
even	odd	53
even	even	157

(Source: p. 913)

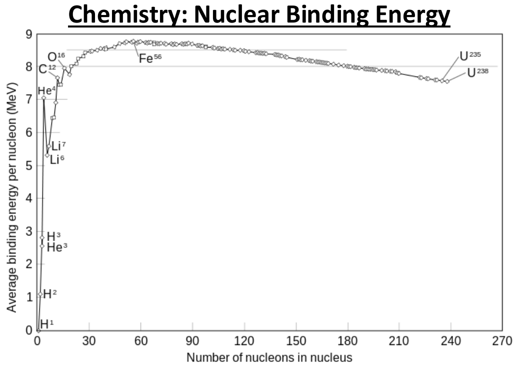
Chemistry: Bohr Hydrogen Atom and Electron Binding Energy

1. Electron orbits are discrete and non-radiating, and an electron may not remain between these orbits.
2. The energy change experienced by an electron changing from one orbit to another is quantized.
3. Classical mechanics does not hold when the electron is between orbits.
4. Angular momentum is quantized.

Bohr's equation $\bar{f} = R_\infty \left[\frac{1}{n_2^2} - \frac{1}{n_1^2} \right]$

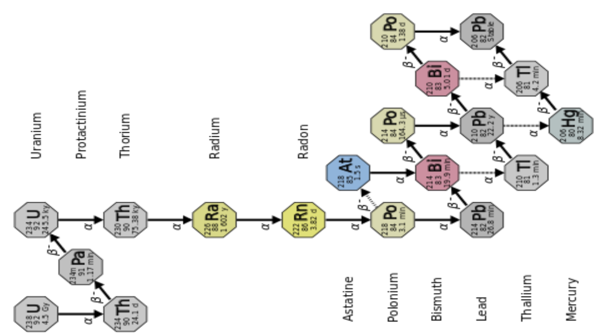
electron binding energy $E_{binding} = \frac{1}{2} mv^2 - \left| \frac{ke^2}{r} \right|$

Chemistry: Nuclear Binding Energy



(Image source: https://en.wikipedia.org/wiki/Nuclear_binding_energy#/media/File:Binding_energy_curve_-_common_isotopes.svg, public domain)

Chemistry: Uranium Decay Series



(Image source: https://en.wikipedia.org/wiki/Decay_chain#/media/File:Decay_chain(4n%2B2,_Uranium_series).svg, Author: Tosaka, CC BY 3.0)

Chemistry: Pauli Exclusion Principle, Hund's Rule, Aufbau Principle

Pauli exclusion principle: no two electrons in an atom can have the same four quantum numbers: (n, ℓ, $m_ℓ$, m_s), an atom's *n*th electron shell can accommodate $2n^2$ electrons

paramagnetic: refers to substances that are attracted to a magnet

diamagnetic: refers to substances that are slightly repelled by a magnet

Hund's rule: the most stable arrangement of electrons in subshells is the one with the greatest number of parallel spins

Aufbau principle: as protons are added one by one to the nucleus to build up the elements, electrons are similarly added to the atomic orbitals

Chemistry: Rydberg Formula

energy of a photon emitted by a hydrogen atom is given by the difference of two hydrogen energy levels:

$$E = E_i - E_f = R_E \left(\frac{1}{n_f^2} - \frac{1}{n_i^f} \right)$$

R_E = 1.097373 x 10^7 / meter

n_f = final energy level n_i = initial energy level

the wavelength of the emitted photon:

$$\frac{1}{\lambda} = \frac{R_E}{2\pi} \left(\frac{1}{n_f^2} - \frac{1}{n_i^f} \right)$$

Chemistry: Atomic Orbitals (1)

classification according to outermost subshell filled with electrons

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 9 10 ← 8B →	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1s															1s
2s										2p					
3s										3p					
4s		3d								4p					
5s		4d								5p					
6s		5d								6p					
7s		6d													
				4f											
				5f											

Chemistry: Atomic Orbitals (2)

principal quantum number n: describes energy of the electron; always a positive integer; large numbers seldom encountered; each atom has many orbitals associated with each value of n; these orbitals together are sometimes called electron shells

azimuthal quantum number ℓ: describes orbital angular momentum of each electron; a non-negative integer; within a shell where n is some integer n_0, ℓ ranges across all integer values satisfying the relation $0 \le ℓ \le n_0 - 1$; set of orbitals associated with a particular value of ℓ are sometimes collectively called a subshell

magnetic quantum number $m_ℓ$: describes the magnetic moment of an electron in an arbitrary direction; is also always an integer; within a subshell where ℓ is some integer $ℓ_0$, $m_ℓ$ ranges from $-ℓ_0 \le m_ℓ \le ℓ_0$

electron spin quantum number m_S: counterclockwise +1/2, clockwise -1/2

Chemistry: Atomic Orbitals (3)

	$\ell = 0$	$\ell = 1$	$\ell = 2$	$\ell = 3$	$\ell = 4$	...
n = 1	$m_\ell = 0$					
n = 2	0	-1, 0, 1				
n = 3	0	-1, 0, 1	-2, -1, 0, 1, 2			
n = 4	0	-1, 0, 1	-2, -1, 0, 1, 2	-3, -2, -1, 0, 1, 2, 3		
n = 5	0	-1, 0, 1	-2, -1, 0, 1, 2	-3, -2, -1, 0, 1, 2, 3	-4, -3, -2, -1, 0, 1, 2, 3, 4	
...	...	...	...	...	...	...

Chemistry: Atomic Orbitals (4)

1 H hydrogen $1s^1$	13 Al aluminum [Ne] $3s^2\ 3p^1$
2 He helium $1s^2$	14 Si silicon [Ne] $3s^2\ 3p^2$
3 Li lithium [He] $2s^1$	15 P phosphorus [Ne] $3s^2\ 3p^3$
4 Be beryllium [He] $2s^2$	16 S sulfur [Ne] $3s^2\ 3p^4$
5 B boron [He] $2s^2\ 2p^1$	17 Cl chlorine [Ne] $3s^2\ 3p^5$
6 C carbon [He] $2s^2\ 2p^2$	18 Ar argon [Ne] $3s^2\ 3p^6$
7 N nitrogen [He] $2s^2\ 2p^3$	19 P potassium [Ar] $4s^1$
8 O oxygen [He] $2s^2\ 2p^4$	20 Ca calcium [Ar] $4s^2$
9 F fluorine [He] $2s^2\ 2p^5$	21 Sc scandium [Ar] $3d^1\ 4s^2$
10 Ne neon [He] $2s^2\ 2p^6$	22 Ti titanium [Ar] $3d^2\ 4s^2$
11 Na sodium [Ne] $3s^1$	23 V vanadium [Ar] $3d^3\ 4s^2$
12 Mg magnesium [Ne] $3s^2$	24 Cr chromium [Ar] $3d^5\ 4s^1$

Chemistry: Atomic Orbitals (5)

25 Mn manganese [Ar] $3d^5\ 4s^2$	37 Rb rubidium [Kr] $5s^1$
26 Fe iron [Ar] $3d^6\ 4s^2$	38 Sr strontium [Kr] $5s^2$
27 Co cobalt [Ar] $3d^7\ 4s^2$	39 Y yttrium [Kr] $4d^1\ 5s^2$
28 Ni nickel [Ar] $3d^8\ 4s^2$	40 Zr zirconium [Kr] $4d^2\ 5s^2$
29 Cu copper [Ar] $3d^{10}\ 4s^1$	41 Nb niobium [Kr] $4d^4\ 5s^1$
30 Zn zinc [Ar] $3d^{10}\ 4s^2$	42 Mo molybdenum [Kr] $4d^5\ 5s^1$
31 Ga gallium [Ar] $3d^{10}\ 4s^2\ 4p^1$	43 Tc technetium [Kr] $4d^5\ 5s^2$
32 Ge germanium] $3d^{10}\ 4s^2\ 4p^2$	44 Ru ruthenium [Kr] $4d^7\ 5s^1$
33 As arsenic [Ar] $3d^{10}\ 4s^2\ 4p^3$	45 Rh rhodium [Kr] $4d^8\ 5s^1$
34 Se selenium [Ar] $3d^{10}\ 4s^2\ 4p^4$	46 Pd palladium [Kr] $4d^{10}$
35 Br bromine [Ar] $3d^{10}\ 4s^2\ 4p^5$	47 Ag silver [Kr] $4d^{10}\ 5s^1$
36 Kr krypton [Ar] $3d^{10}\ 4s^2\ 4p^6$	48 Cd cadmium [Kr] $4d^{10}\ 5s^2$

Chemistry: Atomic Orbitals (6)

49 In indium [Kr] $4d^{10}\ 5s^2\ 5p^1$	61 Pm promethium [Xe] $4f^5\ 6s^2$
50 Sn tin [Kr] $4d^{10}\ 5s^2\ 5p^2$	62 Sm samarium [Xe] $4f^5\ 6s^2$
51 Sb antimony [Kr] $4d^{10}\ 5s^2\ 5p^3$	63 Eu europium [Xe] $4f^6\ 6s^2$
52 Te tellurium [Kr] $4d^{10}\ 5s^2\ 5p^4$	64 Gd gadolinium [Xe] $4f^7\ 5d^1\ 6s^2$
53 I iodine [Kr] $4d^{10}\ 5s^2\ 5p^5$	65 Tb terbium [Xe] $4f^9\ 6s^2$
54 Xe xenon [Kr] $4d^{10}\ 5s^2\ 5p^6$	66 Dy dysprosium [Xe] $4f^{10}\ 6s^2$
55 Cs caesium [Xe] $6s^1$	67 Ha holmium [Xe] $4f^{11}\ 6s^2$
56 Ba barium [Xe] $6s^2$	68 Er erbium [Xe] $4f^{12}\ 6s^2$
57 La lanthanum [Xe] $5d^1\ 6s^1$	69 Tm thulium [Xe] $4f^{13}\ 6s^2$
58 Ce cerium [Xe] $4f^1\ 5d^1\ 6s^2$	70 Yb ytterbium [Xe] $4f^{14}\ 6s^2$
59 Pr praseodmium [Xe] $4f^3\ 6s^2$	71 Lu lutetium [Xe] $4f^{14}\ 5d^1\ 6s^2$
60 Nd neodymium [Xe] $4f^4\ 6s^2$	72 Hf hafnium [Xe] $4f^{14}\ 5d^2\ 6s^2$

Chemistry: Atomic Orbitals (7)

73 Ta tantalum [Xe] $4f^{14}\ 5d^3\ 6s^2$	85 At astatine [Xe] $4f^{14}5d^{10}\ 6s^2\ 6p^5$
74 W tungsten [Xe] $4f^{14}\ 5d^4\ 6s^2$	86 Rn radon [Xe] $4f^{14}5d^{10}\ 6s^2\ 6p^6$
75 Re rhenium [Xe] $4f^{14}\ 5d^5\ 6s^2$	87 Fr francium [Rn] $7s^1$
76 Os osmium [Xe] $4f^{14}\ 5d^6\ 6s^2$	88 Ra radium [Rn] $7s^2$
77 Ir iridium [Xe] $4f^{14}\ 5d^7\ 6s^2$	89 Ac actinium [Rn] $6d^1\ 7s^1$
78 Pt platinum [Xe] $4f^{14}\ 5d^9\ 6s^1$	90 Th thorium[Rn] $6d^2\ 7s^1$
79 Au gold [Xe] $4f^{14}\ 5d^{10}\ 6s^1$	91 Pa protactinium [Rn] $5f^2\ 6d^1\ 7s^1$
80 Hg mecury [Xe] $4f^{14}5d^{10}\ 6s^2$	92 U uranium [Rn] $5f^3\ 6d^1\ 7s^1$
81 Tl thallium [Xe] $4f^{14}5d^{10}\ 6s^2\ 6p^1$	93 Np neptunium [Rn] $5f^4\ 6d^1\ 7s^1$
82 Pb lead [Xe] $4f^{14}5d^{10}\ 6s^2\ 6p^2$	94 Pu plutonium [Rn] $5f^6\ 7s^2$
83 Bi bismuth [Xe] $4f^{14}5d^{10}\ 6s^2\ 6p^3$	95 Am americium [Rn] $5f^7\ 7s^2$
84 Po polonium [Xe] $4f^{14}5d^{10}\ 6s^2\ 6p^4$	96 Cm curium [Rn] $5f^7\ 6d^1\ 7s^2$

Chemistry: Atomic Orbitals (8)

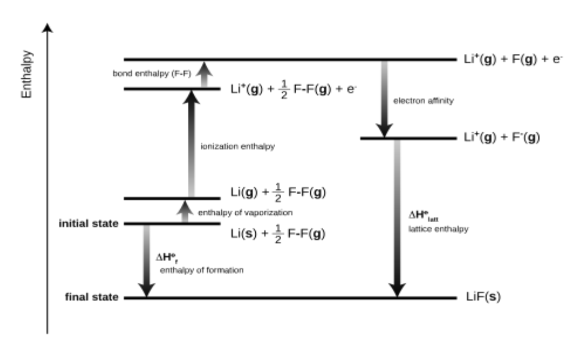
97 Bk berkelium [Rn] $5f^9\ 7s^2$	109 Mt meitnerium [Rn] $5f^{14}\ 6d^7\ 7s^2$
98 Cf californium [Rn] $5f^{10}\ 7s^2$	110 Ds darmstadtium [Rn] $5f^{14}\ 6d^8\ 7s^2$
99 Es einsteinium [Rn] $5f^{11}\ 7s^2$	111 Rg roentgenium [Rn] $5f^{14}\ 6d^9\ 7s^2$
100 Fm fermium [Rn] $5f^{12}\ 7s^2$	112 Cn copernicium [Rn] $5f^{14}\ 6d^{10}\ 7s^2$
101 Md mendelevium [Rn] $5f^{13}\ 7s^2$	113 Nh nihonium [Rn] $5f^{14}\ 6d^{10}\ 7s^2\ 7p^1$
102 No nobelium [Rn] $5f^{14}\ 7s^2$	114 Fl flerovium [Rn] $5f^{14}\ 6d^{10}\ 7s^2\ 7p^2$
103 Lr lawrencium [Rn] $5f^{14}\ 7s^2\ 7p^1$	115 Mc moscovium [Rn] $5f^{14}\ 6d^{10}\ 7s^2\ 7p^3$
104 Rf rutherfordium [Rn] $5f^{14}\ 6d^2\ 7s^2$	116 Lv livermorium [Rn] $5f^{14}\ 6d^{10}\ 7s^2\ 7p^4$
105 Db dubnium [Rn] $5f^{14}\ 6d^3\ 7s^2$	117 Ts tennesine [Rn] $5f^{14}\ 6d^{10}\ 7s^2\ 7p^5$
106 Sg seaborgium [Rn] $5f^{14}\ 6d^4\ 7s^2$	118 Og oganesson [Rn] $5f^{14}\ 6d^{10}\ 7s^2\ 7p^6$
107 Bh bohrium [Rn] $5f^{14}\ 6d^5\ 7s^2$	119 Uue ununennium [Og] $8s^1$
108 Hs hassium [Rn] $5f^{14}\ 6d^6\ 7s^2$	120 Ubn unbinilium [Og] $8s^2$

Chemistry: Born-Haber Cycle

Born-Haber cycle: relates lattice energies of ionic compounds to ionization energies, electron affinities, and other atomic and molecular properties

Chemistry: Lattice Energy of Ionic Compounds

lithium-fluorine example



(Image source: https://en.wikipedia.org/wiki/Born%E2%80%93Haber_cycle#/media/File:Born-haber_cycle_LiF.svg, Author : Jkwchui, CC BY-SA 3.0)

Chemistry: Molecular Bonds (1)

bond energy: enthalpy required to break a particular bond in 1 mole of gaseous molecules
ionic bond: electrostatic force that holds ions together in an ionic compound, forms when the electronegativity difference between the two bonding atoms is 2.0 or more
covalent bond: involves the sharing of electron pairs between atoms where the electron pairs are known as shared pairs or bonding pairs
single bond: two atoms are held together by one electron pair
double bond: bonds formed when two atoms share two or more pairs of elctrons
triple bond: when two atoms share three pairs of electrons
resonance: using two or more Lewis structures for a single molecule that cannot be represented accurately by only one Lewis structure
octet rule: an atom other than hydrogen tends to form bonds until it is surrounded by 8 valence electrons

Chemistry: Molecular Bonds (2)

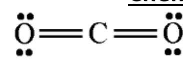
covalent bond: a bond in which two electrons are shared by two atoms
covalent compounds: contain only covalent bonds
polar bond: electrons spend more time in the vicinity of one atom than the other
valence shell: outermost electron-occupied shell of an atom, holds the electrons that are usually involved in bonding
valence-shell electron-pair repulsion (VSEPR) model: accounts for geometric arrangements of electron pairs around a central atom in terms of the electrostatic repulsion between electron pairs
dipole moment: product of charge and distance between the charges
polar molecule: have dipole moments
nonpolar molecules: do not have dipole moments
valence bond theory: stable molecule forms from reacting atoms when the potential energy of the system has decreased to a minimum

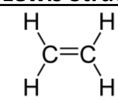
Chemistry: Lewis Structure (1)

Lewis structure: representation of covalent bonding, shared electron pairs
shown either as lines or as pairs of dots between two atoms, lone pairs are shown as
pairs of dots on individual atoms

(Image source on Lewis Structure (3): https://en.wikipedia.org/wiki/Lewis_structure#/media/File:Infographic_-_Draw_a_Lewis_Dot_Structure._Beaker_Babe_-_2015_(2000x2592).jpg, Author: Lisa Staugaard, CC BY-SA 4.0)

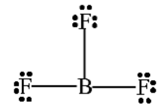
Chemistry: Lewis Structure (2)

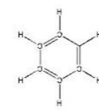

carbon dioxide
double bonds

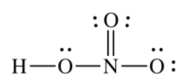

ethelyne
double bonds

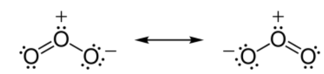
:N≡N:
nitrogen
molecule
N_2triple bond

H—Be—H
beryllium hydride

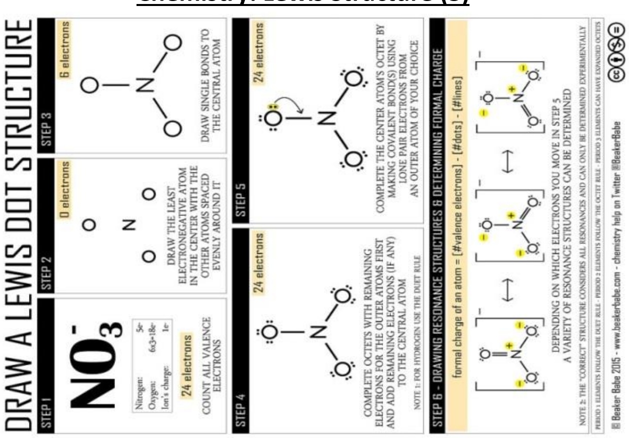

boron
hydrofluoride


benzene

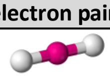
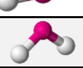
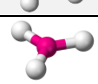
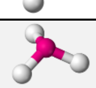
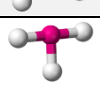

nitric acid


ozone

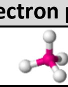
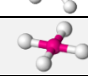
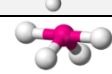
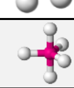
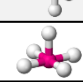
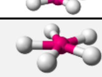
Chemistry: Lewis Structure (3)



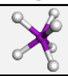
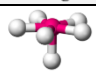
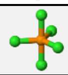
Chemistry: Electron Pair Arrangements around a Central Atom (1)

number of electron pairs	arrangement of electron pairs	geometry	examples
2		linear	BeF_2
2		bent	OF_2
3		trigonal planar	BF_3
3		trigonal pyramidal	NH_3, PCl_3, XeO_3
3		t-shaped	ClF_3

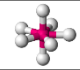
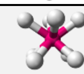
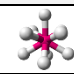
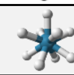
Chemistry: Electron Pair Arrangements around a Central Atom (2)

number of electron pairs	arrangement of electron pairs	geometry	examples
4		tetrahedral	CH_4,PO_4^{3}, SO_2^{4-}
4		square planar	$[Pt(NH_3)_2Cl_2]$
4		seesaw	SF_4
5		trigonal bipyramidal	PF_5
5		square pyramidal	$XeOF_4$
5		pentagonal planar	XeF_5^{-}

Chemistry: Electron Pair Arrangements around a Central Atom (3)

number of electron pairs	arrangement of electron pairs	geometry	examples
6		octahedral	$SF_6Mo(CO)_6$
6		trigonal prismatic	$W(CH_3)_6$
6		pentagonal pyramidal	$XeOF_5^-$, IOF_5^{2-}
6		distorted octahedral	XeF_6, IF_6^-

Chemistry: Electron Pair Arrangements around a Central Atom (4)

number of electron pairs	arrangement of electron pairs	geometry	examples
7		pentagonal bipyramidal	IF_7
8		square antiprismatic	XeF_8^{2-}
9		tricapped trigonal prismatic	ReH_9^{2-}
9		capped square antiprismatic	$[\{LaCl(H_2O)_7\}_2]^{4+}$

(Image sources: https://en.wikipedia.org/wiki/Linear_molecular_geometry, public domain)

Chemistry: Hybridization

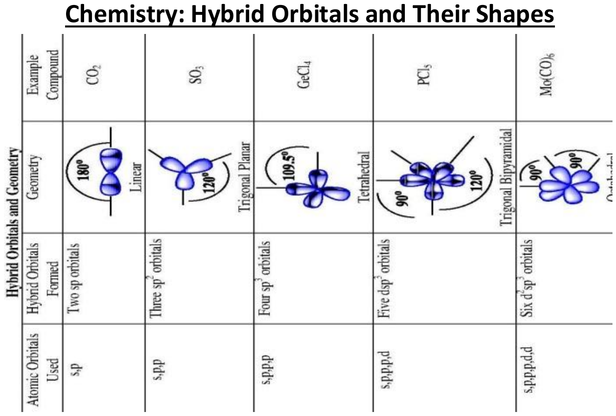
hybrid orbitals: atomic orbitals obtained when two or more nonequivalent orbitals of the same atom combine in preparation for covalent bond formation
hybridization: the mixing of atomic orbitals in an atom to generate a set of hybrid orbitals
sigma bonds: covalent bonds formed by orbitals overlapping end-to-end with the electron density concentrated between the nuclei of the bonding atoms
pi bonds: a covalent bond formed by sideways overlapping orbitals with electron density concentrated above and below the plane of the nuclei of the bonding atoms

Chemistry: Hybridization Rules

- hybridization is used only to explain covalent bonding
- hybridization is the mixing of at least two nonequivalent atomic orbitals; a hybrid is not a pure atomic orbital; hybrid orbitals and pure atomic orbitals have different shapes
- the number of hybrid orbitals generated is equal to the number of pure atomic orbitals that participate in the hybridization
- hybridization requires input energy; the system recovers this energy during bond formation
- covalent bonds in polyatomic molecules and ions are formed by the overlap of hybrid orbitals with unhybridized orbitals

(Source:)

Chemistry: Hybrid Orbitals and Their Shapes



(Image source: Hybrid orbital and geometries by Chem507f10grp4\ , public domain)

Chemistry: Molecular Orbital Theory

molecular orbitals: result from interaction of the atomic orbitals of the bonding atoms and are associated with the entire molecule
bonding molecular orbital: has lower energy and greater stability than the atomic orbitals from which it was formed
antibonding molecular orbital: has higher energy and lower stability than the atomic orbitals from which it was formed
sigma molecular bond: electron density is concentrated symmetrically around a line between the two nuclei of the bonding atoms
bond order: ½(number of electrons in bonding MOs – number of electrons in antibonding MOs)
delocalized molecular orbitals: are not confined between two adjacent bonding atoms, but actually extend over three or more atoms

Chemistry: Molecular Orbital Theory Rules

- number of molecular orbitals formed is always equal to the number of atomic orbitals combined
- the more stable the bonding molecular orbital, the less stable the corresponding antibonding molecular orbit
- filling molecular orbitals proceeds from low to high energies
- each molecular orbital can accommodate up to two electrons with opposite spins, according to the Pauli exclusion principle
- when electrons are added to molecular orbitals of the same energy, the most stable arrangement follows Hund's rule
- number of electrons in the molecular orbitals is equal to the sum of all the electrons on the bonding atoms

(Source:)

Chemistry: Stoichiometry

stoichiometry: quantitative study of reactants and products in a chemical reaction

1. Write correct formulas for reactants and products, balance the equation.
2. Convert the quantities of reactants into moles.
3. Use the coefficients to calculate the number of moles of products.
4. Convert the quantities to grams.
5. Check that the answer is reasonable.

$2H_2$	**$+O_2$**	**→**	**$2H_2O$**
two moles	**+ one molecule**	**→**	**two molecules**
2 moles	**+ 1 mole**	**→**	**2 moles**
2(2.02 g) = 4.04 g	**+ 32.00 g**	**→**	**2(18.02 g) = 36.04 g**

Chemistry: Reaction Rates

elementary steps: series of simple reactions representing progress of overall reaction at the molecular level
reaction mechanism: elementary steps leading to product formation
intermediates: steps that appear in the mechanism of the reaction but not in overall balanced equation
molecularity of a reaction: number of molecules reacting in an elementary step
bimolecular reaction: elementary step that involves two molecules
unimolecular reaction: elementary step in which only one reacting molecule participates
termolecular reaction: reactions involving participation of three molecules in one elementary step
rate determining step: slowest step in the sequence
reaction order: sum of the powers to which all reactant concentrations appearing in the rate law are raised

Chemistry: Equilibrium and Le Chatelier's Principle

homogeneous equilibrium: applies to reactions in which all reacting species are in the same phase
heterogeneous equibrium: results from a reversible reaction involving reactants and products that are in different phases

Le Chatelier's principle: if an external stress is applied to a system at equilibrium the system adjusts so that the stress is partially offset as the system reaches a new equilibrium

change in concentration, pressure, or volume may alter the equilibrium position, but will not change the equilibrium constant; only a change in temperature will change the equilibrium constant;
a catalyst lowers activation energy but does not change the equilibrium constant or shift the position of a system's equilibrium

Chemistry: First and Second Order Reactions

order	rate law	concentration time equation	half-life
1	rate = $\frac{-\Delta[A]}{\Delta t} = k[A]$	$\ln \frac{[A]}{[A]_0} = -kt$	$\frac{0.693}{k}$
2	rate = $\frac{-\Delta[A]}{\Delta t} = k[A]^2$	$\frac{1}{[A]} = \frac{1}{[A]_0} + kt$	$\frac{1}{k[A]_0}$

(Source: p. 520)

Arrhenius equation: graphical determination of activation energy

$$k = Ae^{-E_a/RT} \rightarrow \ln k = \left(\frac{E_a}{R}\right)\left(\frac{1}{T}\right) + \ln A$$

rate constants at two different temperatures $\ln \frac{k_1}{k_2} = \left(\frac{E_a}{R}\right)\left(\frac{T_1 - T_2}{T_1 T_2}\right)$

Chemistry: Equilibrium Constant of a Chemical Reaction (1)

$$aA + bB \Leftrightarrow cC + dD \qquad K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b} = \frac{k_{forward}}{k_{reverse}}$$

$$\begin{array}{l} A + B \Leftrightarrow C + D \\ C + D \Leftrightarrow E + F \end{array} \quad K_C{}' = \frac{[C][D]}{[A][B]} \quad K_C{}'' = \frac{[E][F]}{[C][D]} \quad K_C = (K_C{}')(K_c{}'')$$

$$K_P = \frac{P_B^b}{P_A^a} = \frac{[B]^b}{[A]^a}(RT)^{b-a}$$ P_A and P_B are the partial pressures

rate law: if $aA + bB \rightarrow cC + dD$ then rate = $k[A]^x[B]^y$, x and y determined experimentally

Chemistry: Equilibrium Constant of a Chemical Reaction (2)

reaction direction: if $Q_c > K_c$ the ratio of initial concentrations of products to reactants indicates that products must be converted to reactants; if $Q_c < K_c$ the ratio of initial concentrations of products to reactants indicates that reactants must be converted to products; if $Q_c = K_c$ the system is in equilibrium

Q_c = reaction quotient, where initial amounts of product and reactant are substituted into the equation for K_{eq}

Chemistry: Acids and Base

acid: substance that yields hydrogen ions (H^+) when dissolved in water; sour taste; cause color change in plant dyes; react with certain metals, such as zinc, magnesium, and iron to produce hydrogen gas, aqueous acid solutions conduct electricity, pH between 0 and 7
Brönsted acid: proton donor
conjugate acid: results from addition of a proton to a Brönsted base
base: a substance that yields hydroxide ions (OH-) when dissolved in water; bitter taste, feels slippery, cause color change in plant dyes, aqueous base solutions conduct electricity, pH between 7 and 14
Brönsted base: proton acceptor
conjugate base: species that remains when one proton has been removed from the acid

Chemistry: Acids and Bases (2)

neutralization reaction: a reaction between an acid and a base

pH = - log $[H_3O^+]$ pOH = - log [OH-] pH + pOH = 14

monoprotic: each unit of acid yields one hydrogen ion upon ionization
diprotic: each unit of acid yields two hydrogen ions in two separate steps
triprotic: each unit of acid yields three hydrogen ions in three separate steps

Chemistry: Acid-Base Properties of Water

$$\underset{acid_1}{H_2O} + \underset{base_2}{H_2O} \Leftrightarrow \underset{acid_2}{H_3O^+} + \underset{base_1}{OH^-} \qquad K_C = \frac{[H^+][OH^-]}{[H_2O]}$$

Chemistry: Common Acid-Base Indicators

indicator	in acid	in base	pH range
thymol blue	red	yellow	1.2 – 2.8
bromophenol blue	yellow	bluish purple	3.0 – 4.6
methyl orange	orange	yellow	3.1 – 4.4
methyl red	red	yellow	4.4 – 6.2
methyl purple	purple	green	4.8 – 5.4
phenol red	yellow	red	6.4 – 8.0
naphtholphthalein	pale red	greenish blue	7.3 – 8.7
cresolphthalein	colorless	purple	8.2 – 9.8
phenolphthalein	colorless	purple-pink	8.3 – 10.0
alizarine yellow R	yellow	red	10.2 – 12.0
indigo carmen	blue	yellow	11.4 – 13.0

(Source: https://en.wikipedia.org/wiki/PH_indicator)

Chemistry: Aqueous Solutions

aqueous solution: solute is initially a liquid or a solid and the solvent is water

electrolyte: substance, that when dissolved in water, results in a solution that can conduct electricity

non-electrolyte: substance, that when dissolved in water, does not result in a solution that can conduct electricity

hydration: the process in which an ion is surrounded by water molecules arranged in a specific manner

precipitation reaction: results in the formation of an insoluble product or precipitate

precipitate: insoluble solid that separates from a solution

solubility: the maximum amount of solute that will dissolve in a given quantity of solvent at a specific temperature

Chemistry: Solubility Rules for Common Ionic Compounds in Water at 25^{0}C

soluble compounds	exceptions
compounds containing alkali metal ions (Li^+, Na^+, K^+, Rb^+, Cs^+), ammonium ion (NH_4^+))	
nitrates (NO_3^-),	
bicarbonates (HCO_3^-)	
chlorates (ClO_3^-)	
halides (Cl^-, Br^-, I^-)	halides of Ag^+, Hg_2^{2+}, Pb^{2+}
sulfates (SO_4^{2-})	sulfates of Ag^+, Ca^{2+},Sr^{2+}, Ba^{2+}, Hg^{2+}, Pb^+
insoluble compounds	**exceptions**
carbonates (CO_3^{2-}), phosphates (PO_4^{3-}), chromates (CrO_4^{2-})	compounds containing alkali metal ions and the ammonium ion
sulfides (S^{2-}) hydroxides (OH^-)	compounds containing alkali metal ions and the Ba^{2+} ion

(Source: p. 109)

Chemistry: Oxidation-Reduction (Redox) Reactions (1)

electrochemistry: branch of chemistry that deals with the relationship between electrical and chemical energy

oxidation reaction: half-reaction that involves loss of electrons; oxidation state increases; oxidation occurs at the anode (positive terminal) in electrolytic reactions

oxidizing agent: substance that accepts electrons and becomes less negative

oxidation number: signifies the number of charges the atom would have in a molecule if the electrons were transferred completely

reduction reaction: half-reaction that involves gain of electrons; oxidation state decreases; reduction occurs at the cathode (negative terminal) in electrolytic reactions

reducing agent: substance that donates electrons and becomes more negative

number of electrons lost by a reducing agent must be equal to the number of electrons gained by an oxidizing agent

Chemistry: Oxidation Reduction (Redox) Reactions (2)

combination reaction: A + B → C

decomposition reaction: C → A + B

displacement reaction: A + BC → AC + B

- hydrogen displacement: all alkali metals and some alkaline earth metals will displace hydrogen from cold water
- metal displacement: a metal in a compound can be displaced by another metal in the element state
- halogen displacement: $F_2 > CL_2 > Br_2 > I_2$, halogens are the most reactive of the nonmetallic elements. fluorine is the strongest known oxidizing agent

disproportion reaction: an element in one oxidation state is simultaneously oxidized and reduced

Chemistry: Calculating Oxidation Number (1)

1. in free elements (in the uncombined state) each atom has an oxidation number of 0
2. for ions composed of only one atom (monoatomic ions) the oxidation number is equal to the charge on the ion; all alkali metals have an oxidation number of +1, all alkaline earth metals have an oxidation number of +2 in their compounds, aluminum has an oxidation number of +3 in all of its compounds
3. the oxidation number of oxygen in most compounds is -2, but in hydrogen peroxide (H_2O_2) and peroxide ion (O_2^{2-}) is -1
4. the oxidation number of hydrogen is +1 except when it is bonded to metals in binary compounds, for example, in LiH, NaH, CaH_2, its oxidation number is -1

Chemistry: Calculating Oxidation Number (2)

5. fluorine has an oxidation number of -1 in all its compounds; other halogens (Cl, Br, I) have negative oxidation numbers when they occur as halide ions in their compounds; when combined with oxygen, for example in oxoacids and oxoanions, they have positive oxidation numbers
6. in a neutral molecule, the sum of the oxidation numbers of all the atoms must be 0; in a polyatomic ion the sum of oxidation numbers of all the elements in the ion must be equal to the net charge of the ion
7. oxidation numbers do not have to be integers; for example, the oxidation number of O in the superoxide ion O_2^-

(Source:)

Chemistry: Types of Solutions

component A	component B	solution state	examples
gas	gas	gas	air
gas	liquid	liquid	CO_2 in water
gas	solid	solid	H_2 gas in palladium
liquid	liquid	liquid	ethanol in water
liquid	solid	liquid	NaCl in water
solid	solid	solid	brass, solder

(Source: p. 468)

Chemistry: Types of Colloids

dispersing medium	dispersed phase	name	example
gas	liquid	aerosol	fog, mist
gas	solid	aerosol	smoke
liquid	gas	foam	whipped cream
liquid	liquid	emulsion	mayonnaise
liquid	solid	sol	milk of magnesia
solid	gas	foam	plastic foam
solid	liquid	gel	jelly, butter
solid	solid	solid sol	alloys, gemstones

(Source: p. 493)

Chemistry: Solution Concentration (1)

solution: homogeneous mixture of two or more substances
dilution: procedure for preparing a less concentrated solution from a more concentrated solution
catalyst: substance that increases the rate of a chemical reaction without being consumed

mole fraction of component A $X_A = \dfrac{moles\ of\ A}{sum\ of\ moles\ of\ all\ components}$

molarity $M = \dfrac{moles\ of\ solute}{1\ liter\ of\ solution}$ molality $m = \dfrac{moles\ of\ solute}{mass\ of\ solvent\ in\ kg}$

$M_i V_i = M_f V_f$ M_i, M_f in molarity V_i, V_f in liters

Chemistry: Solution Concentration (2)

dilution: procedure for preparing a less concentrated solution from a more concentrated solution
titration: a solution of accurately known concentration is gradually added to another solution of unknown concentration until the chemical reaction between the two solutions is complete
equivalence point: point at which an acid has been completely neutralized by a base
indicator: substance that has a distinctly different color in an acid and a base
hydrophilic: water loving
hydrophobic: water fearing

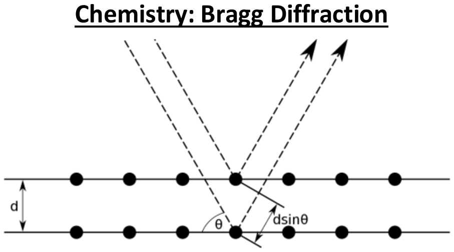
Chemistry: Kinetic and Molecular Theory of Liquids

phase: homogeneous part of the system in contact with other parts of the system but separated by a well-defined boundary
intramolecular forces: hold atoms together in a molecule
van der Waals forces: dipole-dipole, dipole-induced dipole, dispersion forces
dipole-dipole forces: attractive forces between polar molecules
ion-dipole forces: attract an ion and a polar molecule to each other
dispersion forces: attractive forces that arise as a result of temporary dipoles
surface tension: amount of energy required to increase the surface of a liquid by a unit area
cohesion: intermolecular attraction between like molecules
adhesion: an attraction between unlike molecules
viscosity: measure of fluid's resistance to flow
colloid: dispersion of particles of one substance throughout a dispersing medium of another

Chemistry: Kinetic and Molecular Theory of Solids

crystalline solid: possesses rigid and long-range order
unit cell: basic repeating structure of a crystalline solid
coordination number: number of atoms or ions surrounding an atom or ion in a crystal lattice
closest packing: most efficient arrangement of spheres
X-ray diffraction: refers to the scattering of X-rays by the units of a crystalline solid
amorphous solid: lacks a regular three-dimensional arrangement of atoms
glass: an optically transparent fusion product of inorganic materials that has cooled to a rigid state without crystallizing
phase change: transition from one phase to another

Chemistry: Bragg Diffraction



$2d\sin\theta = n\lambda$ d = distance between adjacent planes
θ = angle the X-rays and the plane of the crystal
λ = X-ray wavelength n = integral multiple of wavelength
(Image source: https://en.wikipedia.org/wiki/Bragg's_law#/media/File:BraggPlaneDiffraction.svg, Author : Furiouslettuce, public domain)

Chemistry: Types of Crystals

type	forces	properties	examples
ionic	electrostatic attraction	hard, brittle, high melting point, poor heat and electrical conductor	NaCl, LiF, MgO, $CaCO_3$
covalent	covalent bond	hard, high melting point, poor heat and electrical conductor	C, SiO_2
molecular	dispersion forces, dipole-dipole forces, hydrogen bonds	soft, low melting point, poor heat and electrical conductor	Ar, CO_2, I_2, H_2O, $C_{12}H_{22}O_{11}$
metallic	metallic bond	soft to hard, low to high melting point, good conductor	all metallic elements

Chemistry: Naming Acids and Bases

oxoacid	removal of all H^+ ions →	oxoanion
per- -ic acid	→	per- -ate
↑ +[O]		
representative "–ic" acid	→	-ate
↓ -[O]		
"-ous" acid	→	-ite
↓ -[O]		
hypo- -ous acid	→	hypo- ite

Chemistry: Common Inorganic and Organic Acids

substance	formula	substance	formula
acetic	CH_3COOH	nitric	HNO_3
acrylic	C_2H_3COOH	oleic	$C_{17}H_{33}COOH$
benzene sulfonic	$C_6H_5SO_3H$	oxalic	$H_2C_2O_4$
benzoic	C_6H_5COOH	perchloric	$HClO_4$
butyric	C_3H_7COOH	phenol	C_6H_5OH
carbolic	C_6H_5OH	phosphoric	H_3PO_4
carbonic	H_2CO_3	propionic	C_2H_5COOH
chloric	$HClO_3$	stearic	$C_{17}H_{35}COOH$
formic	$HCOOH$	sulfuric	H_2SO_4
hydrobromic	HBr	sulfurous	H_2SO_3
hydrochloric	HCl	valeric	C_4H_9COOH
hydrosulfuric	H_2S		

Chemistry: Common Inorganic Anions

bromide (Br^-)	hydroxide (OH^-)
carbonate (CO_3^{2-})	iodide (I^-)
chlorate (ClO_3^-)	nitrate (NO_3^-)
chloride (Cl^-)	nitride (N^{3-})
chromate (CrO_4^{2-})	nitrite (NO_2^-)
cyanide (CN^-)	oxide (O^{2-})
dichromate ($Cr_2O_7^{2-}$)	permanganate (MnO_4^-)
dihydrogen phosphate ($H_2PO_4^-$)	peroxide (O_2^{2-})
fluoride (F^-)	phosphate (PO_4^{3-})
hydride (H^-)	sulfate (SO_4^{2-})
hydrogen carbonate, bicarbonate (HCO_3^-)	sulfide (S^{2-})
hydrogen phosphate (HPO_4^{2-})	sulfite (SO_3^{2-})
hydrogen sulfate, bisulfate (HSO_4^-)	thiocyanate (SCN^-)

Chemistry: Radioactive Decay

radioactive decay $N = N_0 e^{-\lambda t}$ N_0 = original amount

half-life $T_{1/2} = \dfrac{0.693}{\lambda}$ λ = decay constant t = time

daughter product activity

$$N_2 = \frac{\lambda_1 N_{10}}{\lambda_2 - \lambda_1}(e^{-\lambda_1 t} - e^{-\lambda_2 t})$$ λ_1, λ_2 = decay constants

N_{10} = initial activity of parent nuclei

daughter product maximum activity time

$$t' = \frac{\ln \lambda_2 - \ln \lambda_1}{\lambda_2 - \lambda_1}$$

Chemistry: Ideal Gas Law

Ideal gas law: $PV = nRT = NkT$

P = pressure in pascals V = volume in meters^3

n = number of moles T = temperature in kelvins

R = universal gas constant = 8.314 joules/mol K

N = number of molecules

k = Boltzmann's constant = 1.381×10^{-23} joules/K = R / N_A

N_A = Avogadro's number = 6.022×10^{23}/mol

M = molar mass m = mass in grams

absolute zero = 0 K = -273.15^{0}C

$$n = \frac{m}{M} \qquad \frac{n}{V} = \frac{m}{MV} = \frac{P}{RT} \qquad \text{density } d = \frac{m}{V} = \frac{PM}{RT}$$

Chemistry: Boyle's Law, Charles' Law, Henry's Law, Raoult's Law

Boyle's Law: $P_i V_i = P_f V_f$ constant temperature

Charles' Law: $\dfrac{V_i}{T_i} = \dfrac{V_f}{T_f}$ constant pressure

Henry's Law: the solubility of a gas in a liquid is proportional to the pressure of the gas over the solution $c = kP$

c = molar concentration in mol/liter

k in units of mol/liter atm P = pressure of the gas over the solution

Raoult's Law: $P_1 = X_1 P_1^0$ partial pressure of a solvent over a solution P_1 is the vapor pressure of the pure solvent P_1^0 times the mole fraction of the solvent in solution X_1

Chemistry: Kinetic Theory of Ideal Gases

average kinetic energy of an ideal gas: $K_{avg} = \dfrac{3}{2} kT$

root mean square velocity: $v_{rms} = \sqrt{\dfrac{3RT}{M}}$

diffusion: the gradual mixing of molecules of one gas with molecules of another by virtue of their kinetic properties

Chemistry: Common Gases

elements	compounds
H_2 (molecular hydrogen)	HF (hydrogen fluoride)
N_2 (molecular nitrogen)	HCl (hydrogen chloride)
O_2 (molecular oxygen)	HBr (hydrogen bromide)
O_3 (ozone)	HI (hydrogen iodide)
F_2 (molecular fluorine)	CO (carbon monoxide)
Cl_2 (molecular chlorine)	CO_2 (carbon dioxide)
He (helium)	NH_3 (ammonia)
Ne (neon)	NO (nitric oxide)
Ar (Argon)	NO_2 (nitrogen dioxide)
Kr (krypton)	N_2O (nitrous oxide)
Xe (xenon)	SO_2 (sulfur dioxide)
Rn (radon)	H_2S (hydrogen sulfide)
	HCN (hydrogen cyanide)

Chemistry: Partial Pressure

Dalton's law of partial pressure: the total pressure of a mixture of gases is the sum of the pressures that each gas would exert if it were present alone

$$P_A = \frac{n_A RT}{V} \qquad P_B = \frac{n_B RT}{V}$$

P_A = pressure exerted by gas *A*

n_A = number of moles of gas *A*

P_B = pressure exerted by gas *B*

n_B = number of moles of gas *B*

total pressure $P_T = P_A + P_B$

Chemistry: Atmospheric Partial Pressure

partial pressure of oxygen:

$$P_{O_2} = X_{O_2} P_{total} = \frac{n_{O_2}}{n_{O_2} + n_{N_2}} P_{total} = \frac{V_{O_2}}{V_{O_2} + V_{N_2}} P_{total}$$

$$= \frac{\sim 20\%}{\sim 20\% + \sim 80\%}(1\,atm) = 0.20\,atm$$

to maintain the same partial oxygen pressure of P_{total} = 0.20 atm:

$$P_{O_2} = \frac{\sim 10\%}{\sim 10\% + \sim 90\%}(2\,atm) = 0.20\,atm$$

partial pressure of nitrogen:

$$P_{N_2} = X_{N_2} P_{total} = \frac{n_{N_2}}{n_{O_2} + n_{N_2}} P_{total} = \frac{V_{N_2}}{V_{O_2} + V_{N_2}} P_{total}$$

Chemistry: van der Waals Equation

van der Waals equation $\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$

gas	*a* (atm L^2/mol^2)	*b* (L/mol)	gas	*a* (atm L^2/mol^2)	*b* (L/mol)
He	0.034	0.0237	O_2	1.36	0.0318
Ne	0.211	0.0171	Cl_2	6.49	0.0562
Ar	1.34	0.0322	CO_2	3.59	0.0427
Kr	2.32	0.0398	CH_4	2.25	0.0428
Xe	4.19	0.0266	CCl_4	20.4	0.138
H_2	0.244	0.0266	NH_3	4.17	0.0371
N_2	1.39	0.0391	H_2O	5.46	0.0305

Chemistry: Energy Changes

thermochemistry: study of heat change in chemical reactions

open system: can exchange mass and energy, usually in the form of heat with the surroundings

closed system: allows the transfer of energy, usually in the form of heat, but not mass, with the surroundings

isolated system: does not allow the transfer of mass or energy

exothermic process: any process that emits heat to the surroundings

endothermic process: any process that requires heat from the surroundings

change of enthalpy: represents the amount of heat given off or absorbed during a reaction

heat capacity: mass x specific heat

standard enthalpy of formation: heat change resulting when one mole of a compound is formed from its elements at a pressure of 1 atm

Chemistry: Types of Reactions Involving Heat

heat of neutralization: when one equivalent of an acid and one equivalent of a base undergo a neutralization reaction to form water and a salt; defined as the energy released with the formation of 1 mole of water

heat of ionization: increase in enthalpy when 1 mole of a substance is completely ionized at constant pressure

heat of fusion: change in its enthalpy resulting from providing energy, typically heat, to a specific quantity of the substance to change its state from a solid to a liquid at constant pressure

Chemistry: Types of Reactions Involving Heat (2)

heat of vaporization: energy (enthalpy) that must be added to the liquid substance, to transform a quantity of that substance into a gas. The enthalpy of vaporization is a function of the pressure at which that transformation takes place

heat of reaction: change in the enthalpy of a chemical reaction that occurs at a constant pressure

heat of solution: heat generated or absorbed when a certain amount of solute dissolves in a certain amount of solvent

heat of dilution: heat change associated with the dilution process

Chemistry: Calorimetry and Latent Heat

for an isolated system

$$Q_{system} = Q_{water} + Q_{cal} + Q_{reaction} = 0$$

$$Q_{water} = m_{water} c_{water} \Delta T_{water}$$

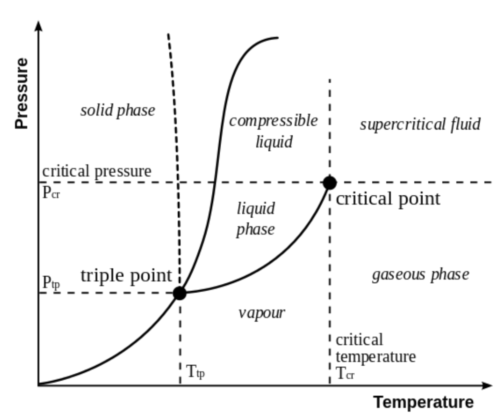
$$Q_{cal} = m_{cal} c_{cal} \Delta T_{cal}$$

$$Q_{reaction} = m_{reaction} c_{reaction} \Delta T_{reaction}$$

latent heat of fusion $L_{fusion} = \frac{Q_{fusion}}{m_{material}}$

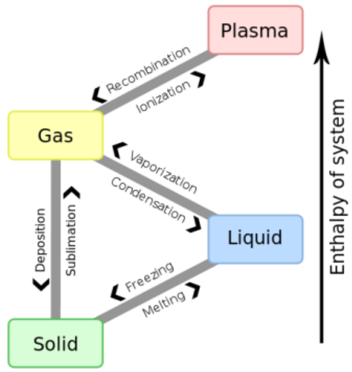
latent heat of vaporization $L_{vaporization} = \frac{Q_{vaporization}}{m_{material}}$

Chemistry: Phase Change Diagram



(Image source: https://en.wikipedia.org/wiki/Phase_transition#/media/File:Phase-diag2.svg, Author: Matthieumarechal, CC BY-SA 3.0)

Physics Phase Changes (1)



(Image source: https://commons.wikimedia.org/wiki/File:Phase_change_-_en.svg, Author: Flanker, penubag, public domain)

Chemistry: Phase Changes (2)

		to			
		solid	liquid	gas	plasma
from	solid	--	melting	sublimation	--
	liquid	freezing	--	boiling/ evaporation	--
	gas	deposition	condensation	--	ionization
	plasma	--	--	recombination/ deionization	--

Chemistry: Heat of Vaporization and Clausius-Clapeyron Equation

$$\ln P = \frac{-\Delta H_{vap}}{RT} + C$$

P = vapor pressure
ΔH_{vap} = molar heat of vaporization required to vaporize 1 mole of a liquid
R = gas constant, 8.314 J/K mol
T = temperature

Chemistry: Critical Temperature and Pressure

critical temperature: temperature above which a substance's gas phase cannot be made to liquify no matter how great the pressure is

critical pressure: minimum pressure that must be applied to bring about liquification at the critical temperature

Chemistry: Batteries (1)

battery: an electrochemical cell, or a series of combined electrochemical cells, that can be used as a source of direct electric current at a constant voltage

dry cell battery: anode consists of a zinc container in contact with manganese dioxide (MnO_2) and an electrolyte, consisting of ammonium chloride and zinc chloride in water with added starch
anode: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$
cathode: $2NH_4^+(aq) + 2MnO_2(s) + 2e^- \rightarrow MnO_3(s) + 2NH_3(aq) + H_2O(l)$
overall: $Zn(s) + 2NH_4^+ + 2MnO_2(s) \rightarrow$
$Zn^{2+}(aq) + 2NH_3(aq) + H_2O(l) + Mn_2O_3(s)$

Chemistry: Batteries (2)

mercury battery: contained in a stainless steel cylinder, consists of a zinc anode amalamated with mercury in contact with a strongly alkaline electrolyte containing zinc oxide and mercury(II) oxide
anode: $Zn(Hg) + 2OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^-$
cathode: $HgO(s) + H_2O(l) + 2e^- \rightarrow Hg(l) + 2OH^-(aq)$
overall: $Zn(Hg) + HgO(s) \rightarrow ZnO(s) + Hg(l)$

solid-lithium battery: employs a solid as the electrolyte connecting the electrodes, cathode made of either TiS_2 or V_6O_{13}, can be recharged

Chemistry: Batteries (3)

lead storage battery: each cell has a lead anode and a cathode of lead dioxide (PbO_2) packed on a metal plate
anode: $Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$
cathode: $PbO_2(s) + 4H^+(aq) + SO_4^{2-}(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$
overall: $Pb(s) + PbO_2(s) + 4H^+(aq) + 2SO_4^{2-}(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$

rechargeable, replenishing the original materials:
$PbSO_4(s) + 2e^- \rightarrow Pb(s) + SO_4^{2-}(aq)$
$PbSO_4(s) + 2H_2O(l) \rightarrow PbO_2(s) + 4H^-(aq) + SO_4^{2-}(aq) + 2e^-$
overall: $PbSO_4(s) + 2H_2O(l) \rightarrow Pb(s) + PbO_2(s) + 4H^+(aq) + 2SO_4^{2-}(aq)$

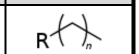
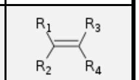
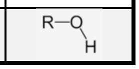
Chemistry: Fuel Cells and Electrolysis in Water

fuel cell: an electrochemical cell that requires a continuous supply of reactants to keep it functioning
hydrogen-oxygen fuel cell: consists of an electrolyte solution, such as potassium hydroxide solution and two inert electrodes, hydrogen and oxygen are bubbled through the anode and cathode compartments
anode: $2H_2(g) + 4OH^-(aq) \rightarrow 4H_2O(l) + 4e^-$
cathode: $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$
overall: $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$
electrolysis in water in a 0.1 molar H_2SO_4 solution:
anode: $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$
cathode: $4\,[\,H^+(aq) + e^- \rightarrow H_2(g)/2\,]$
overall: $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$

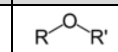
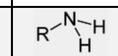
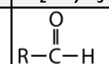
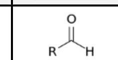
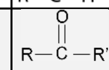
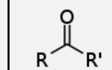
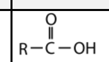
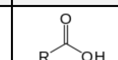
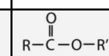
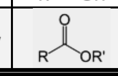
Chemistry: Formation of Organic Compounds

organic chemistry: the branch of chemistry that deals with carbon compounds
aliphaic hydrocarbons: do not contain the benzene group or the benzene ring
aromatic hydrocarbons: contain one or more benzene rings
oxidation: replacement of a hydrogen atom with a hydroxyl group
reduction: replacement of a hydroxyl group with a hydrogen atom
hydrogenation: addition of hydrogen atoms
hydrolysis: addition of one or more water molecules
dehydration: removal of one or more water molecules
polymer: molecular compound distinguished by a high molar mass, ranging into thousands and millions of grams, and made up of many repeating units

Chemistry: Organic Compounds (1)

	IUPAC name	common name	general formula	structural formula
alkane	ethane	ethane	RH	
alkene	ethene/ ethylene	ethylene	$RCH=CH_2$ $RCH=CHR$ $R_2C=CHR$ $R_2C=CR_2$	
alkyne	ethyne/ acetylene	acetylene	RC ≡ CH RC ≡ CR	RC≡C-R’
arene	benzene	benzene	ArH	ArH
haloalkane	chloro-ethane	ethyl chloride	RX	R-X
alcohol	ethanol	ethyl alcohol	ROH	

Chemistry: Organic Compounds (2)

	IUPAC name	common name	general formula	structural formula
ether	methoxy-mexane	dimethyl ether	ROR	
amine	methan-amine	methyl-amine	RNH_2 R_2NH, R_3	
aldehyde	ethanal	acetal-dehyde		
ketone	acetone	dimethyl ketone		
carboxylic acid	ethanoic acid	acetic acid		
ester	methyl ethanoate	methyl acetate		

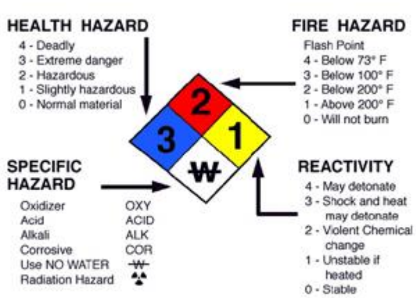
Chemistry: Common Names of Organic and Inorganic Chemicals (1)

common name	chemical name	formula
muriatic acid	hydrochloric acid	HCl
cumene	isopropyl benzene	$C_6H_5CH(CH_3)_2$
styrene	vinyl benzene	$C_6H_5CH=CH_2$
epsom salt	magnesium sulfate	$MgSO_4$
hydroquinone	p-dihydroxy benzene	$C_6H_4(OH)_2$
soda ash	sodium carbonate	Na_2CO_3
potash	potassium carbonate	K_2CO_3
baking soda	sodium bicarbonate	$NaHCO_3$
lye/caustic soda	sodium hydroxide	$NaOH$
carbolic acid	phenol	C_6H_5OH

Chemistry: Common Names of Organic and Inorganic Chemicals (2)

common name	chemical name	formula
aniline	aminobenzene	$C_6H_5NH_2$
toluene	methyl benzene	$C_6H_5CH_3$
xylene	dimethyl benzene	$C_6H_4(CH_3)_2$
neopentane	2,2-dimethylpropane	$CH_3C(CH_3)_2CH_3$
heavy water	deuterium oxide	$(H^2)_2O$
eyewash	boric acid solution	H_3BO_3
laughing gas	nitrous oxide	N_2O
brine	sodium chloride solution	$NaCl$
battery acid	sulfuric acid	H_2SO_4

Chemistry: Fire Hazard Diamond (1)



(Image source: https://riskmanagement.unt.edu/riskman/index.php?section=onlinetraining&group=art safety&module=3)

Chemistry: Fire Hazard Diamond (2)

Position A (left, blue) – Hazard
0 = ordinary combustible hazard
1 = slightly hazardous
2 = hazardous
3 = extreme danger
4 = deadly
Position B (top, red) – Flammability
0 = will not burn
1 = will ignite if preheated
2 = will ignite if moderately heated
3 = will ignite at most ambient temperature
4 = burns readily at ambient conditions 100°F (38°C).

Chemistry: Fire Hazard Diamond (3)

Position C (right, yellow) – Reactivity

0 = stable and not reactive with water

1 = unstable if heated

2 = violent chemical change

3 = shock short may detonate

4 = may detonate

Position D (bottom, white)

OXY = oxidizer ACID = acid ALKALI = alkali

Cor = corrosive W = use no water ☢ = radiation hazard

Flammable

Describes any solid, liquid, vapor, or gas that will ignite easily and burn rapidly. A flammable liquid is defined by NFPA and DOT as a liquid with a flash point below 100^0F (38^0C)

Engineering

Engineering: Engineering Method

- Define the problem. Why is this a problem?
- Do background research. Have others investigated this if so, what did they discover? Does this information help you?
- Specify requirements. What are the time, resource, cost, and technical requirements?
- Brainstorm possible solutions. Communicate, cooperate, and collaborate with colleagues.
- Choose the best solution. Why do you think the solution you chose will work?
- Develop the project. Gather the required resources.
- Build a prototype. What works? What doesn't work?
- Test and redesign. Make the required changes to your design.

Engineering: Systems

system: group of interacting, interrelated, or interdependent elements forming a complex whole

closed system: no matter enters or leaves the system

open system: energy and matter can enter or leave the system

positive feedback: mechanism that enhances or drives a change

negative feedback: mechanism that works to maintain existing conditions

Engineering: Engineering Notation

engineering notation: $m\ x10^n$, where n is an integer divisible by 3, meaning that $1 \le m < 1{,}000$

Engineering: Polar Coordinates

particle position $\vec{r} = r\vec{u}_r$

particle instantaneous velocity $\vec{v} = v_r\vec{u}_r + v_\theta\vec{u}_\theta = \dot{r}\vec{u}_r + r\dot{\theta}\vec{u}_\theta$

velocity magnitude $v = \sqrt{(\dot{r})^2 + (r\dot{\theta})^2}$

particle instantaneous acceleration

$$\vec{a} = \dot{\vec{v}} = a_r\vec{u}_r + a_\theta\vec{u}_\theta = (\ddot{r} - r\dot{\theta}^2)\vec{u}_r + (r\ddot{\theta} + 2\dot{r}\dot{\theta})\vec{u}_\theta$$

$$= \ddot{r}\vec{u}_r + \dot{r}\dot{\vec{u}}_r + \dot{r}\dot{\theta}\vec{u}_\theta + r\ddot{\theta}\vec{u}_\theta + r\dot{\theta}\dot{\vec{u}}_\theta$$

acceleration magnitude $a = \sqrt{(\ddot{r} - r\dot{\theta}^2)^2 + (r\ddot{\theta} + 2\dot{r}\dot{\theta})^2}$

Engineering: Cylindrical Coordinates

particle position $\vec{r}_p = r\vec{u}_r + z\vec{u}_z$

particle instantaneous velocity

$$\vec{v} = v_r\vec{u}_r + v_\theta\vec{u}_\theta + v\vec{u}_z = \dot{r}\vec{u}_r + r\dot{\theta}\vec{u}_\theta + \dot{z}\vec{u}_z$$

velocity magnitude $v = \sqrt{(\dot{r})^2 + (r\dot{\theta})^2}$

particle instantaneous acceleration

$$\vec{a} = \dot{\vec{v}} = a_r\vec{u}_r + a_\theta\vec{u}_\theta = (\ddot{r} - r\dot{\theta}^2)\vec{u}_r + (r\ddot{\theta} + 2\dot{r}\dot{\theta})\vec{u}_\theta + \ddot{z}u_z$$

acceleration magnitude $a = \sqrt{(\ddot{r} - r\dot{\theta}^2)^2 + (r\ddot{\theta} + 2\dot{r}\dot{\theta})^2}$

Engineering: Steady Fluid Streams

constant mass:

$$\sum F_x = \frac{dm}{dt}(\vec{v}_{Bx} - \vec{v}_{Ax}) \qquad \sum F_y = \frac{dm}{dt}(\vec{v}_{By} - \vec{v}_{Ay})$$

$$\frac{dm}{dt} = \rho_A v_A A_A = \rho_B v_B A_B = \rho_A Q_A = \rho_B Q_B$$

mass loss:

$$\sum F_s = m\frac{dv}{dt} - (v + v_e)\frac{dm_e}{dt}$$

v_e = velocity of expelled mass $\qquad \frac{dm_e}{dt}$ = rate of mass loss

Engineering: Vibrations and Simple Harmonic Motion

$$-kx = m\ddot{x} = m\dot{v} = ma$$

standard form oscillating spring $\ddot{x} + p^2x = 0 \qquad p = \sqrt{\frac{k}{m}}$

$$x = A\sin pt + B\cos pt = \frac{v_1}{p}\sin pt + x_1\cos pt$$

$$v = \dot{x} = Ap\cos pt + Bp\sin pt \qquad A = C\cos\phi$$

$$a = \ddot{x} = -Ap^2\sin pt - Bp^2\cos pt \qquad B = C\sin\phi$$

$$x = C\cos\phi\sin pt + C\sin\phi\cos pt$$

suspended block: $\ddot{y} + p^2y = 0$

Engineering: Undamped Forced Vibrations

$$F_{\max}\sin\omega t - kx = m\ddot{x} \qquad \ddot{x} + \frac{k}{m}x = \frac{F_{\max}}{m}\sin\omega t$$

complementary solution $x_c = A\sin pt + B\cos pt$

particular solution $x_p = C\sin\omega t \qquad \ddot{x}_p = -C\omega^2\sin\omega t$

$F_{\max}$ = maximum force $\qquad k$ = spring constant

m = mass $\qquad \omega$ = forcing frequency

$$-C\omega^2\sin\omega t + \frac{k}{m}(C\sin\omega t) = \frac{F_{\max}}{m}\sin\omega t \qquad x_p = \frac{F_{\max}/k}{1 - \left(\frac{\omega}{p}\right)^2}$$

Engineering: Mechanical Properties of Materials (1)

brittleness: ability of a material to break or shatter without significant deformation when under stress; opposite of plasticity

bulk modulus: ratio of pressure to volumetric compression (GPa)

$K = -V\frac{dP}{dV} \qquad P$ = pressure $\qquad V$ = volume

coefficient of friction: dimensionless scalar value μ which describes ratio of the force of friction between two bodies and force pressing them together

coefficient of restitution: e, measure of "restitution" of a collision between two objects; how much of the kinetic energy remains for rebounding vs. how much is lost as heat or work of deformation

$$e = \frac{\text{relative velocity after collision}}{\text{relative velocity before collision}}$$

Engineering: Mechanical Properties of Materials (2)

compressive strength: maximum stress a material can withstand before compressive failure (MPa); corresponds to the point on the engineering stress strain curve $(\varepsilon_e^*, \sigma_e^*)$ defined by

$\varepsilon_e^* = \frac{l^* - l}{l_0} \qquad \sigma_e^* = \frac{F^*}{A_0} \qquad l^*$ = length just before crushing

l_0 = original length $\qquad F^*$ = load just before crushing $\qquad A_0$ = original area

Engineering: Mechanical Properties of Materials (3)

creep: slow and gradual deformation of an object with respect to time

$$\frac{d\varepsilon}{dt} = \frac{C\sigma^m}{d^b} e^{-Q/kT}$$ ε = creep strain

C = constant dependent on the material and creep mechanism

m = exponent depending on creep mechanism

b = exponent dependent on the creep mechanism

Q = activation energy of the creep mechanism

σ = applied stress $\quad$ d = grain size of the material

k = Boltzmann's constant $\quad$ T = absolute temperature

Engineering: Mechanical Properties of Materials (4)

ductility: ability of a material to deform under tensile stress

durability: Ability to withstand wear, pressure, or damage; hard-wearing

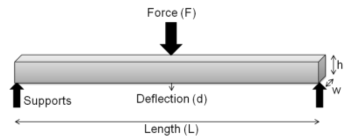
elasticity: Ability of a body to resist a distorting influence or stress and to return to its original size and shape when the stress is removed

$\sigma = E\varepsilon$ $\quad$ σ = stress $\quad$ E = constant $\quad$ ε = strain

fatigue limit: maximum stress a material can withstand under repeated loading (MPa)

flexural modulus: intensive property that is computed as the ratio of stress to strain in flexural deformation

$$E_{bend} = \frac{L^3 F}{4wh^3 d}$$

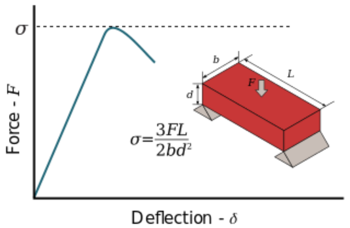


(Image source: https://en.wikipedia.org/wiki/Flexural_modulus#/media/File:Flexural_modulus_measurement.png, Author: Adjwilley, CC SA-BY 4.0)

Engineering: Mechanical Properties of Materials (5)

flexural strength: material property, defined as the stress in a material just before it yields in a flexure test

$$\sigma = \frac{3FL}{2bd^2}$$



fracture toughness: ability of a material containing a crack to resist fracture (MPa $m^{1/2}$)

hardness: measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied

(Image source: https://en.wikipedia.org/wiki/Flexural_strength#/media/File:Flexural_strength.svg, Author: Nicoguaro, CC BY 4.0)

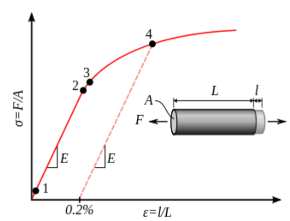
Engineering: Mechanical Properties of Materials (6)

malleability: material's ability to deform under compressive stress

plasticity: describes the deformation of a solid material undergoing non-reversible changes of shape in response to applied forces

Poisson's ratio: length change $\nu \approx \frac{\Delta L'}{\Delta L}$

volume change $\frac{\Delta V}{V} \approx (1-2\nu)\frac{\Delta L}{L}$



(Image sources https://en.wikipedia.org/wiki/Plasticity_(physics)#/media/File:Metal_yield.svg, Author: Sigmund, public domain)

1 = true elastic limit; 2 = proportionality limit, 3 = elastic limit, 4 = offset yield strength

Engineering: Mechanical Properties of Materials (7)

resilience: the ability of a material to absorb energy when it is deformed elastically, and release that energy upon unloading

modulus of resilience $U_r = \frac{\sigma_y^2}{2E} = \frac{\sigma_y * \varepsilon_y}{2}$ $\quad$ σ_y = yield strength

ε_y = yield strain $\quad$ E = Young's modulus

shear modulus: ratio of shear stress to shear strain

$G = \frac{\tau_{xy}}{\gamma_{xy}} = \frac{Fl}{A\Delta x}$ $\quad$ $\tau_{xy} = F/A$ = shear stress $\quad$ $\gamma_{xy} = \Delta x / l$ = shear strain

F = force $\quad$ l = initial length $\quad$ A = area $\quad$ Δx = transverse displacement

Engineering: Mechanical Properties of Materials (8)

shear strength: strength of a material or component against the type of yield or structural failure where the material or component fails in shear

$\tau = \frac{\sigma_1 - \sigma_3}{2}$ $\quad$ σ_1 = major principle stress $\quad$ σ_3 = minor principle stress

specific modulus: consisting of the elastic modulus per mass density of a material

specific strength: material's strength divided by its density

specific weight: weight per unit volume

stiffness: measure of the resistance offered by an elastic body to deformation

$k = \frac{F}{\delta}$ $\quad$ k = stiffness $\quad$ F = force applied on the body

δ = displacement produced by force along same degree of freedom

surface roughness: quantified by the deviations in the direction of the normal vector of a real surface from its ideal form

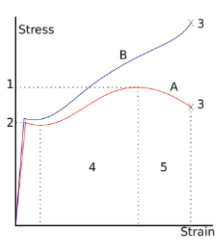
Engineering: Mechanical Properties of Materials (9)

tensile strength: capacity of a material or structure to withstand loads tending to elongate, as opposed to compressive strength, which withstands loads tending to reduce size

toughness: ability of a material to absorb energy and plastically deform without fracturing

$\frac{\text{energy}}{\text{volume}} = \int_0^{\varepsilon_f} \sigma d\varepsilon$ $\quad$ σ = stress

σ = strain $\quad$ ε_f = strain at failure



1=ultimate strength, 2=yield strength, 3=rupture, 4=strain hardening region, 5=necking region, A=apparent stress, B=actual stress

(Image source: https://en.wikipedia.org/wiki/Ultimate_tensile_strength#/media/File:Stress_v_strain_A36_2.svg, Author: David Richfield, CC BY-SA 3.0)

Engineering: Mechanical Properties of Materials (10)

viscosity: measure of its resistance to gradual deformation by shear stress or tensile stress

$F = \mu A \frac{u}{y}$ $\quad$ F = force $\quad$ μ = proportionality factor $\quad$ A = plate area

u = speed $\quad$ y = separation

yield strength: stress at which a material begins to deform plastically

$$\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + 2\nu(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_1\sigma_3) \le \sigma_y^2$$

Young's modulus: measure of the stiffness of a solid material

$$E = \frac{\sigma(\varepsilon)}{\varepsilon} = \frac{FL_0}{A_0 \Delta L}$$

F = force $\quad$ L_0 = initial length $\quad$ A_0 = initial area $\quad$ ΔL = change of length

Engineering: Uniaxial Load Deformation

stress on cross section $\sigma = \dfrac{P}{A}$

P = loading A = cross-sectional area

$$\varepsilon = \frac{\partial}{L} \qquad E = \frac{\sigma}{\varepsilon} = \frac{P/A}{\delta / L}$$

∂ = elastic longitudinal deformation

L = length of member

Engineering: Cylindrical Pressure Vessel

internal pressure tangential hoop stress $\sigma_t = P_i \dfrac{r_0^2 + r_i^2}{r_0^2 - r_i^2}$

external pressure tangential hoop stress $\sigma_t = -P_0 \dfrac{r_0^2 + r_i^2}{r_0^2 - r_i^2}$

σ_r = radial stress

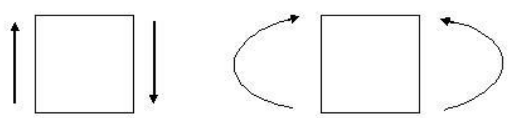
P_i = internal pressure P_0 = external pressure

r_i = inside radius r_0 = outside radius

for vessels with end caps axial stress $\sigma_a = P_i \dfrac{r_i^2}{r_0^2 - r_i^2}$

Engineering: Shearing Force and Bending Moment Sign Conventions

1. Bending moment is positive if it produces bending of the beam concave upward (compression in top fibers and tension in bottom fibers).
2. The shearing force is positive if the right portion of the beam tends to shear downward with respect to the left.



(Image source: https://en.wikipedia.org/wiki/Shear_and_moment_diagram#/media/File:Shear_and_Moment_Convention.jpg, Author ; Brett Mattas, public domain)

Engineering: Fluid Drag Flow

drag force on objects immersed in a large body of flowing fluid or objects moving through a stagnant fluid $F_D = \dfrac{C_D \rho V^2 A}{2}$

C_D = drag coefficient ρ = fluid density

V = velocity (m/s) of the undisturbed fluid

A = projected area (m^2) of blunt objects such as spheres, ellipsoids, disks, and plates, cylinders, ellipses, and air foils with axes perpendicular to the flow.

Engineering: Airfoil Theory (1)

lift force on an airfoil $F_L = \dfrac{C_L \rho V^2 A_P}{2}$

C_L = lift coefficient ρ = fluid density

V = velocity (m/s) of undisturbed fluid

A_P = projected area of the airfoil as seen from above

lift coefficient $C_L = 2\pi k_1 \sin(\alpha + \beta)$

k_1 = constant of proportionality

α = angle of attack (angle between airfoil chord and direction of flow)

β = negative of angle of attack for zero lift.

Engineering: Airfoil Theory (2)

drag coefficient $C_D \approx C_{D\infty} + \dfrac{C_L^2}{\pi AR}$

$C_{D\infty}$ = infinite span drag coefficient

$$AR = \frac{b^2}{A_P} = \frac{A_P}{c^2}$$

aerodynamic moment $M = \dfrac{C_M V^2 A_P c}{2}$

C_M = moment coefficient

A_P = plan area

c = chord length

Engineering: Reynolds Number

Newtonian fluid Reynolds number $\mathrm{Re} = \dfrac{VD\rho}{\mu} = \dfrac{VD}{v}$

ρ = the mass density

D = pipe diameter or dimension of the fluid streamline

μ = dynamic viscosity

v = kinematic viscosity

Engineering: Static Beam Equation

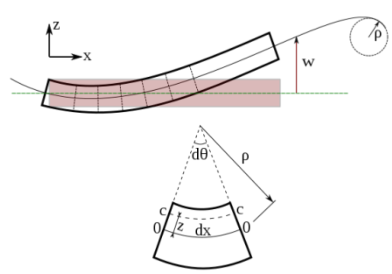
$$\frac{d^2}{dx^2}\left(EI \frac{d^2 w(x)}{dx^2}\right) = q$$

E = elastic modulus

I = second moment of area

$w(x)$ = equation describing the deflection of the beam in the z direction at some position x

q = force/area



(Image source: https://en.wikipedia.org/wiki/Euler%E2%80%93Bernoulli_beam_theory#/media/File:Euler-Bernoulli_beam_theory-2.svg, Author: MIntz, CC BY-SA 3.0)

Engineering: Sheer Stress in a Shaft and Polar Moment of Inertia

sheer stress in a shaft $\tau = \frac{Tr}{J}$ (MPa, psi)

T = twisting moment (Nmm, lb)

r = distance from center to stressed surface in given position (mm, in)

J = polar moment of inertia of an area (mm^4, in^4)

polar moment of inertia: a measure of a beam's ability to resist torsion; defined with respect to an axis perpendicular to the area considered; analogous to the "Area Moment of Inertia" which characterizes a beam's ability to resist bending required to predict deflection and stress in a beam; also called Second Moment of Area", "Area Moment of Inertia", "Polar Moment of Area" or "Second Area Moment"

Engineering: Circular Shaft and Maximum Moment or Torque

maximum moment in a circular shaft: $T_{max} = \frac{\tau_{max} R}{J}$ (Nmm, in lb)

τ_{max} = maximum shear stress (MPa, psi)

R = radius of shaft (mm, in)

solid shaft $T_{max} = \frac{\pi}{16} \tau_{max} D^3$

hollow shaft $T_{max} = \frac{\pi}{16} \tau_{max} \frac{(D^4 - d^4)}{D}$

D = outside diameter = $1.72(T_{max} / \tau_{max})^{1/3}$

d = inside diameter

Engineering: Tortional Deflection of a Shaft

angular shaft deflection $\theta = \frac{LT}{JG}$

L = length of shaft (mm, in)

G = modulus of rigidity (MPa, psi)

angular deflection of a torsion solid shaft $\theta = \frac{32LT}{G\pi D^4}$

angular deflection of a torsion hollow shaft $\theta = \frac{32LT}{G\pi (D^4 - d^4)}$

Engineering: Specific Heat Capacities for Gases

Substance	Mol wt	c_P in kJ/kg K	c_V in kJ/kg K	k
air	29	1.00	0.718	1.40
argon	40	0.520	0.312	1.67
butane	58	1.72	1.57	1.09
carbon dioxide	44	0.846	0.657	1.29
carbon monoxide	28	1.04	0.744	1.40
ethane	30	1.77	1.49	1.18
helium	4	5.19	3.12	1.67
hydrogen	2	14.3	10.2	1.40
methane	16	2.25	1.74	1.30
neon	20	1.03	0.618	1.67
nitrogen	28	1.04	0.743	1.40
octane vapor	114	1.71	1.64	1.04
oxygen	32	0.918	0.658	1.40
propane	44	1.68	1.49	1.12
steam	18	1.87	1.41	1.33

Engineering: Specific Heat Capacities for Liquids and Solids

substance	c_P kJ/kg K	density kg/m^3
liquids		
ammonia	4.80	602
mercury	0.139	13,560
water	4.18	997
solids		
aluminum	0.900	2,700
copper	0.386	8,900
ice at 0 C	2.11	917
iron	0.450	7,840
lead	0.128	11,310

Geoscience

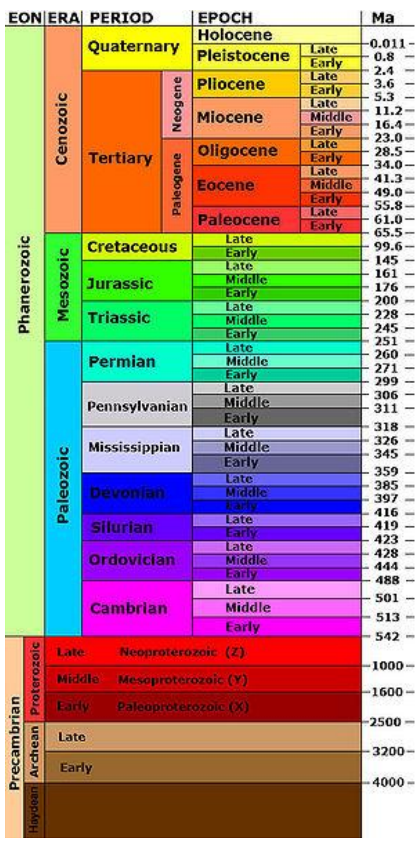
Geosciences: Geologic Principles (1)

- Principle of Uniformitarianism - geologic processes observed in operation that modify the Earth's crust at present have worked in much the same way over geologic time
- Principle of Intrusive Relationships - when an igneous intrusion cuts across a formation of sedimentary rock, it can be determined that the igneous intrusion is younger than the sedimentary rock
- Principle of Cross-cutting Relationships - faults are younger than the rocks they cut
- Principle of Inclusions and Components - if inclusions are found in a formation, then the inclusions must be older than the formation that contains them

Geosciences: Geologic Principles (2)

- Principle of Original Horizontality - deposition of sediments occurs as essentially horizontal beds
- Principle of Superposition - sedimentary rock layer in a tectonically undisturbed sequence is younger than the one beneath it and older than the one above it
- Principle of Faunal Succession - As organisms exist at the same time period throughout the world, their presence or (sometimes) absence may be used to provide a relative age of the formations in which they are found

Geologic Time Scale (1)



(Image source: https://commons.wikimedia.org/wiki/File:Geologic_time_scale.jpg, Author: United States Geological Survey, public domain)

Geologic Time Scale (2)

eon	description
Chaotian	began with Solar System formation; Earth from planetesimals
Hadean	frequent bombardment; Mars-sized body struck Earth, resulting in the creation of the Moon; outgassing of first atmosphere, oceans; extensive volcanism; formation of first crust; atmosphere and oceans form
Archean	diverse microbial life in primordial oceans; continental shields developed from volcanic activity; anaerobic atmosphere enabled Archaea to develop; plate tectonics followed regime of continental drift; cyanobacteria produced oxygen as metabolic by-product; eventual build-up of oxygen eventually proved fatal to many life-forms
Proterozoic	atmosphere changed from reducing to oxygenated; original anaerobic inhabitants driven into a few restricted refuges; rise of aerobic prokaryote and eukaryotic life; stromatolites common; modern continental drift began; formation of Rodinia; several extensive ice ages and “Snowball Earth;” appearance of first metazoan
Paleozoic	atmospheric oxygen reached present levels, generating ozone shield; age of invertebrates, fish, tetrapods, and reptiles; life emerged from sea to land, pteridophyte and later gymnospermous plants flourished; mild to tropical conditions with warm shallow seas; continents clustered into Pangea; increasing aridity; end of the great Carboniferous swamps and unique flora and fauna; ended by Permian mass-extinction
Mesozoic	dinosaurs; terrestrial megafauna; diverse sea-reptiles ruled the oceans; invertebrates, ammonites extremely diverse; pterosaurs and later birds; mammals remained small; warm, tropical climate; Pangea broke up into Laurasia and Gondwana; modern forms of corals, insects, new fishes and flowering plants; dinosaurs and many other animals abruptly died out at end of Cretaceous
Cenozoic	mammals; current continents emerged; initial tropical conditions replaced by colder drier climate, rise of grazing mammals; anthropoid apes that culminated in the australopithecine hominids of Africa; decreasing temperatures and a polar landmass of Antarctica resulted in a new Ice Age; rise of Homo erectus, Neanderthal and Cro-Magnon; extinction of Megafauna, and civilization

(Source: http://palaeos.com/timescale/index.html, Author: M. Alan Kazlev, CC)

Geoscience: Chemical Abundance of Earth

symbol	element	percent
O	oxygen	46.6
Si	silicon	27.7
Al	aluminum	8.1
Fe	iron	5.0
Ca	calcium	3.6
Na	sodium	2.8
K	potassium	2.6
Mg	magnesium	2.1

Geoscience: Igneous Rocks

rock name	origin	grain Size	color
andesite	extrusive	fine	intermediate, medium
basalt	extrusive	fine	mafic, dark
diorite	intrusive	coarse	intermediate, medium, dark
gabbro	intrusive	coarse	mafic, medium
granite	intrusive	coarse	felsic, light
obsidian	extrusive	very fine	dark
pumice	lava, ash	fine	felsic, medium
rhyolite	extrusive	fine	light
syenite	intrusive	coarse	light, dark, looks like granite without quartz
tuff	pyroclast/extrusive	fine, holes	medium

Geoscience: Sedimentary Rocks

rock name	color	hardness	composition silica/calcite	fossils
arkose	dark rose	<2.5	silica, sand	no
conglomerate	rose, gray	5.5> >4.5	boulders, pebbles, resembles concrete	
coquina	whitish tan	softer than glass	carbonate, limestone	yes
fossil limestone	pale gray	softer than glass	calcite	yes
micrite limestone	white, mocha, red	5.5> >4.5	calcite, carbonate	
oil shale	black, gray	softer than glass	silt and organic debris	yes
oolitic limestone		softer than glass	calcite, $CaCO_3$, carbonate	invertebrates
sandstone	sandy	>5.5	calcite, calcium carbonate, silica, or iron	animals, plants
shale (black or grey)	black, gray	softer than glass	quartz and clay	plant fossils, bones, fish
siltstone		harder than glass	clays and muds	
travertine	white		calcium carbonate	no

Geoscience: Metamorphic Rocks

rock name	luster	hardness	color	texture and grain size	composition
gneiss	non-metallic	>5.5	grayish white	coarse	magmatites, granites
hornfels	non-metallic	<3.5	dull black	fine- grained	quartz, mica, pyroxene
marble	non-metallic	5.5> >4.5	milky white	variable grain size	calcite, calcium carbonate
phyllite	non-metallic		pale grayish green	medium	garnetporphyroblasts
quartzite	glassy	7	dark rose	variable grain size	quartz grains
schist, mica	non-metallic	=5.0	gray	medium to coarse-grained	sparkles
slate, plate	non-metallic	<2.5	dull gray	fine-grained	compression of mud

Geoscience: Minerals

mineral: naturally occurring object, stable at room temperature, represented by a single chemical formula, usually abiogenic (not resulting from the activity of living organisms), has ordered atoms

mineral characteristics: color, crystal habit (geometric shape of crystals), cleavage (minerals break along particular planes of weakness), fracture (minerals also break in places where they aren't weak), tenacity (refers to resistance to breaking), hardness, luster (character of the light reflected), streak (color of the mineral when it is scratched or powdered), diaphaneity (ability of light to pass through), specific gravity (ratio of the density of a mineral to the density of water), fluorescence (emission of light by a substance that has absorbed light or other electromagnetic radiation), magnetism

Geoscience: Mineral Groups

group	elements	notation and information
carbonate	carbon and oxygen	CO_3
halide	fluorine or chlorine	F or Cl
hydroxide	oxygen and hydrogen	OH together
native	carbon	C by itself
oxide	oxygen	anything with O
phosphate	phosphorus and oxygen	PO_4
silicate	silicon and oxygen	Si and O
sulfate	sulfur and oxygen	SO_4
sulfide	sulfur	S without O

Geoscience: Special Properties of Minerals

Property	Minerals
fluorescence: emission of visible light by a mineral exposed to ultraviolet light; emission ends when exposure ends.	barite, calcite, fluorite, sphalerite
phosphorescence: emission of visible light when exposed to ultraviolet light; emission continues after exposure ends.	calcite
thermoluminescence: some minerals to glow when they are heated.	apatite, calcite, feldspars, fluorite.
triboluminescence: some minerals glow when crushed, struck, scratched, or rubbed.	calcite, feldspars, fluorite, micas, and quartz.

Geoscience: Mineral Crystal Systems

cubic	3 equal axes, mutually perpendicular, a = b = c $\alpha = \beta = \gamma = 90^0$
tetragonal	3 perpendicular axes, only 2 equal, a = b ≠ c, $\alpha = \beta = \gamma = 90^0$
hexagonal	3 equal coplanar at 120^0, 4^{th} unequal axis perpendicular to their plane, a = b ≠ c, $\alpha = \beta = 90^0$, $\gamma = 120^0$
rhombohedral	3 equal axes not at right angles, a = b = c, $\alpha = \beta = \gamma \neq 90^0$
orthorhombic	3 unequal axes all perpendicular, a ≠ b ≠ c, $\alpha = \beta = \gamma = 90^0$
monoclinic	3 unequal axes, 1 perpendicular to the other 2, a ≠ b ≠ c, $\alpha = \gamma = 90^0 \neq \beta$
triclinic	3 perpendicular unequal axes, a ≠ b ≠ c, $\alpha \neq \beta \neq \gamma \neq 90^0$

Geoscience: Moh's Scale of Mineral Hardness

hard-ness	mineral	composition	absolute hardness	common objects
1	talc	$Mg_3Si_4O_{10}(OH)_2$	1	
2	gypsum	$CaSO_4 \cdot 2H_2O$	2	fingernail
3	calcite	$CaCO_3$	9	penny
4	fluorite	CaF_2	21	
5	apatite	$Ca_5(PO_4)_3$(OH-,Cl-,F-)	48	knife
6	orthoclase feldspar	$KalSi_3O_8$	72	glass
7	quartz	SiO_2	100	steel file
8	topaz	Al_2SiO_4 (OH-,F-)$_2$	200	
9	corundum	Al_2O_3	400	
10	diamond	C	1500	

Geoscience: Mineral Groups, Hardness, Formula, Luster (1)

mineral	group	hardness	formula	luster
augite	silicate	5.5-6	(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)2O_6	non-metallic
barite	sulfate	3-3.5	$BaSO_4$	non-metallic
bauxite	hydroxide	2.3-2.7	Fe0(OH) and $Al_2O_32H_2O$	non-metallic,earthy
biotite	silicate	less than 3.5	$K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH,F)_2$	non-metallic
calcite	carbonate	3	$CaCO_3$	non-metallic
chalcopyrite	sulfide	3.5-4	Cu_5FeS_2	metallic
corundum	oxide	9	Al_2O_3	vitreous to adamantine
dolomite	carbonate	3.5-4	$CaMg(CO_3)_2$	non-metallic
fluorite	halide	4	CaF_2	non-metallic
galena	sulfide	2.5	PbS	metallic
graphite	native element	1-2	C	metallic
gypsum	sulfate	2	$CaSO_42H_2O$	non-metallic
halite	halide	2	NaCl	vitreous

Geoscience: Mineral Groups, Hardness, Formula, Luster (2)

mineral	group	hardness	formula	luster
hematite	oxide	5-6	Fe_2O_3	non-metallic, earthy
hornblende	silicate	5-6	$Ca_2(Mg,Fe)_4Al(Si_2Al)O_{22}(OH,F)_2$	vitreous
magnetite	oxide	5.5-6.5	$FeFe_2O_4$	metallic
malachite	carbonate	between 3 and 4	$Cu_2CO_3(OH)_2$	non-metallic
microcline potassium feldspar	silicate	6-6.6	$KalSi_3O_8$	non-metallic, vitreous
muscovite	silicate	2.5-4	$Kal_2(Si_3Al)O_{10}(OH,F)_2$	non-metallic, pearly
olivine	silicate	6.5-7	$Mg_2SiO_4Fe_2SiO_4$	vitreous
plagioclase feldspar	silicate	6 to 7	$(Na,Ca)(Si,Al)_4O_8$	non-metallic
pyrite	sulfide	6-6.5	FeS_2	metallic
quartz	oxide	7	SiO_2	vitreous
staurolite	silicate	7-7.5	$(Fe,Mg,Zn)_2Al_9(Si,Al)_4O_{22}(OH)_2$	vitreous toresinous
talc	silicate	1	$MgSi_4O_{10}(OH)_2$	dull to greasy

Geoscience: Mineral Specific Gravity, Color, Uses (1)

mineral	specific gravity	color	uses
augite	3.23-3.52	gray	ore of lithium, making steel
barite	4.5	white, orange	copper ore for pipes, electrical circuits, coins, ammunition, gemstone
bauxite	2.3-2.7	variable, tannish	aluminum ore
biotite	2.7-3.4	black	fire-resistant tiles, rubber, paint
calcite	2.71	gray, white	antacid, fertilizer, cement
chalcopyrite	4.3-4.4	brassy yellow	copper ore for pipes, electrical circuits, coins, ammunition, gemstone
corundum	4.0-4.1	many	abrasive powders to polish lenses, gemstone
dolomite	2.85	pale rose	magnesium ore, soft abrasive, used to make paper
fluorite	3.1-3.3	purple, green, white	fluorine source for processing aluminum

Geoscience: Mineral Specific Gravity, Color, Uses (2)

mineral	specific gravity	color	uses
galena	7.58	gray	lead or for TV glass, auto batteries, solder, ammunition, paint
graphite	2.1-2.3	gray	lubricant, pencils, fishing rods
gypsum	2.32	milky white	plaster-of-paris, wallboard, drywall, art sculptures
halite	2.1-2.2	clear, green, orange, reddish	salt, water softeners, sodium ore
hematite	5.26	brown	red pigment, iron ore, steel tools, vehicles, nails and bolts, bridges
hornblende	3.28-3.41	green, greenish brown, black	fire-resistant clothing, tiles, brake linings
magnetite	5.2	brown	iron ore for steel, brass, bronze, vehicles, nails and bolts, bridges
malachite	4.0	grayish green	copper ore for pipes, electrical circuits, coins, ammunition, gemstone

Geoscience: Mineral Specific Gravity, Color, Uses (3)

mineral	specific gravity	color	uses
microcline potassium feldspar	2.55-2.63	rose	
muscovite	2.77-2.88	silvery	computer chip substrates, electrical insulation, roof shingles, makeup
olivine	3.27-4.23	green, greenish yellow	gemstone, magnesium ore
plagioclase feldspar	2.6-2.8	grayish white	ceramics, glass, enamel, soap, false teeth, scouring powder
pyrite	5	brassy yellow	sulfur ore, sulfuric acid, explosives, fertilizers, pulp processing, insecticides
quartz	2.65	variable	abrasive, glass, gemstone
staurolite	3.65-3.83	translucent to opaque	gemstone, “fairy crosses”
talc	2.58-2.83	gray, white	talcum powder, makeup, ceramics, paint, sculptures

Geoscience: Earth’s Atmosphere (1)

symbol	atom/molecule	percent
N_2	molecular nitrogen	78.084
O_2	molecular oxygen	20.946
Ar	argon	0.9340
CO_2	carbon dioxide	0.0407
Ne	neon	0.001818
He	helium	0.000524
CH_4	methane	0.00018
Kr	krypton	0.000114
H_2	molecular hydrogen	0.000055

Geoscience: Earth’s Atmosphere (2)

weather: the state of the atmosphere, to the degree that it is hot or cold, wet or dry, calm or stormy, clear or cloudy
climate: long-term weather patterns, usually averaged over 30 years
aerosol: liquid and solid particles suspended in the atmosphere
ozone: inorganic molecule with the chemical formula O_3
albedo: ratio of radiation reflected from the surface to the incident radiation expressed as a number between 0 and 1
humidity: term used to describe the amount of water vapor in the air
relative humidity: ratio of the air’s actual water vapor content compared with the amount of water vapor required for saturation at that temperature and pressure

Geoscience: Earth's Atmosphere (3)

absolute humidity: mass of water vapor in a given column of air
vapor pressure: that part of the total atmospheric pressure attributable to its water vapor content
saturation: balance reached when the number of water molecules returning to the surface equals the number leaving
dew point: temperature at which a parcel of air would need to be cooled to reach saturation
stable air: air that resists vertical movement
unstable air: air that rises to reach an altitude where its temperature reaches that of its surroundings
adiabatic temperature change: temperature changes in which heat is neither added or subtracted
environmental lapse rate: rate at which atmospheric temperature decreases with an increase in altitude

Geoscience: Earth's Atmosphere (4)

cyclone: large scale air mass that rotates around a strong center of low atmospheric pressure, counter-clockwise in the Northern Hemisphere, clockwise in the Southern Hemisphere
anticyclone: a large-scale circulation of winds around a central region of high atmospheric pressure, clockwise in the Northern Hemisphere, counterclockwise in the Southern Hemisphere
trough: elongated regions of low pressure
ridge: elongated regions of high pressure
land breeze: develops because land cools more quickly than the sea
sea breeze: develops as cooler air over the water moves onto the land
jet stream: narrow ribbons of high speed winds that extend for thousands of kilometers
temperature inversion: a situation in which the atmosphere is very stable and the mixing depth is significantly restricted

Geoscience: Earth's Atmosphere (5)

El Niño: warm phase of the El Niño Southern Oscillation (ENSO), associated with a band of warm ocean water that develops in the central and east-central equatorial Pacific between approximately the International Date Line and 120°W, including off the Pacific coast of South America
La Niña: El Niño counterpart, part of the El Niño–Southern Oscillation climate pattern; sea surface temperature across the equatorial Eastern Central Pacific Ocean will be lower than normal by 3 to 5°C; in the U.S. an appearance of La Niña happens for at least five months of La Niña conditions

Geoscience: Earth's Atmosphere Layers (1)

troposphere: lowest layer; where all weather occurs; contains approximately 75% of atmospheric mass and 99% of the total mass of water vapor and aerosols; average depths of the troposphere are 20km (12 mi) in the tropics, 17 km (11 mi) in mid latitudes, 7 km (4.3 mi) in polar regions in winter.
tropopause: border between the troposphere and stratosphere
stratosphere: above troposphere, below mesosphere; contains about 20% of atmospheric mass; warmer layers higher and cooler layers closer to the Earth due to absorption of Sun's ultraviolet radiation by ozone stratosphere; near the equator; starts at 18 km (11 mi); at mid latitudes, it starts at 10–13 km (6.2–8.1 mi) and ends at 50 km (31 mi); at poles; starts at about 8 km (5.0 mi); temperatures vary within the stratosphere with the seasons, in particular with the polar night (winter)
stratopause: between the stratosphere and mesophere; highest temperatures

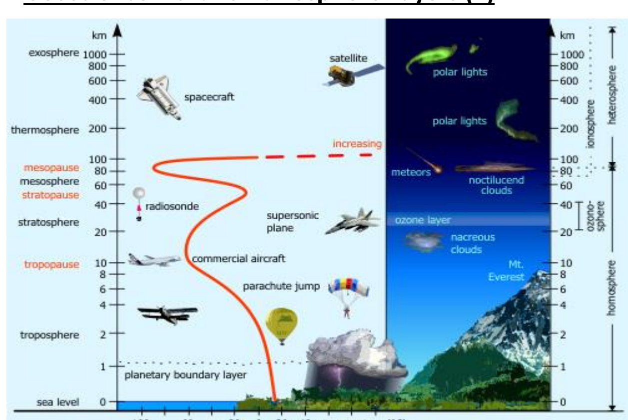
Geoscience: Earth's Atmosphere Layers (2)

mesosphere: above stratosphere, below thermosphere; temperature decreases as altitude increases; exact upper and lower boundaries vary by latitude and season; lower boundary usually located at about 50 kilometers above the Earth's surface and higher boundary usually at heights near 100 kilometers, except at middle and high latitudes in summer where it descends to 85 kilometers
mesopause: boundary between mesosphere and thermosphere; can be coldest temperatures below −143 °C (−225°F; 130 K)
thermosphere: above mesosphere, below exosphere; ultraviolet radiation causes photoionization/photodissociation, creating ions in ionosphere; begins about 85 kilometers (53 mi) above the Earth; temperatures increase with altitude due to absorption of highly energetic solar radiation and are highly dependent on solar activity; can rise to 2,000°C (3,630°F)
thermopause: temperature can range up to absolute zero to 987.548^{0}C (1,810°F)

Geoscience: Earth's Atmosphere Layers (3)

exosphere: above the thermosphere; highest layer, atmosphere thins out and merges with interplanetary space; hydrogen present throughout the exosphere, with some helium, carbon dioxide, and atomic oxygen near its base; may be considered a part of outer space
ionosphere: region of Earth's upper atmosphere, from about 60 km (37 mi) to 1,000 km (620 mi); includes thermosphere and parts of mesosphere and exosphere; ionized by solar radiation, plays an important part in atmospheric electricity ; forms the inner edge of the magnetosphere; . influences radio propagation to distant places on Earth

Geoscience: Earth's Atmosphere Layers (4)



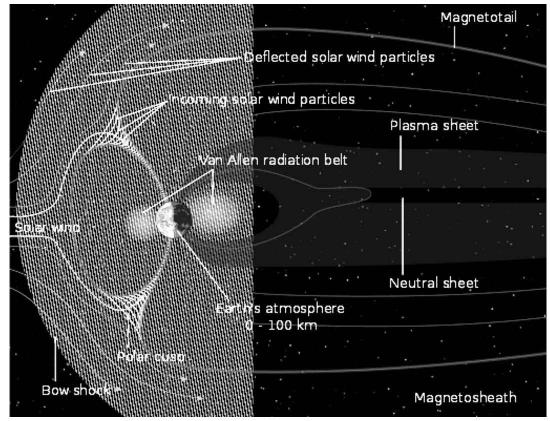
(Image source: http://www.theozonehole.com/atmosphere.htm, Author: Ozone Hole, Inc.)

Geoscience: Magnetosphere (1)

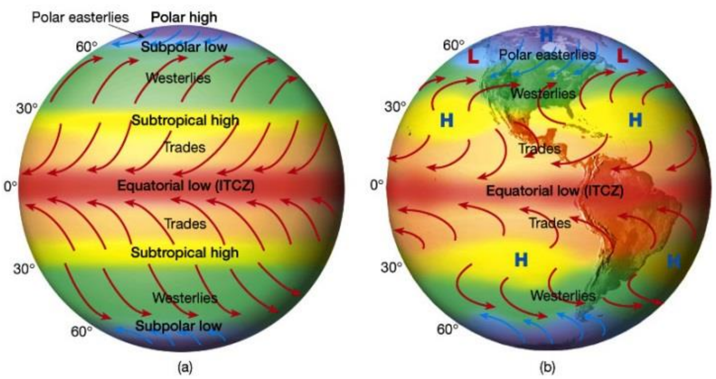
magnetosphere: over Earth's equator, magnetic field lines become almost horizontal, then return to reconnect at high latitudes, .where magnetic field is distorted by solar wind and solar magnetic field; on Earth's day side, magnetic field significantly compressed by solar wind to approximately 65,000 kilometers (40,000 mi); Earth's bow shock is about 17 kilometers (11 mi) thick and located about 90,000 kilometers (56,000 mi) from Earth; magnetopause exists at a distance of several hundred kilometers above Earth's surface; Earth's magnetopause allows solar wind particles to enter; magnetic field lines break and reconnect, solar wind particles are able to enter the magnetosphere; on Earth's night side, the magnetic field extends in the magnetotail, which lengthwise exceeds 6,300,000 kilometers (3,900,000 mi); Earth's magnetotail is primary source of polar aurora

Geoscience: Magnetosphere (2)

(Image source: https://en.wikipedia.org/wiki/Magnetosphere#/media/File:Structure_of_the_magnetosphere-en.svg, Author: NASA and Aaron Kaase, public domain)

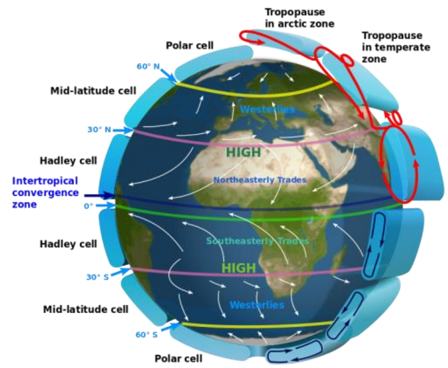


Geoscience: Atmospheric Circulation (1)



(Image source: The Atmosphere, 8th edition, Lutgens and Tarbuck, 8th edition, 2001)

Geoscience: Atmospheric Circulation (2)



(image source: https://en.wikipedia.org/wiki/Hadley_cell#/media/File:Earth_Global_Circulation_-_en.svg, Author: Kaidor, CC BY-SA 3.0)

Geoscience: Air Lifting Systems

1. orographic lifting: air is forced to rise over a mountain-related barrier
2. frontal wedging: warmer, less dense air is forced over cooler, denser air
3. convergence: a pile-up of horizontal air flow results in upward movement
4. localized convective uplifting: unequal surface heating causes localized pockets of air to rise because of their buoyancy

(Source: Atmospheres, Lutgens & Tarbuck, 2004, 9th ed.)

Geoscience: Winds

scale	time scale	distance scale	examples
macroscale			
planetary	weeks or longer	1,000 - 40,000 km	Westerlies, Trade Winds
synoptic	days to weeks	100 – 5,000 km	midlatitude cyclones, anticyclones, hurricanes
mesoscale	minutes to hours	1- 100 km	thunderstorms, tornadoes, land-sea breeze
microscale	seconds to minutes	< 1 km	turbulence, dust devils, gusts

(Source: Atmospheres, Lutgens & Tarbuck, 2004, 9th ed.)

Geoscience: Terrestrial Coordinates

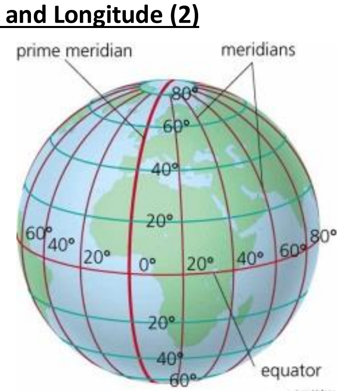
equator: imaginary line on Earth's surface equidistant from the North Pole and South Pole, dividing the Earth into the Northern Hemisphere and Southern Hemisphere; it is about 40,075 kilometers long; about 78.7% lies across water and 21.3% lies over land

latitude: geographic coordinate that specifies the north-south position of a point on the Earth's surface; it is is an angle which ranges from 0° at the Equator to 90° north or south) at the poles; . lines of constant latitude, called parallels, run east–west as circles parallel to the equator

longitude: geographic coordinate that specifies the east-west position of a point on the Earth's surface; .it is an angle expressed in degrees, denoted by the letter λ; meridians, lines running from the North Pole to the South Pole, connect points with the same longitude.

Geoscience: Latitude and Longitude (2)

Prime Meridian:passes through the Royal Observatory, Greenwich, England; was allocated the position of zero degrees longitude;.the longitude of other places is measured as the angle east or west from the Prime Meridian, ranging from 0° at the Prime Meridian to +180° eastward and −180° westward



(Image source: https://socratic.org/questions/what-is-the-prime-meridian-1, Author: Jerry Malone)

Geoscience: Air Masses (1)

air mass	source region	temperature/ moisture	stability	associated weather
cA	Arctic basin and Greenland ice cap	very cold and dry	stable	cold waves in winter
cP	interior Canada and Alaska	very cold and dry in winter	stable entire year	a. cold waves in winter; b. produces lake effect snow
mP	North Pacific	mild, cool, and humid entire year	unstable in winter, stable in summer	a. low clouds and showers in winter; b. heavy orographic precipitation on western mountains in winter; c. low stratus and fog along coast in summer

Geoscience: Air Masses (2)

air mass	source region	temperature/ moisture	stability	associated weather
mP	Northwestern Atlantic	cold and humid in winter, cool and humid in summer	unstable in winter, stable in summer	a. occasional “nor easter” in winter; b. occasional periods of clear, cool weather in summer
cT	Northern interior Mexico and southwestern U.S., summer	hot and dry	unstable	a. hot, dry and cloudless, rarely influences other regions; b. occasional drought to southern Great Plains

Geoscience: Air Masses (3)

air mass	source region	temperature/ moisture	stability	associated weather
mT	Gulf of Mexico, Caribbean Sea, western Atlantic	warm and humid entire year	unstable entire year	a. in winter usually moves northward bringing precipitation; b. in summer, hot and humid with frequent cumulus and thunderstorms
mT	subtropical Pacific	warm and humid entire year	stable entire year	a. in winter brings fog, drizzle; b. in summer ocassionally reaches western U.S., moisture source

(Source: The Atmosphere, Lutgens & Tarbuck, 2004, 9th ed.)

Geoscience: Coriolis Force

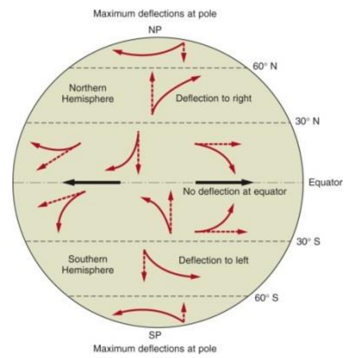
Coriolis force: an inertial force that acts on objects that are in motion relative to a rotating reference frame; in a reference frame with clockwise rotation, force acts to the left of the motion of the object; in one with anticlockwise rotation, force acts to the right

Coriolis force $F_{co} = 2\nu\Omega\sin\phi$

ν = wind speed

Ω = Earth’s angular velocity, 7.29×10^{-5} radians/second

ϕ = latitude



(Image source: http://www.geogrify.net/GEO1/Lectures/Circulation/AirPressure.html)

Geoscience: International Standard Atmosphere (1)

elevation z (m)	temper-ature T (K)	pressure p (bar)	relative density ρ/ρ_o	kinematic viscosity $\nu \times 10^{-5}$ (m^2/s)	thermal conductivity $k \times 10^{-2}$ (W/m K)	speed of sound c (m/s)
-2000	301.2	1.2778	1.2067	1.253	2.636	347.9
-1500	297.9	1.2070	1.1522	1.301	2.611	346.0
-1000	294.7	1.1393	1.0996	1.352	2.585	344.1
-500	291.4	1.0748	1.0489	1.405	2.560	342.2
0	288.15	1.01325	1.0000	1.461	2.534	340.3
500	284.9	0.9546	0.9529	1.520	2.509	338.4
1000	281.7	0.8988	0.9075	1.581	2.483	336.4
1500	278.4	0.8456	0.8638	1.646	2.457	334.5
2000	275.2	0.7950	0.8217	1.715	2.431	332.5
2500	271.9	0.7469	0.7812	1.787	2.405	330.6
3000	268.7	0.7012	0.7423	1.863	2.379	328.6

Geoscience: Standard Atmosphere (2)

elevation z (m)	temper-ature T (K)	pressure p (bar)	relative density ρ/ρ_o	kinematic viscosity $\nu \times 10^{-5}$ (m^2/s)	thermal conductivity $k \times 10^{-2}$ (W/m K)	speed of sound c (m/s)
3500	265.4	0.6578	0.7048	1.943	2.353	326.6
4000	262.2	0.6166	0.6689	2.028	2.327	324.6
4500	258.9	0.5775	0.6343	2.117	2.301	322.6
5000	255.7	0.5405	0.6012	2.211	2.275	320.5
5500	252.4	0.5054	0.5694	2.311	2.248	318.5
6000	249.2	0.4722	0.5389	2.416	2.222	316.5
6500	245.9	0.4408	0.5096	2.528	2.195	314.4
7000	242.7	0.4111	0.4817	2.646	2.169	312.3
7500	239.5	0.3830	0.4549	2.771	2.142	310.2
8000	236.2	0.3565	0.4292	2.904	2.115	308.1
8500	233.0	0.3315	0.4047	3.046	2.088	306.0

Geoscience: International Standard Atmosphere (3)

elevation z (m)	temper-ature T (K)	pressure p (bar)	relative density ρ/ρ_o	kinematic viscosity $\nu \times 10^{-5}$ (m^2/s)	thermal conductivity $k \times 10^{-2}$ (W/m K)	speed of sound c (m/s)
9000	229.7	0.3080	0.3813	3.196	2.061	303.8
9500	226.5	0.2858	0.3589	3.355	2.034	301.7
10000	223.3	0.2650	0.3376	3.525	2.007	299.8
10500	220.0	0.2454	0.3172	3.706	1.980	297.4
11000	216.8	0.2270	0.2978	3.899	1.953	295.2
11500	216.7	0.2098	0.2755	4.213	1.952	295.1
12000	216.7	0.1940	0.2546	4.557	1.952	295.1
12500	216.7	0.1793	0.2354	4.930	1.952	295.1
13000	216.7	0.1658	0.2176	5.333	1.952	295.1
13500	216.7	0.1533	0.2012	5.768	1.952	295.1
14000	216.7	0.1417	0.1860	6.239	1.952	295.1

Geoscience: International Standard Atmosphere (4)

elevation z (m)	temper-ature T (K)	pressure p (bar)	relative density ρ/ρ_o	kinematic viscosity $\nu \times 10^{-5}$ (m^2/s)	thermal conductivity $k \times 10^{-2}$ (W/m K)	speed of sound c (m/s)
14500	216.7	0.1310	0.1720	6.749	1.952	295.1
15000	216.7	0.1211	0.1590	7.300	1.952	295.1
15500	216.7	0.1120	0.1470	7.895	1.952	295.1
16000	216.7	0.1035	0.1359	8.540	1.952	295.1
16500	216.7	0.09572	0.1256	9.237	1.952	295.1
17000	216.7	0.08850	0.1162	9.990	1.952	295.1
17500	216.7	0.08182	0.1074	10.805	1.952	295.1
18000	216.7	0.07565	0.09930	11.686	1.952	295.1
18500	216.7	0.06995	0.09182	12.639	1.952	295.1
19000	216.7	0.06467	0.08489	13.670	1.952	295.1
19500	216.7	0.05980	0.07850	14.784	1.952	295.1

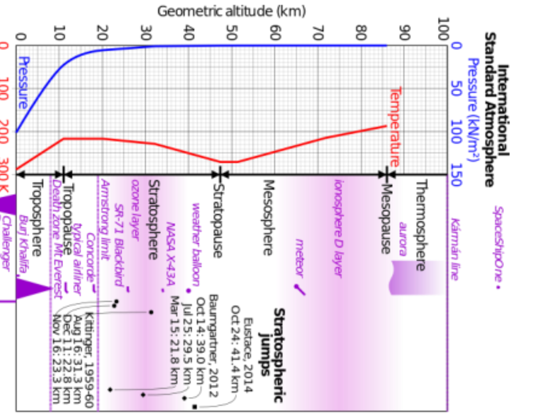
Geoscience: International Standard Atmosphere (5)

elevation z (m)	temper-ature T (K)	pressure p (bar)	relative density ρ/ρ_o	kinematic viscosity $\nu \times 10^{-5}$ (m^2/s)	thermal conductivity $k \times 10^{-2}$ (W/m K)	speed of sound c (m/s)
20000	216.7	0.05529	0.07258	15.989	1.952	295.1
22000	218.6	0.04047	0.05266	22.201	1.968	296.4
24000	220.6	0.02972	0.03832	30.743	1.985	297.7
26000	222.5	0.02188	0.02797	42.439	2.001	299.1
28000	224.5	0.01616	0.02047	58.405	2.018	300.4
30000	226.5	0.01197	0.01503	80.134	2.034	301.7

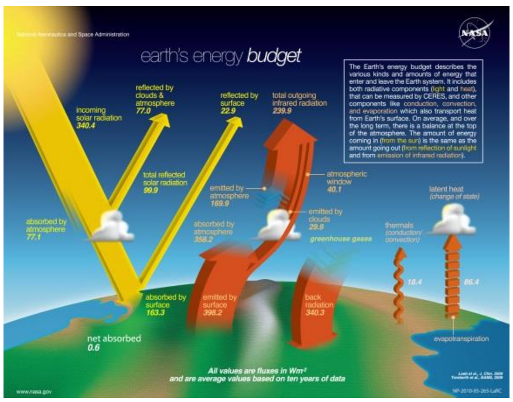
(Source: https://en.wikipedia.org/wiki/International_Standard_Atmosphere)

Geoscience: International Standard Atmosphere (6)

(Image source: https://en.wikipedia.org/wiki/International_Standard_Atmosphere#/media/File:Comparison_International_Standard_Atmosphere_space_diving.svg, Author: Cmglee, CC BY-SA 3.0)



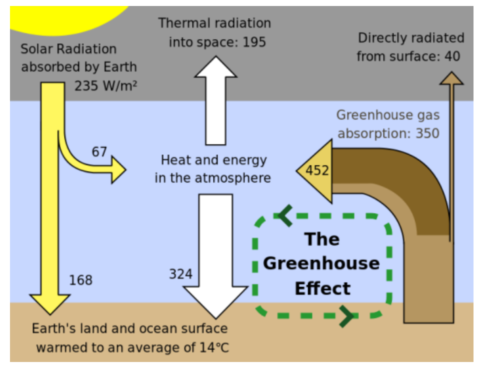
Geoscience: Earth's Energy Budget



(Image source: https://upload.wikimedia.org/wikipedia/commons/b/bb/The-NASA-Earth%27s-Energy-Budget-Poster-Radiant-Energy-System-satellite-infrared-radiation-fluxes.jpg, Author: NASA, public domain)

Geoscience: Greenhouse Effect

greenhouse effect: the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without its atmosphere



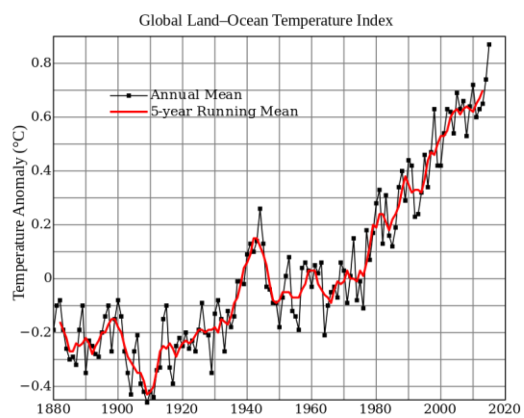
(Image source: https://en.wikipedia.org/wiki/Greenhouse_effect#/media/File:Greenhouse_Effect.svg, Author: Robert A. Rohde, GDFL 1.2)

Geosciences: Global Warming and Climate Change (1)

Global warming and climate change are terms for the observed century-scale rise in the average temperature of the Earth's climate system and its related effects. Multiple lines of scientific evidence show that the climate system is warming. Although the increase of near-surface atmospheric temperature is the measure of global warming often reported in the popular press, most of the additional energy stored in the climate system since 1970 has gone into the oceans. The rest has melted ice and warmed the continents and atmosphere. Many of the observed changes since the 1950s are unprecedented over tens to thousands of years.

(Source: https://en.wikipedia.org/wiki/Global_warming)

Geosciences: Global Warming and Climate Change (2)



(Image source: https://en.wikipedia.org/wiki/Global_warming#/media/File:Global_Temperature_Anomaly.svg, Author: NASA, public domain)

Geoscience: Earth's Spheres

asthenosphere: Earth layer is between 100 and 200 km below the surface, but may extend as deep as 400 km, the weak or soft zone in the upper mantle

biosphere: the sum of all ecosystems integrating all living beings and their relationships, interaction with the elements of the lithosphere, hydrosphere, and atmosphere

cryosphere: the sphere consists of portions of Earth's surface covered by sea ice, lake ice, river ice, snow cover, glaciers, ice caps and ice sheets, and frozen ground

hydrosphere:

lithosphere: Earth's solid, outermost layer and includes the crust and the uppermost mantle; lies above the asthenosphere

pedosphere: Outermost layer of the Earth that is composed of soil and subject to soil formation processes; exists at the interface of the lithosphere, atmosphere, hydrosphere and biosphere

Geoscience: Carbon Cycle (1)

carbon dioxide produced when carbon compounds burned :

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

carbon dioxide as a by-product of sugar fermentation:

$C_6H_{12}O_6(aq) \rightarrow 2C_2Cl_2H_5OH(aq) + 2CO_2(g)$

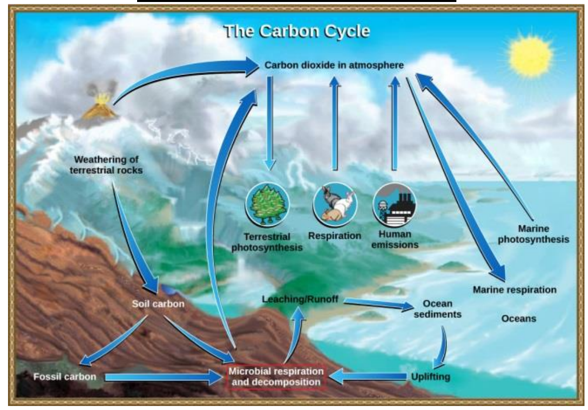
carbohydrates consumed by animals, which release carbon dioxide:

$C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$

carbon dioxide removed from the atmosphere by photosynthetic plants and certain microorganisms:

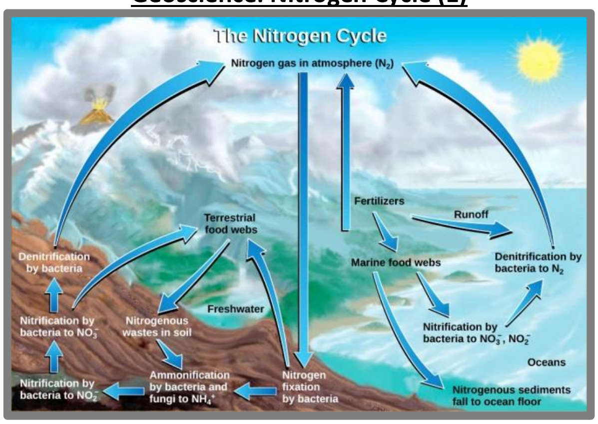
$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$

Geoscience: Carbon Cycle (2)



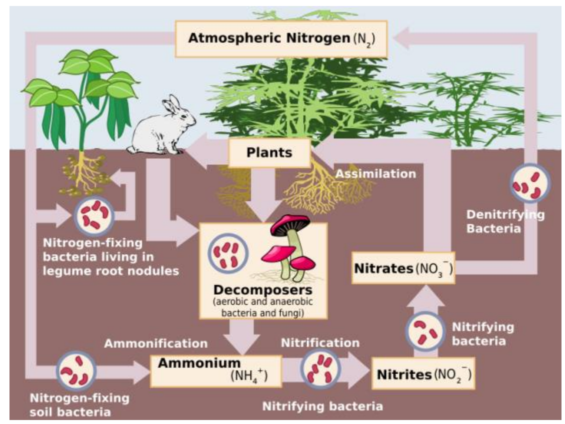
(Image source: USGS, Authors: John M. Evans and Howard Perlman, public domain)

Geoscience: Nitrogen Cycle (1)



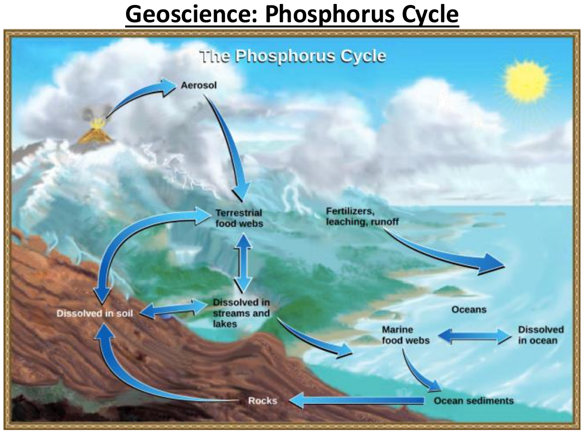
(Image source: USGS, Authors: John M. Evans and Howard Perlman, public domain)

Geoscience: Nitrogen Cycle (2)



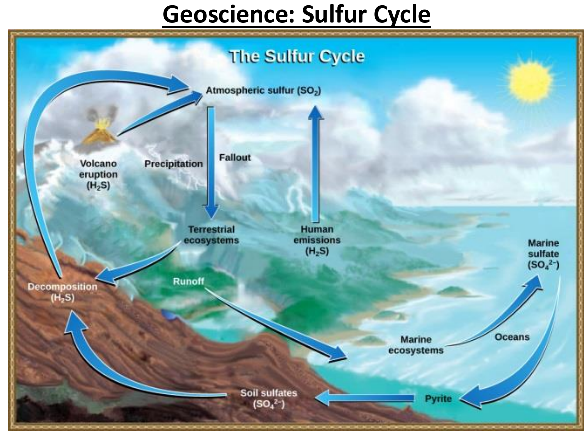
(Image source: https://en.wikipedia.org/wiki/Nitrogen_cycle#/media/File:Nitrogen_Cycle.svg, Author: Johann Dréo, CC BY-SA 3.0)

Geoscience: Phosphorus Cycle



(Image source: USGS, Authors: John M. Evans and Howard Perlman, public domain)

Geoscience: Sulfur Cycle



(Image source: USGS, Authors: John M. Evans and Howard Perlman, public domain)

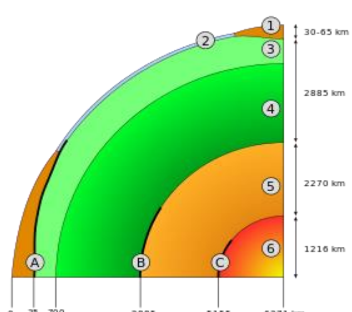
Geoscience: Earth's Structure

1. continental crust
2. oceanic crust
3. upper mantle
4. lower mantle
5. outer core
6 inner core

A: Mohorovičić discontinuity

B. Gutenberg Discontinuity

C: Lehmann–Bullen discontinuity



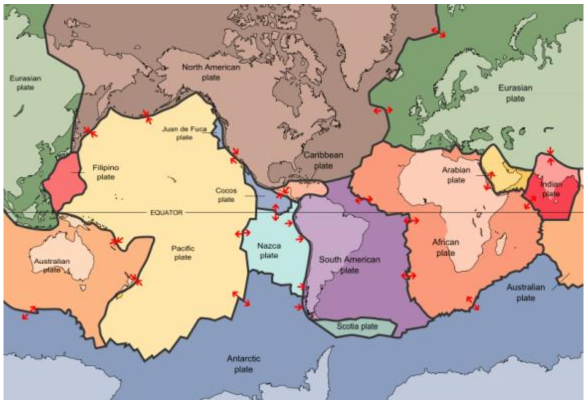
(Image source: https://en.wikipedia.org/wiki/Structure_of_the_Earth , Author: Dake, CC BY-SA 2.5)

Geoscience: Geologic Processes

uniformitarianism: the assumption that the same natural laws and processes that operate in the universe now have always operated in the universe in the past and apply everywhere in the universe, processes include plate tectonics, erosion, glaciation, drought, desertification

catastrophism: theory that the Earth has been affected in the past by sudden, short-lived, violent events, possibly worldwide in scope processes include earthquakes, meteorite impacts, floods, tsunamis, blizzards, fires, hurricanes, tornadoes

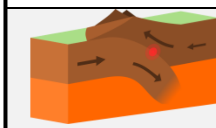
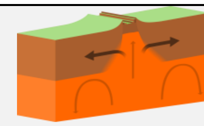
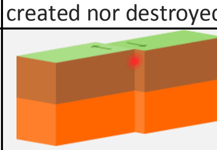
Geoscience: Earth Plates



(Image source: https://en.wikipedia.org/wiki/Plate_tectonics#/media/File:Plates_tect2_en.svg, Author: USGS, public domain)

Geoscience: Plate Tectonics

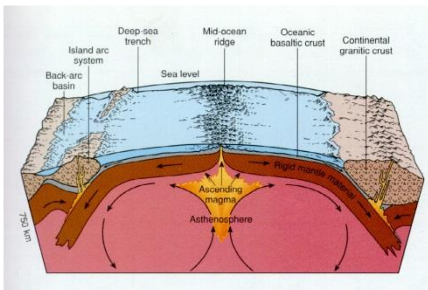
plate tectonics: theory that Earth's surface is made of pieces that move, collide, and slide past each other, resulting in earthquakes and volcanoes

convergent boundary	divergent boundary	transform boundary
two plates slide toward each other to form a subduction zone or a continental collision	two plates slide away from each other	two plates slide past each other along transform faults, where plates are neither created nor destroyed
		

(Images source: https://en.wikipedia.org/wiki/Plate_tectonics, Author Domdomegg, CC BY 4.0)

Geoscience: Sea Floor Spreading

sea floor spreading: process that occurs at mid-ocean ridges, where new oceanic crust is formed through volcanic activity and then gradually moves away from the ridge. Seafloor spreading helps explain continental drift in the theory of plate tectonics



Source: https://en.wikipedia.org/wiki/Seafloor_spreading) (Image source : https://blueteamscience.files.wordpress.com/2014/06/seafloor.jpg)

Geoscience:

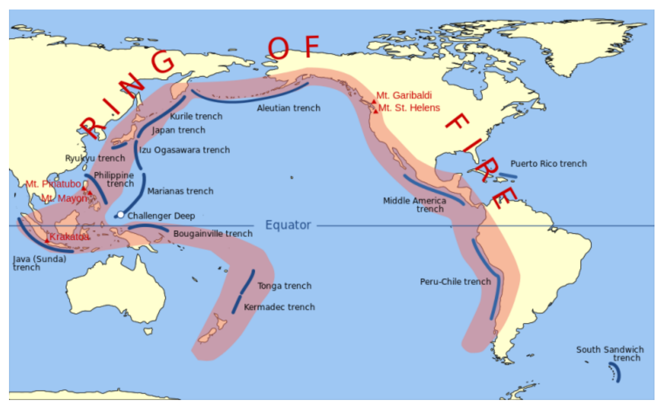
Geoscience: Earthquakes

- longitudinal P-waves (shock- or pressure waves): first waves from an earthquake to arrive at a seismograph; "P" can stand for either pressure as it is formed from alternating compressions and rarefactions or primary, since it has the highest velocity
- transverse S-waves (both body waves): moves as a shear or transverse wave, so motion is perpendicular to the direction of wave propagation; "S" can stand for either shear or secondary
- surface waves (Rayleigh and Love waves): span a wide frequency range, and the period of waves that are most damaging is usually 10 seconds or longer; can travel around the globe many times from the largest earthquakes; are caused when P waves and S waves come to the surface

(Source: https://en.wikipedia.org/wiki/Earthquake#Induced_seismicity)

Geoscience: Ring of Fire

(Image source: https://en.wikipedia.org/wiki/Ring_of_Fire#/media/File:Pacific_Ring_of_Fire.svg, Author: Gringer , public domain)



Geoscience: Richter Scale (1)

magni-tude	descrip-tion	Mercalli intensity	average earthquake effects	average estimated frequency
1.0–1.9	micro	I	microearthquakes, rarely felt if at all;. recorded by seismographs	several million/year
2.0–2.9	minor	I to II	felt slightly by some people; no building damage	over one million/year
3.0–3.9		III to IV	often felt, rarely causes damage; shaking of indoor objects noticeable	over 100,000/year
4.0–4.9	light	IV to VI	noticeable shaking of indoor objects; felt by most people in area; slightly felt outside; no to minimal damage	10,000 to 15,000/year
5.0–5.9	mod-erate	VI to VIII	can cause damage to poorly constructed buildings; no to slight damage to other buildings; felt by everyone	1,000 to 1,500/year

Geoscience: Richter Scale (2)

magni-tude	descrip-tion	Mercalli intensity	average earthquake effects	average estimated frequency
6.0–6.9	strong	VII to X	well-built structures damaged; poorly designed structures severe damage	100 to 150/year
7.0–7.9	major	VIII or greater	most buildings damaged, some collapse; well-designed structures likely damaged	10 to 20/year
8.0–8.9	great		major building damage; damage to earthquake-resistant buildings; felt in large regions	one/year
9.0 and greater			at or near total destruction; severe damage to all buildings; permanent changes in ground topography	one per 10 to 50 years

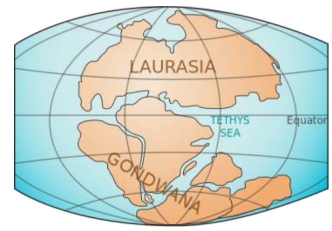
(Source: https://en.wikipedia.org/wiki/Richter_magnitude_scale)

Geoscience: Ancient Tectonic Plates (1)

- Columbia: likely existed approximately 2.5 to 1.6 billion years ago in Paleoproterozoic Era; assembly may have been completed by global-scale collisional events during 2.1–1.8 Ga; consisted of proto-cratons that made up cores of continents of Laurentia, Baltica, Ukrainian Shield, Amazonian Shield, Australia, and possibly Siberia, North China, and Kalaharia
- Euramerica: minor supercontinent created in Devonian by collision between the Laurentian, Baltica, and Avalonia cratons 433 million years ago
- Gondwana: believed to have sutured between about 570 and 510 million years ago; joined East Gondwana to West Gondwana. Gondwana formed prior to Pangaea, and later became part of it
- Kenorland: thought to have formed during Neoarchaean Era c. 2.72 billion years ago by accretion of Neoarchaean cratons and formation of new continental crust; comprised what later became Laurentia, Baltica, Western Australia and Kalaharia

Geoscience: Ancient Tectonic Plates (2)

- Laurasia: the more northern of two supercontinents, with Gondwana, that formed part of the Pangaea supercontinent around 335 to 175 million years ago; it separated from Gondwana 215 to 175 Mya, beginning in the late Triassic period, during the breakup of Pangaea, drifting farther north after the split
- Nena: ancient minor supercontinent that consisted of the cratons of Arctica, Siberia, Baltica, and East Antarctica; it formed about 1.95 billion years ago but became part of the global supercontinent Columbia around 1.82 billion years ago



TRIASSIC
200 million years ago

(Image source: https://en.wikipedia.org/wiki/Laurasia#/media/File:Laurasia-Gondwana.svg, Author: LennyWikidata, CC BY 3.0)

Geoscience: Ancient Tectonic Plates (3)

- Pangaea: supercontinent that existed during the late Paleozoic and early Mesozoic eras; assembled from earlier continental units approximately 335 Mya; it began to break apart about 175 million years ago; much of Pangaea was in the southern hemisphere and surrounded by a superocean, Panthalassa; last supercontinent to have existed and first to be reconstructed by geologists

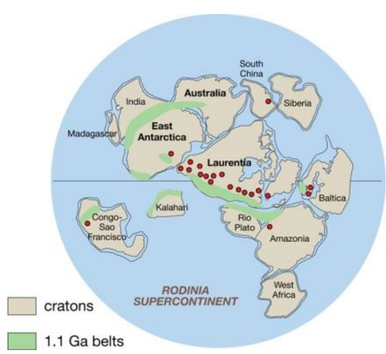
(Image source: https://en.wikipedia.org/wiki/Pangaea#/media/File:Pangaea_continents.svg, Author: Kieff, CC BY-SA 3.0)

Geoscience: Ancient Tectonic Plates (4)

- Pannotia: was a relatively short-lived Neoproterozoic supercontinent that formed at the end of the Precambrian during the Pan-African orogeny, 650–500 Ma and broke apart 560 Ma with the opening of the Iapetus Ocean; formed when Laurentia was located adjacent to the two major South American cratons, Amazonia and Río de la Plata; the opening of the Iapetus Ocean separated Laurentia from Baltica, Amazonia, and Río de la Plata
- Proto-Laurasia: Laurasia is known as a Mesozoic phenomenon, but today it is believed that the same continents that formed the later Laurasia also existed as a coherent supercontinent after the breakup of Rodinia around 750 million years ago; this is referred to as Proto-Laurasia

Geoscience: Ancient Tectonic Plates (5)

- Rodinia: Neoproterozoic supercontinent that was assembled 1.3–0.9 billion years ago and broke up 750–600 million years ago; formed formed at c. 1.0 Ga by accretion and collision of fragments produced by breakup of an older supercontinent, Columbia, assembled by global-scale 2.0–1.8 Ga collisional events



(Image source: https://en.wikipedia.org/wiki/Rodinia#/media/File:Rodinia_reconstruction.jpg, Author: John Goodge, public domain)

Geoscience: Ancient Tectonic Plates (6)

- Ur: proposed supercontinent that formed in the Archean 3.1 billion years ago
- Vaalbara: an Archean supercontinent that consisted of the Kaapvaal craton, today located in eastern South Africa, and the Pilbara craton, today found in north-western Western Australia; the two cratons are made of 3.6±2.7 Ga-old crust, making Vaalbara the oldest supercontinent on Earth

(Source: https://en.wikipedia.org/wiki/List_of_tectonic_plates)

Geosciences: Craters

- impact: caused by two celestial bodies impacting each other, such as a meteorite hitting a planet
- volcanic: roughly circular depression in the ground caused by volcanic activity
- caldera: large cauldron-like depression formed following the evacuation of a magma chamber/reservoir
- subsidence: from an underground (usually nuclear) explosion
- maar: a relief crater caused by a phreatic eruption or explosion
- pit: crater that forms through sinking of the surface,not as a vent for lava
- crater lake: a lake that forms in a volcanic crater or caldera
- explosion: a hole formed in the ground produced by an explosion near or below the surface
- machtesh: a crater-like formation created by erosion

(Source: https://en.wikipedia.org/wiki/Crater)

Geoscience: Volcanoes (1)

hot spot: volcanic area formed by mantle plumes, columns of hot material rising from the core-mantle boundary in a fixed space that causes large-volume melting
fissure vent: linear volcanic vent through which lava erupts, usually without explosive activity; often a few meters wide, may be many kilometers long; can cause large flood basalts which run first in lava channels and lava tubes
shield volcano: built of fluid lava flows; named for low profile, resembling a warrior's shield lying on the ground; steady accumulation of broad sheets of lava; low viscosity of mafic lava
lava dome: roughly circular mound-shaped protrusion resulting from slow extrusion of viscous lava; most preserved domes have high silica content; high viscosity preventing lava from flowing very far

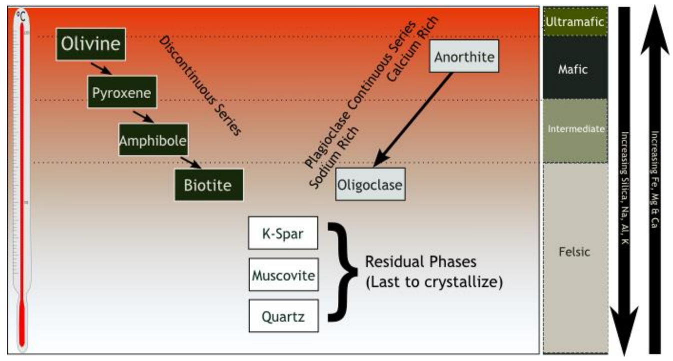
Geoscience: Volcanoes (2)

cryptodome: formed when viscous lava is forced upward causing the surface to bulge; lava beneath the surface of the mountain created an upward bulge which slid down the north side of the mountain
cinder cone: built by ejecta from a volcanic vent, piling up around the vent in the shape of a cone with a central crater; are of different types, depending upon the nature and size of the fragments ejected during the eruption; types include stratocones, spatter, tuff, and cinder
stratovolcano: conical, built up by many layers of hardened lava, tephra, pumice, and volcanic ash; characterized by a steep profile and periodic explosive eruptions and effusive eruptions; some have collapsed craters called calderas

Geoscience: Volcanoes (3)

supervolcano: produces a volcanic eruption with an ejecta mass greater than 10^{15} kg (10^{12} t); occurs when magma in the mantle rises into the crust but unable to break through; pressure builds in a large magma pool until the crust can't contain the pressure
submarine volcano: underwater vents or fissures in the Earth's surface from which magma can erupt; many located near areas of tectonic plate movement, known as mid-ocean ridges, which are estimated to account for 75% of Earth's magma output
subglacial volcano: produced by eruptions beneath a glacier or ice sheet, melted into a lake by rising lava
mud volcano: formations created by geo-exuded mud or slurries, water, and gases; not true igneous volcanoes; produce no lava
(Source: https://en.wikipedia.org/wiki/Volcano)

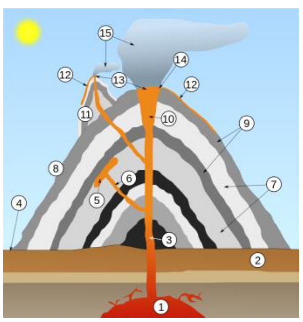
Geoscience: Bowen Reaction Series



(Image source: https://en.wikipedia.org/wiki/Bowen%27s_reaction_series#/media/File:Bowen%27s_Reaction_Series.png, Author: Colivine, CC0)

Geoscience: Stratovolcano

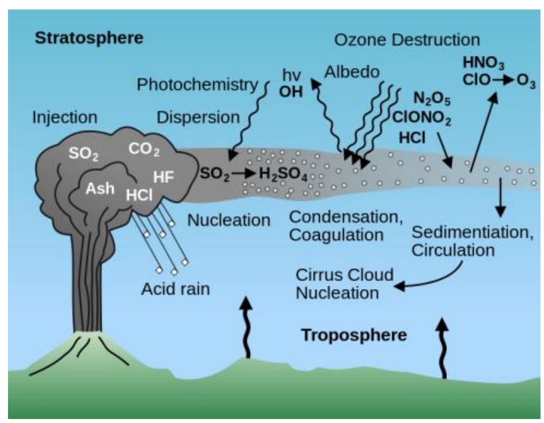
1. **large magma chamber**
2. **bedrock**
3. **conduit (pipe)**
4. **base** 5. **sill**
6. **dike**
7. **layers of ash emitted by the volcano**
8. **flank**
9. **layers of lava emitted by the volcano**
10. **throat**
11. **parasitic cone**
12. **lava flow**
13. **vent** 14. **crater**
15. **ash cloud**



(Image source: https://en.wikipedia.org/wiki/Volcano#/media/File:Volcano_scheme.svg, Author: MesserWoland, CC BY-SA 3.0)

Geoscience: Effects of Volcanoes

(Image source: https://en.wikipedia.org/wiki/Volcano#/media/File:Volcanic_injection.svg, Author: cflm, public domain)

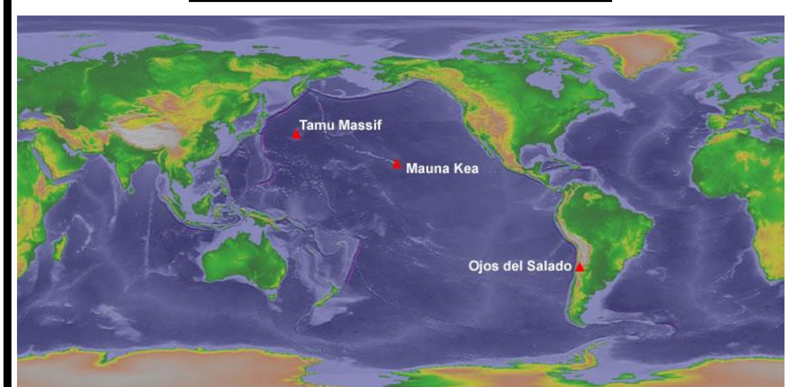


Geoscience: Earth's Largest Volcanoes (1)

name	description	location	dimensions	last eruption
Tamu Massif	most massive	under the Pacific, about 1,600 km east of Japan	volume 2.5 million km^3; 310,800 km^2 footprint	144 million years ago
Mauna Kea	tallest	Big Island of Hawai'i, home to the highest observatories in the world	base is 6,000 m below sea level; summit 4,205 m above sea level	3,600 years ago
Ojos del Salado	highest summit elevation	Argentina-Chile border near the Atacama Desert	6,893 m high	1,300 years ago

(Source: http://geology.com/records/largest-volcano/)

Geology: Earth's Largest Volcanoes (2)



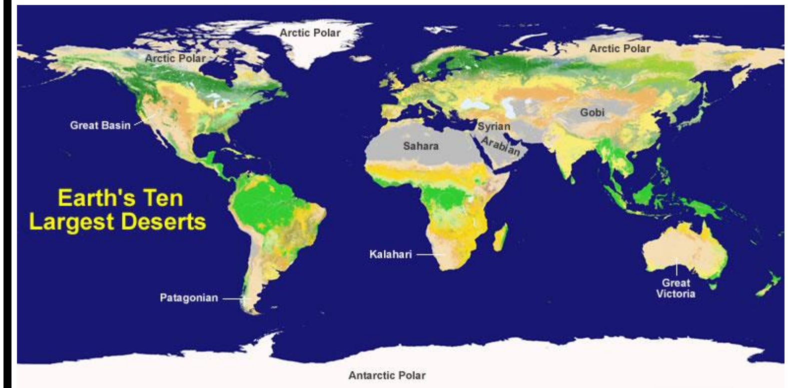
(Image source: http://geology.com/records/largest-volcano/)

Geology: Earth's 10 Largest Deserts (1)

name	type of	surface area	location
Antarctic	polar	5.5 million mi^2	Antarctica
Arctic	polar	5.4 million mi^2	Alaska, Canada, Greenland, Iceland, Norway, Sweden, Finland, Russia
Sahara	subtropical	3.5 million mi^2	Northern Africa
Arabian	subtropical	1 million mi^2	Arabian Peninsula
Gobi	cold winter	500,000 mi^2	China, Mongolia
Patagonian	cold winter	260,000 mi^2	Argentina
Great Victoria	subtropical	250,000 mi^2	Australia
Kalahari	subtropical	220,000 mi^2	South Africa, Botswana, Namibia
Great Basin	cold winter	190,000 mi^2	United States
Syrian	subtropical	190,000 mi^2	Syria, Iraq, Jordan, Saudi Arabia

(Source: http://geology.com/records/largest-desert.shtml)

Geoscience: Earth's 10 Largest Deserts (2)



(Image source: http://geology.com/records/largest-desert.shtml, Author: NOAA, public domain)

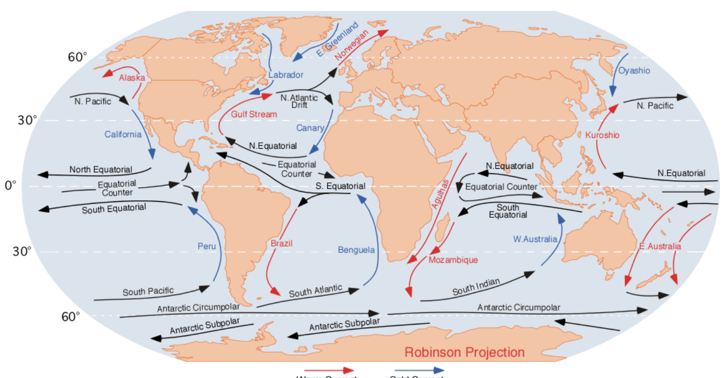
Geoscience: Continents and Oceans

(Image source: https://ourhomeworkhelp.wordpress.com/category/maps/, free for personal and educational use)

Geoscience: Oceans

ocean	area (km^2) / (%)	volume (km^3) / (%)
Pacific	168,723,000 / 46.6	669,880,000 / 50.1
Atlantic	85,133,000 / 23.5	310,410,900 / 23.3
Indian	70,560,000 / 19.5	264,000,000 / 19.8
Southern	21,960,000 / 6.1	71,800,000 / 5.4
Arctic	15,558,000 / 4.3	18,750,000 / 1.4

Geoscience: Ocean Currents



(Image source: https://en.wikipedia.org/wiki/Ocean_current#/media/File:Corrientes-oceanicas.png, Author: Dr. Michael Pidwirny, public domain)

Geoscience: Waves

wave	period	wavelength	wave type	cause
capillary	<0.1 s	< 2 cm	deep or shallow	local winds
chop	1 s - 10 s	1 m – 10 m	deep or shallow	local winds
swell	10 s - 30 s	up to hundreds of m	deep or shallow	distant storm
seiche	10 m – 10 hr	up to hundreds of km	shallow	wind, tsunami, tidal resonance
tsunami	10 min – 60 min	up to hundreds of km	shallow	submarine disturbance
tide	12.4 hr – 24.8 hr	thousands of km	shallow	gravitational attraction of Sun and Moon
internal	min to hr	up to hundreds of km	deep or shallow	disturbance at pycnocline

(Source: Oceanography, Paul R. Pinet, p. 202)

Geoscience: Earth's 10 Longest Rivers (1)

river	length (km)	drainage area (km^2)	average discharge (m^3/	outflow to	location
Amazon–Ucayali–Apurímac	6,992	7,050,000	209,000	Atlantic Ocean	South America
Nile–Kagera	6,853	3,254,555	2,800	Mediterr-anean	Africa
Yangtze	6,300	1,800,000	31,900	East China Sea	China
Mississippi–Missouri–Jefferson	6,275	2,980,000	16,200	Gulf of Mexico	U.S., Canada
Yenisei–Angara–Selenge	5,539	2,580,000	19,600	Kara Sea	Russia Mongolia

Geoscience: Earth's 10 Longest Rivers (2)

river	length (km)	drainage area (km^2)	average discharge (m^3/	outflow to	location
Yellow River	5,464	745,000	2,110	Bohai Sea	China
Ob–Irtysh	5,410	2,990,000	12,800	Gulf of Ob	Russia, Kazakhstan, China, Mongolia
Paraná – Río de la Plata	4,880	2,582,672	18,000	Río de la Plata	South America
Congo–Chambeshi	4,700	3,680,000	41,800	Atlantic Ocean	Africa
Amur–Argun	4,444	1,855,000	11,400	Sea of Okhotsk	Russia, China, Mongolia

(Source: https://en.wikipedia.org/wiki/List_of_rivers_by_length)

Geoscience: Earth's Biggest Lakes (1)

name	countries with shoreline	area (km^2)	length (km)	maximum depth (m)	water volume (km^3)
Caspian Sea	Kazakhstan, Russia, Turkmenistan, Azerbaijan, Iran	436,000	1,199	1,025	78,200
Superior	Canada, United States	82,100	616	406.3	12,100
Victoria	Uganda, Kenya, Tanzania	68,870	322	84	2,750
Huron	Canada, United States	59,600	332	229	3,540
Michigan	United States	58,000	494	281	4,900

Geoscience: Earth's Biggest Lakes (2)

name	countries with shoreline	area (km^2)	length (km)	maximum depth (m)	water volume (km^3)
Tanganyika	Burundi, Tanzania, Zambia, Democratic Republic of the Congo	32,600	676	1,470	18,900
Baikal	Russia	31,500	636	1,637	23,600
Great Bear Lake	Canada	31,000	373	446	2,236
Malawi	Malawi, Mozambique, Tanzania	29,500	579	706	8,400
Great Slave	Canada	27,000	480	614	1,560

(Source: https://en.wikipedia.org/wiki/List_of_lakes_by_area)

Geoscience: Water Cycle (1)

1. The water cycle has no starting point, but we can begin in the oceans, since that is where most of Earth's water exists.
2. The sun, which drives the water cycle, heats water in the oceans.
3. Some of it evaporates as vapor into the air; a relatively smaller amount of moisture is added as ice and snow sublimate directly from the solid state into vapor.
4. Rising air currents take the vapor up into the atmosphere, along with water from evapotranspiration, which is water transpired from plants and evaporated from the soil.
5. The vapor rises into the air where cooler temperatures cause it to condense into clouds.
6. Air currents move clouds around the globe, and cloud particles collide, grow, and fall out of the sky as precipitation.

Geoscience: Water Cycle (2)

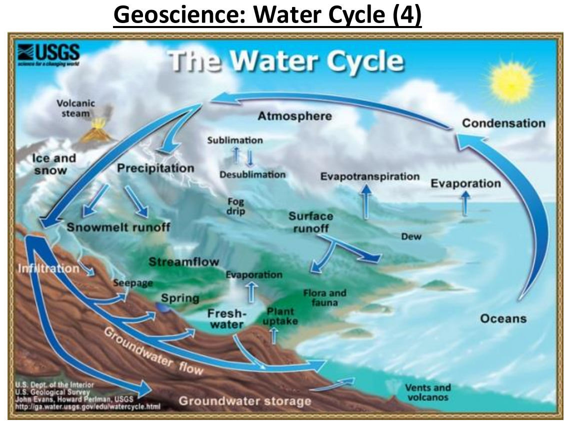
7. Some precipitation falls as snow and can accumulate as ice caps and glaciers, which can store frozen water for thousands of years.
8. Snowpacks in warmer climates often thaw and melt when spring arrives, and the melted water flows overland as snowmelt.
9. Most precipitation falls back into the oceans or onto land, where, due to gravity, the precipitation flows over the ground as surface runoff.
10. A portion of runoff enters rivers in valleys in the landscape, with streamflow moving water towards the oceans.
11. Runoff, and groundwater seepage, accumulate and are stored as freshwater in lakes.
12. Not all runoff flows into rivers, though. Much of it soaks into the ground as infiltration

Geoscience: Water Cycle (3)

13. Some of the water infiltrates into the ground and replenishes aquifers (saturated subsurface rock), which store huge amounts of freshwater for long periods of time.
14. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater discharge, and some groundwater finds openings in the land surface and emerges as freshwater springs.
15. Yet more groundwater is absorbed by plant roots to end up as evapotranspiration from the leaves.
16. Over time, though, all of this water keeps moving, some to reenter the ocean, where the water cycle "begins."

(Source: https://en.wikipedia.org/wiki/Water_cycle)

Geoscience: Water Cycle (4)



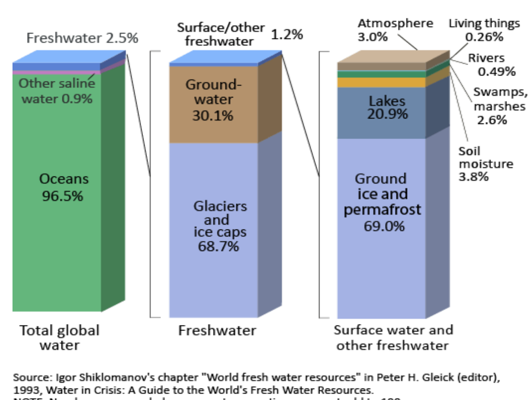
(Image source: https://water.usgs.gov/edu/watercycle.html, Authors: John Evans and Howard Periman, public domain)

Geoscience: Earth's Water (1)

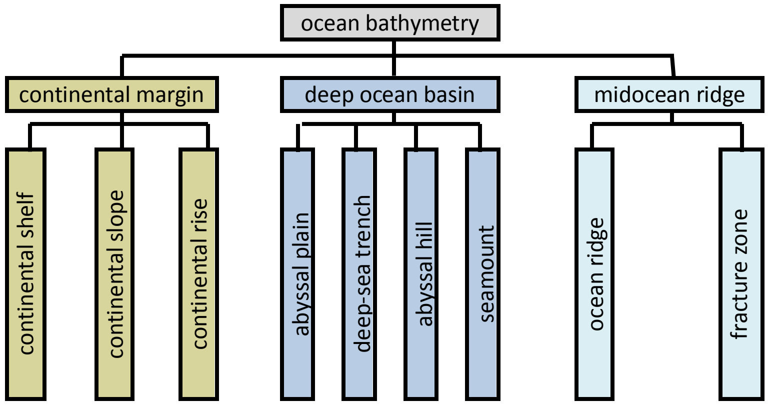
water source	volume in km^3	% of fresh	% of total
oceans, seas, & bays	1,338,000,000	--	96.5
ice caps, glaciers, permanent snow	24,064,000	68.7	1.74
ground water	23,400,000	--	1.69
fresh	10,530,000	30.1	0.76
saline	12,870,000	--	0.93
soil moisture	16,500	0.05	0.001
ground Ice, permafrost	300,000	0.86	0.022
lakes	176,400	--	0.013
fresh	91,000	0.26	0.007
saline	85,400	--	0.006
atmosphere	12,900	0.04	0.001
swamp water	11,470	0.03	0.0008
rivers	2,120	0.006	0.0002
biological water	1,120	0.003	0.0001

Geoscience: Earth's Water (2)

(Source for (1) and Image source: https://water.usgs.gov/edu/earthwherewater.html, public domain)



Geosciences: Bathrythmic Provinces



(Source: Oceanography, Paul R. Pinet, 1992, p. 31)

Geosciences: Continental Margin (1)

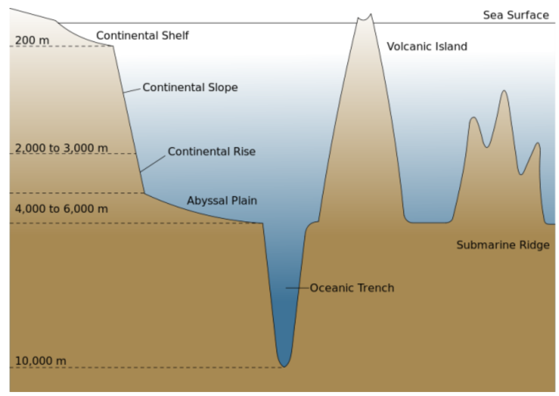
continental margin: comprises a steep continental slope followed by the flatter continental rise; sediment from the continent above cascades down the slope and accumulates as a pile of sediment at the base of the slope, called the continental rise

continental shelf: underwater landmass extending from a continent, resulting in an area of relatively shallow water; many shelves exposed during glacial and interglacial periods; shelf surrounding an island is known as an insular shelf

continental slope: plunges at an average angle of about 4^0 to water depths of 2 to 3 km; huge submarine canyons are cut into many continental slopes which are chutes for sediment transport from continental margins to deep ocean basins

continental rise: nearly flat plain bordering the continent; slopes gently toward the ocean basin; at the bottom of each continental slope, ocean floor flattens to a 1^0 gradient; some extend more than 500 km from the base to water depths approaching 4,000 m (Source: Oceans, Paul R. Pinet, 1992)

Geosciences: Continental Margin (2)



(Image source: https://en.wikipedia.org/wiki/Continental_rise#/media/File:Oceanic_basin.svg, Author: Chris_huh, public domain)

Geoscience: Deep-Ocean Basins (1)

deep ocean basin: varied topography; ranging from flat palns to towering, steep-sided mountain peaks

abyssal plain: flattest area on Earth; slope less than 1 meter per kilometer; broad aprons of land-derived sediments that have buried irregular, volcanic topography; sediment thickness of 100 m to more than 1,000 m

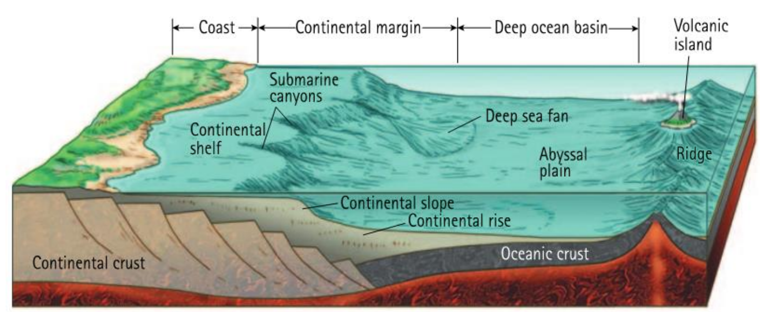
deep-sea trenches: relatively steep-sided narrow basins; can be 3 to 5 km deeper than the surrounding ocean floor; occur at the bases of continental slopes

abyssal hill: low dome or elongated hill no more than 900 m high and 100 m to 100 km wide; composed of volcanic rocks and may be covered by fine-grained sediment

seamount: extinct volcano, rises more than 900 m above the ocean floor; flat-topped seamounts, called guyots, were once volcanoes, but have eroded peaks

(Source: Oceans, Paul R. Pinet, 1992)

Geoscience: Deep-Ocean Basins (2)



(Image source: http://www.quasargroupconsulting.com/Encyclopedia/EarthScience/Geology/oceanBasin.php)

Geoscience: Midocean Ridge

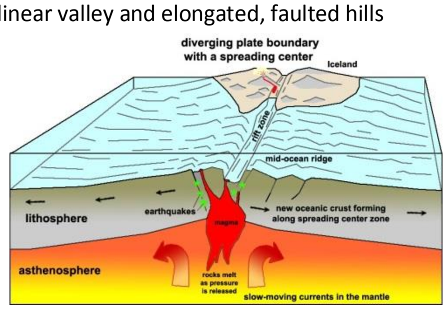
midoecean ridge: longest and most continuous mountain belt on Earth; extends for 60,000 km; occupies almost one-third of the ocean floor

ocean ridge: summit of each ridge is either broadly convex or occupied by a rift valley

fracture zone: parallel series of linear valley and elongated, faulted hills arranged perpendicular to the axid of midocean ridges; 10 to 100 km in length

(Source: Oceans, Paul R. Pinet, 1992)

(Image source: http://gotbooks.miracosta.edu/geology/images/spreading_center.jpg)



Geoscience: Deep Sea Trenches

trench	ocean	maximum depth
Mariana Trench	Pacific Ocean	11,034 m
Tonga Trench	Pacific Ocean	10,882 m
Philippine Trench	Pacific Ocean	10,545 m
Kuril–Kamchatka Trench	Pacific Ocean	10,542 m
Kermadec Trench	Pacific Ocean	10,047 m
Izu-Bonin Trench (Izu-Ogasawara Trench)	Pacific Ocean	9,810 m
Japan Trench	Pacific Ocean	9,504 m
Puerto Rico Trench	Atlantic Ocean	8,800 m
South Sandwich Trench	Atlantic Ocean	8,428 m
Peru–Chile Trench or Atacama Trench	Pacific Ocean	8,065 m

(Source: https://en.wikipedia.org/wiki/Oceanic_trench)

Geoscience: Köeppen Climate Classification System (1)

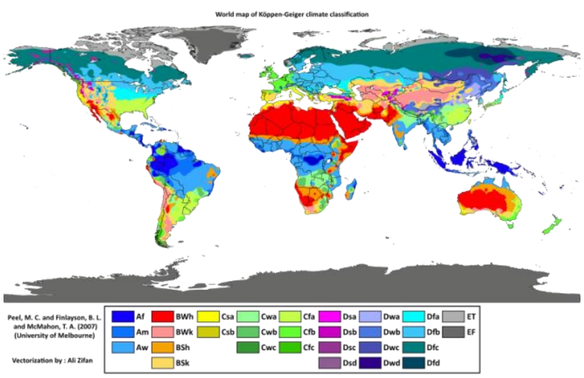
- Group A: Tropical/megathermal climates
  - Tropical rainforest (Af)
  - Tropical monsoon (Am)
  - Tropical wet and dry or savanna (Aw)
- Group B: Dry (arid and semiarid) climates
  - Desert BW: Hot desert (BWh), Cold desert (BWk)
  - Steppe climate (Semiarid) BS: Hot steppe (BSh), Cold steppe (BSk)
- Group C: Temperate/mesothermal climates
  - Dry-summer or Mediterranean climates (Csa, Csb,Csc)
  - Temperate or subtropical hot summer climates (Cfa, Cwa)
  - Maritime temperate climates or Oceanic climates (Cwb, Cwc, Cfb, Cfc)
  - Maritime subarctic climates or subpolar oceanic climate (Cfc)
  - Temperate highland climates with dry winters (Cwb, Cwc)

Geoscience: Köeppen Climate Classification (2)

- Group D: Continental/microthermal climates
  - Hot summer continental climates (Dsa, Dwa, Dfa)
  - Warm summer continental or hemiboreal climates (Dsb, DwbDfb)
  - Continental subarctic or boreal (taiga) climates (Dsc, Dwc, Dfc)
  - Continental subarctic climates with extremely severe winters (Dsd, Dwd, Dfd)
- Group E: Polar and alpine climates
  - Tundra climate (ET)
  - Ice cap climate (EF)

(Source: https://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification)

Geoscience: Köeppen Climate Classification (3)



(Image source: https://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification#/media/File:World_Koppen_Classification_(with_authors).svg, Authors: Peel, M. C., Finlayson, B. L., and McMahon, T. A., CC BY-SA 4.0)

Geoscience: Weather Systems (1)

region	name	pressure	weather and winds
Equator (0°)	Doldrums (ITCZ) (equatorial low)	low	cloudy, precipitation; hurricane breeding ground; light, variable
0°–30° N and S	Trade winds (easterlies)	-	summer wet, winter dry; pathway for tropical disturbances, NE in NH, SE in SH
30°N and S	Horse latitudes	high	light, variable
30°–60° N and S	Prevailing Westerlies		winter wet, summer dry; pathway for subtropical high and low pressure; SW in NH, NW in SH

Geoscience: Weather Systems (2)

region	name	pressure	weather and winds
60° N and S	Polar front	low	stormy, cloudy weather zone; ample precipitation; variable
60°–90° N and S	Polar easterlies	-	cold polar air with very low temperatures; NE in NH, SE in SH
90° N and S	Poles	high	cold, dry air, sparse participation, S in NH, N in SH

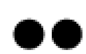
(Source: https://en.wikipedia.org/wiki/Weather)

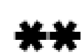
weather: state of the atmosphere, the degree that it is hot, cold, wet, dry, calm, stormy, clear, cloudy, refers to day-to-day temperature and precipitation activity

Geoscience: Weather Instruments

anemometer: measures wind speed
barometer: measures atmospheric pressure
hygrometer: measures the water vapor content in the air
pyranometer: measures solar irradiance and solar radiation flux density from the hemisphere above within a wavelength range 0.3 μm to 3 μm
rain gauge: measures the amount of fallen rain
sling psychrometer: measures relative humidity using the cooling effect of evaporation
thermometer: measures temperature
wind vane: indicates the direction from which the wind blows

Geoscience: Common Weather Map Symbols

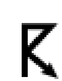

rain


snow


drizzle


rain showers


snow showers


thunderstorm


fog

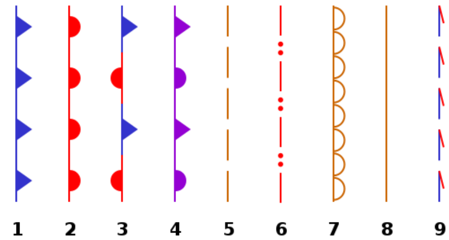
(Images source: http://www.srh.noaa.gov/jetstream/synoptic/wxmaps.html, National Oceanic and Atmospheric Administration, public domain)

Geoscience: Weather Fronts (1)

cold front: located at the leading edge of the temperature drop off; normally lies within a sharp surface trough
warm front: at the leading edge of a homogeneous warm air mass; moves more slowly than the cold front which usually follows
occluded front: formed when a cold front overtakes a warm front; usually forms around mature low-pressure areas
stationary front: a non-moving boundary between two air masses; tend to remain in the same area for extended periods of time
dry line: boundary between air masses with significant moisture differences
squall line: organized areas of thunderstorm activity not only reinforce pre-existing frontal zones, but can outrun cold fronts in a pattern where the upper level jet splits apart into two streams

Geoscience: Weather Fronts (2)

1. cold front
2. warm front
3. stationary front
4. occluded front
5. surface trough
6. squall/shear line
7. dry line
8. tropical wave
9. trowel



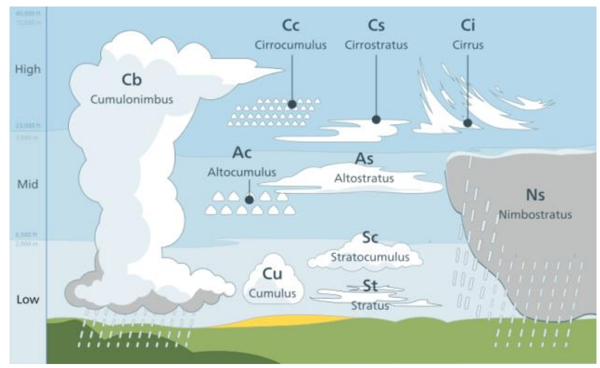
(Image source: https://en.wikipedia.org/wiki/Weather_front#/media/File:NWS_weather_fronts.svg, public domain)

Geoscience: Clouds (1)

classification of major types	stratiform	cirriform	strato-cumuliform	cumuliform	cumulo-nimbiform
extreme level (mesosphere)		nocti-lucent			
very high level (stratosphere)		nacreous			
high-level	cirrostratus	cirrus	layered cirrocumulus	tufted cirrocumulus	
mid-level	altostratus		layered altocumulus	tufted altocumulus	
low-level	stratus		strato-cumulus	small cumulus	
multi-level/vertical	nimbo-stratus			moderate cumulus	
towering vertical				towering cumulus	cumulo-nimbus

Geoscience: Clouds (2)

(Source for (1) and image source: https://en.wikipedia.org/wiki/List_of_cloud_types#/media/File:Cloud_types_en.svg, Author: Valentin de Bruyn, CC BY-SA 3.0)



Geoscience: Precipitation

type	size	state	description
mist	0.0005 to 0.05 mm	liquid	large enough to be felt
drizzle	less than 0.5 mm	liquid	small, uniform, from stratus clouds
rain	0.5 to 5 mm	liquid	produced by nimbostratus or cumulonimbus clouds
sleet	0.5 to 5 mm	solid	small, spherical or lumpy ice particles
glaze	layers 1 mm to 2 mm	solid	supercooled raindrops freeze
rime	variable	solid	ice feathers that point into the wind
snow	1 mm to 2 mm	solid	crystalline, platy, or needle-like
hail	5 mm to 10 cm or larger	solid	hard, rounded pellets
graupel	2 mm to 5 mm	solid	soft hail that forms as rime collects on snow crystals

Geoscience: Fujita Scale

scale	wind speed km/hr	wind speed mph	relative frequency	average damage path in meters	potential damage
F0	64-116	40–72	38.9%	10-50	light
F1	117-180	73–112	35.6%	30-150	moderate
F2	181–253	113–157	19.4%	110-250	significant
F3	254–332	158–206	4.9%	200-500	severe
F4	333–418	207–260	1.1%	400-900	devastating
F5	419–512	261–318	<0.1%	1,100	incredible

(Source: https://en.wikipedia.org/wiki/Fujita_scale)

Math

Math: Divisibility Rules

number	rule
2	right-most digit is divisible by 2
3	sum of the digits is divisible by 3
4	right-most two digits are divisible by 4
5	right-most digit is 0 or 5
6	divisible by both 2 and 3
7	double the right-most digit, subtract it from the number (exclude the right-most digit), if the result is divisible by 7 then the original number is divisible by 7; if the divisibility of the resulting number is unknown, apply the rule again
8	right-most three digits are divisible by 8
9	sum of the digits is divisible by 9
10	right-most digit is 0

Math: Surface Area and Volume

volume of a rectangular solid: $V = lwh$

volume of a sphere: $V = \frac{4}{3}\pi r^3$

volume of a cylinder: $V = \pi r^2 h$

surface area of a sphere: $A = 4\pi r^2$

surface area of a cube: $A = 6s^2$

l = length h = height w = width r = radius

s = length of one side of a cube A = surface area V = volume

Math: Factoring and Exponents

$$x^2 - y^2 = (x+y)(x-y) \qquad (x^a)(x^b) = x^{a+b}$$

$$x^2 + y^2 = (x+yi)(x-yi) \qquad \frac{x^a}{x^b} = x^{a-b}$$

$$x^3 + y^3 = (x+y)(x^2 - xy + y^2) \qquad x^{-a} = \frac{1}{x^a}$$

$$x^3 - y^3 = (x-y)(x^2 + xy + y^2) \qquad x^{a/b} = \sqrt[b]{x^a}$$

$$x^4 - y^4 = (x^2 + y^2)(x^2 - y^2)$$

$$x^n - y^n = (x-y)(x^{n-1} + x^{n-2}y + x^{n-3}y^2 + \dots + xy^{n-2} + y^{n-1})$$

Math: Binomial Expansion

$$(x+y)^n = a_0 x^n y^0 + a_1 x^{n-1} y^1 + a_2 x^{n-2} y^2 + \dots + a_{n-1} x^1 y^{n-1} + a_n x^0 y^n$$

$$a_i = \binom{n}{i} = \frac{n!}{k!(n-k)!} = \frac{n(n-1)\cdots(n-k+1)}{k(k-1)\cdots 1}$$

the coefficients are derived from the nth row of Pascal's triangle

examples:

$$(x+y)^2 = x^2 + 2xy + y^2$$

$$(x+y)^7 = x^7 + 7x^6 y + 21x^5 y^2 + 35x^4 y^3 + 35x^3 y^4 + 21x^2 y^5 + 7xy^6 + x^7$$

Math: Pascal's Triangle

Pascal's triangle: each successive row is the sum of the numbers to the left and right of the row above, except for the right-most and left-most numbers of each row, which are always 1

(Image source: http://www.cut-the-knot.org/arithmetic/combinatorics/PascalTriangleProperties.shtml)

1
1 1
1 2 1
1 3 3 1
1 4 6 4 1
1 5 10 10 5 1
1 6 15 20 15 6 1
1 7 21 35 35 21 7 1
1 8 28 56 70 56 28 8 1
1 9 36 84 126 126 84 36 9 1
1 10 45 120 210 252 210 120 45 10 1

Math: Permutations and Combinations

n objects *r* at a time

permutations $P(n,r) = \frac{n!}{(n-r)!}$

combinations $C(n,r) = \frac{P(n,r)}{r!} = \frac{n!}{r!(n-r)!}$

Math: Linear Equations

linear:

point-slope form: $y - y_1 = m(x - x_1)$ b = y-intercept

slope-intercept form: $y = mx + b$ slope $m = \dfrac{y_2 - y_1}{x_2 - x_1}$

midpoint of a line joining two points $\left(\dfrac{x_1 + x_2}{2}, \dfrac{y_1 + y_2}{2}\right)$

point of intersection of two straight lines

$$\left(\frac{b_2 - b_1}{m_1 - m_{21}}, m_1\left(\frac{b_2 - b_1}{m_1 - m_{21}}\right) + b_1\right) = \left(\frac{b_2 - b_1}{m_1 - m_{21}}, m_2\left(\frac{b_2 - b_1}{m_1 - m_{21}}\right) + b_2\right)$$

angle of intersection of two straight lines $\tan\varphi = \dfrac{m_2 - m1}{1 + m_2 m_1}$

Math: Quadratic and Cubic Equations

quadratic:

$y = ax^2 + bx + c$ $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

cubic:

$y = ax^3 + bx^2 + cx + d$ $\Delta_0 = b^2 - 3ac$

$x = \sqrt[3]{\dfrac{\Delta_1 \pm \sqrt{\Delta_1^2 - 4\Delta_0^3}}{2}}$ $\Delta_1 = 2b^3 - 9abc + 27a^2 d$

Math: Logarithms

$\log_a x = b \rightarrow a^b = x$ $\log_a a = 1$

$\log_b x = \dfrac{\log_a x}{lob_a b}$ $\log_a 1 = 0$

$\log_a x^b = b\log_a x$ $\ln x = \log_e x$

$\log_a xy = \log_a x + \log_a y$ $\ln e^x = x$

$\log_a \dfrac{x}{y} = \log_a x - \log_a y$ $\ln e = 1$

$\log_a x = 1/\log_x a$ $\ln 1 = 0$

$\log_a x = \log_b x / \log_b a$ $e^{\ln x} = x$

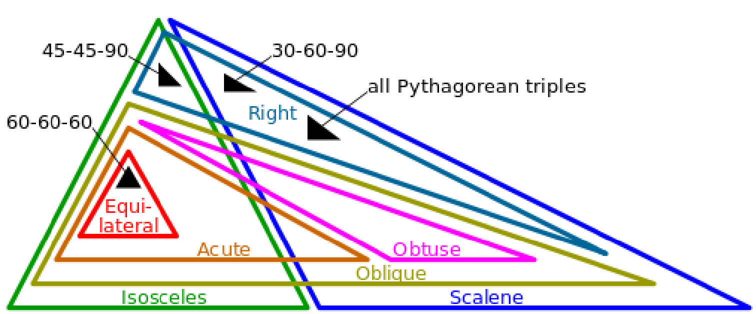
Math: Composition, Even and Odd Functions

composition: $f(g(x)) = (f \; o \; g)(x)$

a function is even if $f(x) = f(-x)$

a function is odd if $f(-x) = -f(x)$

Math: Triangles (1)

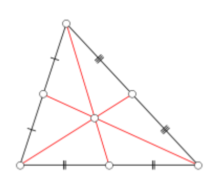


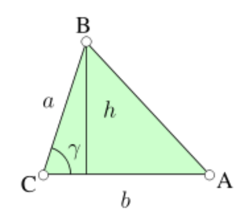
(Image source: https://en.wikipedia.org/wiki/Triangle#/media/File:Euler_diagram_of_triangle_types.svg, Author: Cmglee, CC BY-SA 3.0)

Math: Triangles (2)

area of a triangle $A = \dfrac{1}{2}ab\sin\gamma = \dfrac{1}{2}bc\sin\alpha = \dfrac{1}{2}ca\sin\beta$

centroid of a triangle





(Images source: https://en.wikipedia.org/wiki/Triangle#/media/File:Triangle.TrigArea.svg, Author: Limaner, public domain)

Math: Trigonometry (1)

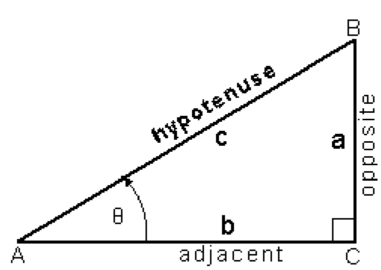
$\boldsymbol{\theta}$	0^0 0^0	30^0 $\frac{\pi}{6}$	45^0 $\frac{\pi}{4}$	60^0 $\frac{\pi}{3}$	90^0 $\frac{\pi}{2}$	180^0 π	270^0 $\frac{3\pi}{2}$	360^0 2π
$\sin\theta$	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1	0	-1	0
$\cos\theta$	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	-1	0	1
$\tan\theta$	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	N. D.	0	N. D.	0
$\operatorname{cosec}\theta$	N. D.	2	$\sqrt{2}$	$\frac{2}{\sqrt{3}}$	1	N. D.	-1	N. D
$\sec\theta$	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	N. D.	-1	N. D.	1
$\cot\theta$	N. D.	$\sqrt{3}$	1	$\frac{1}{\sqrt{3}}$	0	N. D.	0	N. D

Math: Trigonometry (2)

$\sin\theta = \dfrac{a}{c} = \dfrac{opposite}{hypotenuse}$

$\cos\theta = \dfrac{b}{c} = \dfrac{adjacent}{hypotenuse}$

$\tan\theta = \dfrac{a}{b} = \dfrac{opposite}{adjacent}$



$\csc\theta = \dfrac{1}{\sin\theta}$ $\sec\theta = \dfrac{1}{\cos\theta}$ $\cot\theta = \dfrac{1}{\tan\theta}$

Math: Trigonometric Identities

$$\sin^2\theta + \cos^2\theta = 1$$
$$\tan^2\theta + 1 = \sec^2\theta$$
$$\cot^2\theta + 1 = \csc^2\theta$$
$$\sin(\alpha+\beta) = \sin\alpha\cos\beta + \cos\alpha\sin\beta$$
$$\cos(\alpha+\beta) = \cos\alpha\cos\beta - \sin\alpha\sin\beta$$
$$\sin(2\alpha) = 2\sin\alpha\cos\alpha$$
$$\cos(2\alpha) = \cos^2\alpha - \sin^2\alpha = 1 - 2\sin^2\alpha = 2\cos^2\alpha - 1$$
$$\sin(\alpha/2) = \pm\sqrt{(1-\cos\alpha)/2}$$
$$\cos(\alpha/2) = \pm\sqrt{(1+\cos\alpha)/2}$$

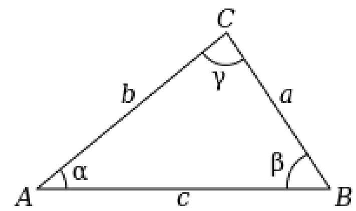
Math: Law of Sines and Law of Cosines

Law of Sines:

$$\frac{\sin\alpha}{a} = \frac{\sin\beta}{b} = \frac{\sin\gamma}{c}$$

Law of Cosines:

$$a^2 = b^2 + c^2 - 2bc\cos\alpha$$
$$b^2 = a^2 + c^2 - 2ac\cos\beta$$
$$c^2 = a^2 + b^2 - 2ab\cos\gamma$$



Math: Polar Coordinates

$x = r\cos\theta$ $\quad$ $y = r\sin\theta$

$\theta = \arctan(y/x)$

$r = |x+iy| = \sqrt{x^2+y^2}$

$x + iy = r(\cos\theta + i\sin\theta) = re^{i\theta}$

$e^{i\theta} = \cos\theta + i\sin\theta$ $\quad$ $e^{-i\theta} = \cos\theta - i\sin\theta$

$\cos\theta = \dfrac{e^{i\theta}+e^{-i\theta}}{2}$ $\quad$ $\sin\theta = \dfrac{e^{i\theta}-e^{-i\theta}}{2i}$

Math: Spherical Coordinates (1)

(r,θ,ϑ) to $(r+dr, \theta+d\theta, \vartheta+d\vartheta)$

$$\hat{r} = \sin\theta\cos\vartheta\hat{x} + \sin\theta\sin\varphi\hat{y} + \cos\theta\hat{z}$$
$$\hat{\theta} = \cos\theta\cos\vartheta\hat{x} + \cos\theta\sin\varphi\hat{y} + \sin\theta\hat{z}$$
$$\hat{\varphi} = -\sin\vartheta\hat{x} + \cos\varphi\hat{y}$$
$$d\vec{r} = dr\hat{r} + rd\theta\hat{\theta} + r\sin\theta d\varphi\hat{\varphi}$$

$dS_r = r^2\sin\theta d\theta d\varphi$ $\quad$ $dS_\theta = r\sin\theta d\varphi dr$ $\quad$ $dS_\vartheta = rdrd\theta$

differential solid angle $d\Omega = \dfrac{dS_r}{r^2} = \sin\theta d\theta d\varphi$

volume element $dV = r^2\sin\theta drd\theta d\varphi$

Math: Spherical Coordinates (2)

$$\vec{r} = r\hat{r}$$
$$\vec{v} = \dot{r}\hat{r} + r\dot{\theta}\hat{\theta} + r\dot{\vartheta}\sin\theta\dot{\vartheta}$$
$$\vec{a} = (\ddot{r} - r\dot{\theta}^2 - r\dot{\vartheta}^2\sin^2\theta)\hat{r}$$
$$+ (r\ddot{\theta} + 2\dot{r}\dot{\theta} - r\dot{\vartheta}^2\sin\theta\cos\theta)\hat{\theta}$$
$$+ (r\ddot{\vartheta}\sin\theta + 2\dot{r}\dot{\vartheta}\sin\theta + 2r\dot{\theta}\dot{\vartheta}\cos\theta)\hat{\vartheta}$$

Math: Matrices

addition: $A + B = \lfloor a_{ij} + b_{ij} \rfloor$ $\quad$ subtraction: $A - B = \lfloor a_{ij} - b_{ij} \rfloor$

multiplication: if A is m x n and B is n x p then the elements of AB are $\sum_{k=1}^{n} a_{ik}b_{kj}$

inverse: if A is n x n and $AB = BA = AA^{-1} = I$ then $B = A^{-1}$

$AB = BA = AA^{-1} = I$ is an identity matrix where all elements are 0 except for the 1s on the diagonal

determinant $\det(A) = \sum_{i=1}^{i=n} a_{ij}A_{ij} = \sum_{j=1}^{j=n} a_{ij}A_{ij}$

Math: Vectors

$A = a_x i + a_y j + a_z k$ $\quad$ $B = b_x i + b_y j + b_z k$

addition $A + B = (a_x + b_x)i + (a_y + b_y)j + (a_z + b_z)k$

subtraction $A - B = (a_x - b_x)i + (a_y - b_y)j + (a_z - b_z)k$

dot product $A \bullet B = a_x b_x + a_y b_y + a_z b_z = |A||B|\cos\theta = B \bullet A$

cross product $A \times B = \begin{vmatrix} i & j & k \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix} = -B \times A = |A||B| n \sin\theta$

where *n* is the unit vector perpendicular to the plane of A and B

Math: Series

a_1 = first term d = common difference r = common ratio

n = number of terms a_n = nth term S = sum of n terms

arithmetic sequence:

$a_n = a_1 + (n-1)d$

$S = n(a_1 + a_n)/2 = n[2a_1 + (n-1)d]/2$

geometric sequence:

$a_n = a_1 r^{n-1}$

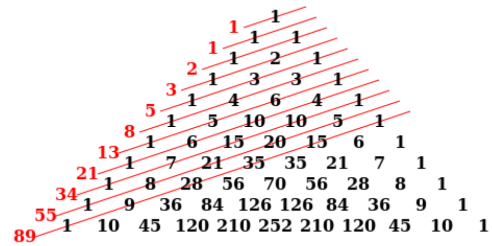
$S_n = a_1(1-r^n)/(1-r) = (a_1 - ra_n)/(1-r), r \neq 1$

$S_n = a_1/(1-r), r < 1$

convergent when $|r| < 1$ divergent when $|r| \geq 1$

Math: Fibonacci Sequence

Fibonacci sequence: each number is the sum of the previous two numbers in the sequence, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144…



$a_n = a_{n-2} + a_{n-1}$

The Fibonacci numbers are the sums of the "shallow" diagonals of Pascal's triangle.

(Image source: https://en.wikipedia.org/wiki/Fibonacci_number#/media/File:PascalTriangleFibanacci.svg, Author: RDBury, CC BY-SA 4.0)

Math: Conic Sections

conic section	equation	eccentricity e	vertices	c	foci	directrix	area
circle	$(x-h)^2 + (y-k)^2 = r^2$	**0**	**0**				πr^2
ellipse a > b (horizontal major axis)	$\frac{(x-h)^2}{a^2} + \frac{(y-k)^2}{b^2} = 1$	$\frac{c}{a}$	$(h \pm a, k)$	$\sqrt{a^2 - b^2}$	$(h \pm c, k)$	$x = h \pm c$	πab
ellipse a < b (vertical major axis)	$\frac{(y-k)^2}{a^2} + \frac{(x-h)^2}{b^2} = 1$	$\frac{c}{a}$	$(h, k \pm a)$	$\sqrt{a^2 - b^2}$	$(h, k \pm c)$	$y = k \pm c$	πab
parabola vertical (opens up or down)	$(x-h)^2 = 4p(y-k)$	**1**	(h, k)		$(h+p, k)$	$y = k - p$	
parabola horizontal (opens left or right)	$(y-k)^2 = 4p(x-h)$	**1**	(h, k)		$(h, k+p)$	$x = h - p$	
hyperbola a > b	$\frac{(x-h)^2}{a^2} - \frac{(y-k)^2}{b^2} = 1$		$(h \pm a, k)$	$\sqrt{a^2 + b^2}$	$(h \pm c, k)$		
hyperbola a < b	$\frac{(y-k)^2}{a^2} - \frac{(x-h)^2}{b^2} = 1$		$(h, k \pm a)$	$\sqrt{a^2 + b^2}$	$(h, k \pm c)$		

Math: Statistics (1)

mean $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ standard deviation $s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$

$\bar{x} \to \mu$ for sufficiently large values of n

weighted arithmetic mean $\bar{x}_w = \frac{\sum_{i=1}^{n} x_{wi} w_i}{\sum_{i=1}^{n} w_i}$

median = n odd: middle value of ordered data

n even: average of the two middle values

mode = value that occurs most frequently

Math: Statistics (2)

correlation coefficient $r = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right) - \left(\sum x\right)^2}\sqrt{n\left(\sum y^2\right) - \left(\sum y\right)^2}}$

population variance

$\sigma^2 = \frac{1}{N}\left[(x_i - \mu)^2 + (x_2 - \mu)^2 + (x_N - u)^2\right] = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2$

population standard deviation $\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$

Math: Statistics (3)

sample variance $s^2 = \frac{1}{(n-1)}\sum_{i=1}^{n}(x_i-\bar{x})^2$

sample standard deviation $s = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(x_i-\bar{x})^2}$

sample geometric mean = $\sqrt[n]{x_1 x_2 \ldots x_n}$

sample root mean square value $\sqrt{\frac{1}{n}\sum_{i=1}^{n}x_i^2}$

Math: Probability

$P(A)\neq 0,\ P(B)\neq 0$

$P(A,B)=P(A)P(B/A)=P(B)P(A/B)$

$P(B/A)$ = probability that B occurs given the fact that A has occured

$P(A/B)$ = probability that A occurs given the fact that B has occurred

Math: Normal Distribution

normal distribution $f(x)=\frac{1}{\sigma\sqrt{2\pi}}e^{\frac{-1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$ where $-\infty \leq x \leq \infty$

mean = $\bar{x}=\mu$ standard deviation = σ variance = σ^2

cumulative distribution $F(x)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{x}e^{-t^2/2}dt$ $erf(x)=\frac{1}{\sqrt{\pi}}\int_{-x}^{x}e^{-t^2}dt$

$F(\mu+n\sigma)-F(\mu-n\sigma)=\Phi(n)-\Phi(-n)=erf\left(\frac{n}{\sqrt{2}}\right)$

n	$F(\mu+n\sigma)-F(\mu-n\sigma)$	n	$F(\mu+n\sigma)-F(\mu-n\sigma)$
1	0.682689492	4	0.999936657
2	0.954499736	5	0.999999426
3	0.997300203	6	0.999999998

Math: Binomial Distribution

probability density function $P(k)=\binom{n}{k}p^k(1-p)^{n-k}$

probability of getting k successes in n trials

cumulative distribution function $P(X\leq k)=\sum_{i=0}^{k}\binom{n}{i}p^i(1-p)^{n-i}$

expected mean $\bar{x}=np$

variance $\sigma^2=np(1-p)$

Math: Exponential Distribution

probability density function $f(x)=ae^{-ax}$

cumulative distribution function $F(x)=1-e^{-ax}$

expected mean $\bar{x}=\frac{1}{a}$

variance $\sigma^2=\frac{1}{a^2}$

Math: Differential Calculus (1)

$f'(a)=\lim_{h-->0}\frac{f(a+h)-f(a)}{h}$ $f'(x)=\frac{dy}{dx}$

$\frac{dx^n}{dx}=nx^{n-1}$ $\frac{da^x}{dx}=\ln a$ $\frac{d\log_a x}{dx}=\frac{1}{x\ln a}$

$\frac{d\log x}{dx}=\frac{1}{x}$ $\frac{de^x}{dx}=e^x$

$\frac{d(\sin x)}{dx}=\cos x$ $\frac{d(\cos x)}{dx}=-\sin x$ $\frac{d(\tan x)}{dx}=\sec^2 x$

Math: Differential Calculus (2)

test for maximum: $y=f(x)$ is a maximum for $x=a$ if $f'(a)=0$ and $f''(a)<0$

test for minimum: $y=f(x)$ is a maximum for $x=a$ if $f'(a)=0$ and $f''(a)>0$

test for inflection point: $y=f(x)$ has a point of inflection at $x=a$ if $f''(a)=0$, and if $f''(x)$ changes sign as x increases through $x=a$

Math: Taylor's Formula and Taylor's Series

$$f(b) = f(a) + \frac{f'(a)}{1!}(b-a) + \frac{f''(a)}{2!}(b-a)^2 + \ldots$$

$$+ \frac{f^n(a)}{n!}(b-a)^n + R_n(b)$$

$$R_n(b) = \frac{f_{(c)}^{(n+1)}}{(n+1)!}(b-a)^{n+1}$$

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \ldots \qquad \cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \ldots$$

$$\tan x = x + \frac{x^3}{3} + \frac{2}{15}x^5 + \frac{17}{315}x^7 + \ldots$$

Math: L'Hospital's Rule

If the fractional function $\frac{f(x)}{g(x)}$ assumes one of the indeterminate forms 0/0 or ∞/∞, where α is finite or infinite, then limit $\frac{f(x)}{g(x)}$ as $x \to a$ is equal to the first of the expressions limit $\frac{f'(x)}{g'(x)}$, limit $\frac{f''(x)}{g''(x)}$, limit $\frac{f'''(x)}{g'''(x)}$ as, $x \to a$, which is not indeterminate, provided such first indicated limit exists

Math: Integral Calculus (1)

The definite integral is defined as limit as $n \to \infty$ of

$$\sum_{i=1}^{n} f(x_i)\Delta x_i = \int_a^b f(x)dx \text{ and } \Delta x_i \to 0 \text{ for all } i$$

$$\int x^m dx = \frac{x^{m+1}}{m+1} + C \qquad \int e^{kx} dx = \frac{e^{kx}}{k} + C$$

$$\int \frac{1}{x} dx = \ln|x| + C \qquad \int xe^{kx} dx = \frac{e^{kx}(kx-1)}{k^2} + C$$

$$\int \ln x dx = x \ln x - x + C \qquad \int k^{ax} dx = \frac{k^{ax}}{a \ln k} + C$$

Math: Integral Calculus (2)

average value = $\frac{1}{b-a}\int_a^b f(x)dx$

area under a curve $A = \int_a^b (f_1(x) - f_2(x))dx$

where $f_1(x)$ is the curve above and $f_2(x)$ is the curve below

arc length = $\int_a^b \sqrt{1+(f'(x))^2}\,dx$

surface of revolution area $A = 2\pi \int_a^b f(x)\sqrt{1+(f'(x))^2}\,dx$

volume of revolution about the x-axis $V = \pi \int_{x=a}^{x=b} f^2(x)dx$

volume of revolution about the y-axis $V = 2\pi \int_{x=a}^{x=b} xf(x)dx$

Math: Differential Equations (1)

homogeneous first order linear, constant coefficients

$y'+ky = 0$, $r+k=0$, root $r=-k$

has solution $y = Ae^{rx} = Ae^{-kx}$

first order linear $y'+p(x)y = g(x)$ where $u(x) = \exp\left[\int p(x)dx\right]$

has solution $y = \frac{1}{u(x)}\left[\int u(x)g(x)dx + C\right]$

first order exact $f_x(x,y) + f_y(x,y)y' = 0$

has solution $f(x,y) - C = 0$

Math: Differential Equations (2)

homogeneous second order linear, constant coefficients

$y''+k_1y'+k_2 = 0$, $r^2 + k_1 r + k_2 = 0$ has solutions

if two roots are real and different

$$y = A_1 e^{r_1 x} + A_2 e^{r_2 x}$$

if two roots are real and the same

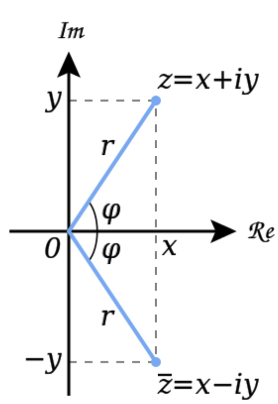
$$y = A_1 e^{rx} + A_2 e^{rx},\ r = \frac{-k_1}{2}$$

if two roots are imaginary

$$y = A_1 e^{\alpha x}\cos(\omega x) + A_2 e^{\alpha x}\sin(\omega x)$$

Math: Complex Numbers

<u>complex number</u>: a number of the form $x+iy$, where x and y are real numbers and i is the imaginary unit, satisfying $i^2 = -1$



(Image source: https://en.wikipedia.org/wiki/Complex_number#/media/File:Complex_conjugate_picture.svg, Author: Oleg Alexandrov, CC BY-SA 3.0)

Math: Euler's Formula

Euler's formula: $e^{ix} = \cos(x) + i\sin(x)$

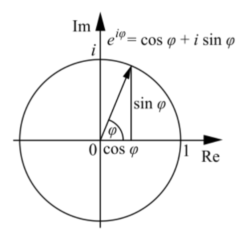
$$e^{2\pi i\varphi} = \cos(2\pi\varphi) + i\sin(2\pi\varphi)$$

$$2\pi i\varphi = \ln[(2\pi\varphi) + i\sin(2\pi\varphi)]$$

$$z = x+iy = |z|\cos(\varphi) + i\sin(\varphi) = re^{i\varphi}$$

$$\bar{z} = x-iy = |z|\cos(\varphi) - i\sin(\varphi) = re^{-i\varphi}$$

$$r = |z| = \sqrt{x^2+y^2} \qquad \varphi = \arctan(y/x)$$



(Image source: https://en.wikipedia.org/wiki/Euler's_formula#/media/File:Euler%27s_formula.svg, Authors: Gunther and Wereon, CC BY-SA 3.0)

Math: Fourier Series

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty}[a_n \cos(nx) + b_n \sin(nx)]$$

$$a_k = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\cos(kx)dx \qquad b_k = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\sin(kx)dx$$

even function $f(x) = f(-x)$

$$a_k = \frac{2}{\pi}\int_{0}^{\pi} f(x)\cos(kx)dx \qquad b_k = 0$$

odd function $f(x) = -f(-x)$

$$a_k = 0 \qquad b_k = \frac{2}{\pi}\int_{0}^{\pi} f(x)\sin(kx)dx$$

Math: Fourier Transforms (1)

$$F(s) = \int_{-\infty}^{\infty} f(x)e^{-i2\pi xs}dx = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} f(x)e^{-ixs}dx$$

$$f(x) = \int_{-\infty}^{\infty} F(s)e^{-i2\pi xs}ds = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} F(s)e^{-ixs}ds$$

convolution theorem $h(x) = (f * g)(x) = \int_{-\infty}^{\infty} f(x)g(x-y)dy$

$$= \int_{-\infty}^{\infty} f(x-y)g(x)dy$$

Math: Fourier Transforms (2)

rectangle function $$\Pi(x) = \begin{cases} 1 & |x| < \frac{1}{2} \\ 0 & |x| > \frac{1}{2} \end{cases}$$

triangle function $$\Lambda(x) = \begin{cases} 1-|x| & |x| < 1 \\ 0 & |x| > 1 \end{cases}$$

Heaviside unit step function $$H(x) = \begin{cases} 1 & x > 0 \\ 0 & x < 0 \end{cases}$$

sign function $$\operatorname{sgn}(x) = \begin{cases} 1 & x > 0 \\ -1 & x < 0 \end{cases}$$

Math: Fourier Transforms (3)

$$\int_{-\infty}^{\infty} e^{-\pi x^2} e^{-i2\pi xs}dx = e^{-\pi s^2} \qquad \int_{-\infty}^{\infty} e^{-\pi x^2} e^{+i2\pi sx}ds = e^{-\pi x^2}$$

$$\int_{-\infty}^{\infty} \operatorname{sinc} x\, e^{-i2\pi xs}dx = \Pi(s) \qquad \int_{-\infty}^{\infty} \Pi(s)e^{+i2\pi sx}ds = \operatorname{sinc} x$$

$$\int_{-\infty}^{\infty} \operatorname{sinc} x^2\, e^{-i2\pi xs}dx = \Lambda(s) \qquad \int_{-\infty}^{\infty} \Lambda(s)e^{+i2\pi sx}ds = \operatorname{sinc}^2 x$$

Math: Laplace Transforms (1)

$$F(s) = \int_0^{\infty} f(t)e^{-(\sigma+i\omega)t}dt = \int_0^{\infty} f(t)e^{-st}dt$$

	time domain	s domain
linearity	$af(t)+bg(t)$	$aF(s)+bG(s)$
frequency domain derivative	$tf(t)$	$-F'(s)$
frequency domain general derivative	$t^n f(t)$	$(-1)^n F^{(n)}(s)$
derivative	$f'(t)$	$sF(s)-f(0)$
second derivative	$f''(t)$	$s^2F(s)-sf(0)-f'(0)$
general derivative	$f^{(n)}(t)$	$s^{(n)}F(s)-\sum_{k=1}^{n} s^{n-k} f^{(k-1)}(0)$

Math: Laplace Transforms (2)

	time domain	s domain
frequency domain integration	$\frac{1}{t}f(t)$	$\int_s^{\infty} F(\sigma)d\sigma$
time domain integration	$\int_0^t f(\tau)d\tau = (u * f)(t)$	$\frac{1}{s}F(s)$
frequency shifting	$e^{at}f(t)$	$F(s-a)$
time shifting	$f(t-a)u(t-a)$	$e^{-as}F(s)$
time scaling	$f(at)$	$\frac{1}{a}F\left(\frac{s}{a}\right)$

Math: Laplace Transforms (3)

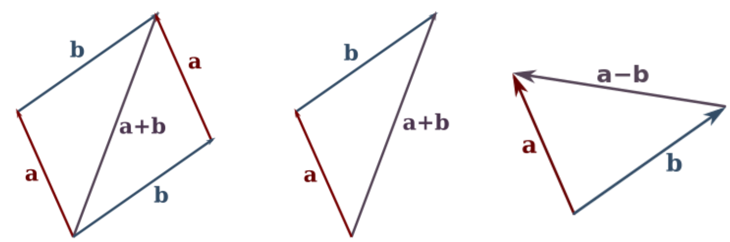
	time domain	s domain
multiplica-tion	$f(t)g(t)$	$\frac{1}{2\pi i}\lim_{T\to\infty}\int_{c-iT}^{c+iT} F(\sigma)G(s-\sigma)d\sigma$
convolu-tion	$f(*g)(t) = \int_0^t f(\tau)g(t-\tau)d\tau$	$F(s)\cdot G(s)$
complex conjuga-tion	$f^*(t)$	$F^*(s^*)$
cross-correlation	$f(t)*g(t)$	$F^*(-s^*)\cdot G(s)$
periodic function	$f(t)$	$\frac{1}{1-e^{-Ts}}\int_0^T e^{-st}f(t)dt$

Physics

Physics: Vector Addition

Vector	x-component	y component	angle
$\vec{A}$	$A_x = A\cos\theta$	$A_x = A\sin\theta$	$\theta = \frac{A_y}{A_x}$
$\vec{B}$	$B_x = B\cos\phi$	$B_x = B\sin\phi$	$\phi = \frac{B_y}{B_x}$
$\vec{R} = \vec{A} + \vec{B}$	$R_x = A_x + B_x$	$R_y = A_y + B_y$	$\vartheta = \frac{R_y}{R_x}$

Physics: Vector Representation



(Image sources:
https://en.wikipedia.org/wiki/Euclidean_vector#/media/File:Vector_addition.svg,
https://en.wikipedia.org/wiki/Euclidean_vector#/media/File:Vector_subtraction.svg,
Author : Benjamin D. Esham, public domain)

Physics: Newton's Laws of Motion

1. The law of inertia: every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force.
2. Acceleration: the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass $\vec{F} = \mathrm{m}\,\vec{a}$
3. Action-reaction: for every action there is an equal and opposite reaction; if object *A* exerts a force $\vec{F}_A$ on a second object *B*, then *B* exerts a force $\vec{F}_B$ on *A*, and the two forces are equal in magnitude and opposite in direction: $\vec{F}_A = -\vec{F}_B$

Physics: Newton's Universal Law of Gravitation

every point mass attracts every single other point mass by a force pointing along the line intersecting both points; the force is proportional to the product of the two masses and inversely proportional to the square of the distance between them

$$F = \frac{Gm_1m_2}{r^2} \quad \text{and} \quad F = mg = W \qquad W = \text{weight}$$

F = force between the masses
G = gravitational constant 6.674×10^{-11} N m/kg^2
m_1 = first mass in kilograms
m_2 = second mass in kilograms
r = distance between the centers of the masses in meters

Physics: Horizontal Kinematics Equations

$$x_f = x_i + v_i t + \frac{1}{2}at^2$$

$$v_f = v_i + at$$

$$v_f^2 = v_i^2 + 2a(x_f - x_i)$$

$$x_f = x_i + \frac{(v_i + v_f)t}{2}$$

x_i = initial displacement
x_f = final displacement
v_i = initial velocity
v_f = final velocity
a = acceleration

t = time

Physics: Vertical Kinematics Equations

$$y_f = y_i + v_i t + \frac{1}{2}gt^2$$

$$v_f = v_i + gt$$

$$v_f^2 = v_i^2 + 2g(y_f - y_i)$$

$$y_f = y_i + \frac{(v_i + v_f)t}{2}$$

y_i = initial displacement
y_f = final displacement
v_i = initial velocity
v_f = final velocity
g = -9.81 m/s

t = time

Physics: Linear Motion and Rotational Motion

Quantity	Linear	Rotational
mass and inertia	m	I
Newton's second law	$F = ma$	torque: $\tau = I\alpha$
momentum	$p = mv$	$L = I\omega = mvr\sin\theta$
work	$W = Fd$	$W = \tau\theta$
kinetic energy	$K = \frac{1}{2}mv^2$	$K = \frac{1}{2}I\omega^2$
power	$P = Fv$	$P = \tau\omega$

Physics: Friction and Work

static friction: $f_{s,\max} = \mu_s F_N \qquad 0 \le f_s \le f_{s,\max}$

kinetic friction: $f_k = \mu_k F_N$

work: $\Delta U =$ change in potential energy

conservative work: $W_c = -(\Delta U)$

ΔE_{mech} = change in mechanical energy

nonconservative work: $W_{nc} = \Delta E_{mech}$

total work: $W_{total} = \Delta K$

Physics: Projectile Motion (1)

	level target	target above	target below	horizontal projectile
parameter	**equation**			
x(t)	$v_0 t\cos\theta$			$v_0 t$
y(t)	$v_0 t\sin\theta - \frac{1}{2}gt^2$			$H - \frac{1}{2}gt^2$
v_x(t)	$v_0\cos\theta$			v_0
v_y(t)	$v_0\sin\theta - gt$			$-gt$
v(t)	$\sqrt{v_0^2 - 2gtv_0\sin\theta + g^2t^2}$			$\sqrt{v_0^2 + g^2t^2}$
v(y)	$\sqrt{v_0 - 2gy}$			$\sqrt{v_0 - 2g(H-y)}$

Physics: Projectile Motion (2)

	level target	target above	target below	horizontal projectile
parameter	**equation**			
H (height)	$\frac{v_0^2\sin^2\theta}{2g}$		$z + \frac{v_0^2\sin^2\theta}{2g}$	$\frac{1}{2}gt^2$
R (range)	$v_0 T\cos\theta$			$v_0 t$
	$\frac{v_0^2\sin 2\theta}{g}$	*	**	

* = $\frac{v_0\cos\theta}{g}\left[v_0\sin\theta + \sqrt{v_0^2\sin^2\theta - 2gz}\right]$

** = $\frac{v_0\cos\theta}{g}\left[v_0\sin\theta + \sqrt{2gz + v_0^2\sin^2\theta}\right]$

Physics: Projectile Motion (3)

	level target	target above	target below	horizontal projectile
parameter	**equation**			
T (total time)	$\frac{R}{v_0\cos\theta}$			
	$2v_0\sin\theta$	***	****	$\sqrt{\frac{2H}{g}}$
t_H (time at max height)	$\frac{v_0\sin\theta}{g} = \frac{T}{2}$			$T = 0$

z = height difference between launch and landing sites

*** = $\frac{v_0\sin\theta}{g} + \sqrt{\frac{2(H-z)}{g}}$

**** = $\frac{v_0\sin\theta}{g} + \sqrt{\frac{2H}{g}}$

Physics: Elastic Deformation

changing the length of a solid: $F = Y\left(\frac{\Delta L}{L_0}\right)A$

F = applied force $\quad Y$ = Young's modulus $\quad L_0$ = initial length

A = cross-sectional area perpendicular to the applied force

shear deformation: $F = S\left(\frac{\Delta x}{L_0}\right)A$

S = shear modulus $\quad \Delta x$ = shear deformation

changing the volume of a solid: $\Delta P = -B\left(\frac{\Delta V}{V_0}\right)$

ΔP = change in pressure $\quad B$ = bulk modulus

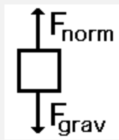
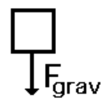
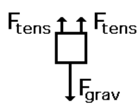
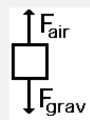
Physics: Mechanical Forces (1)

Contact forces	Notation
air resistance: related to object size and shape, usually ignored unless large surface area or high speeds	F_{air}
applied: usually pushing or pulling exerted by a person or by one object on another object	F_{app}
centripetal	$F_{cp} = mv^2/r$
gravitational: mass x acceleration of gravity	$F_{grav} = mg$
kinetic friction: kinetic friction coefficient x normal force	$f_K = \mu_K F_N$
normal: perpendicular to the surface of object motion	F_N
spring: product of the spring constant and change in length of the stretched object, Hooke's law $F_{spring} = -kx$	$F_{spring} = kx$
static friction: less than or equal to the product of the coefficient of static friction and the normal force	$f_S \le \mu_S F_N$
tension force: usually calculated by resolving other forces first	F_T or T

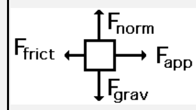
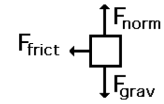
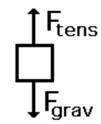
Physics: Mechanical Forces (2)

Conservative force: if the work done by a force in going from an arbitrary point A to an arbitrary point B is independent of the path
gravity
spring force
Nonconservative force: if the work done by a force in going from an arbitrary point A to an arbitrary point B is dependent of the path
friction
tension in a rope, cable, etc.
forces exerted by a motor
forces exerted by muscles

Physics: Free Body Diagrams (1)

an object at rest		a falling object, ignoring air resistance	
an object on a pulley or bar		an object gliding in the air	

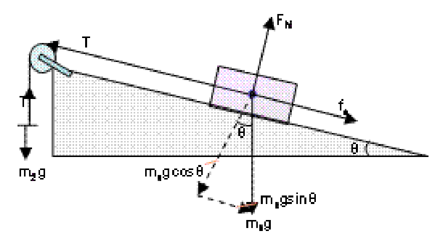
Physics: Free Body Diagrams (2)

an object pushed toward the right, along a surface, constant velocity or constant acceleration		an object coasting to the right and slowing down	
an object suspended from a rope		(Image sources: http://www.physicsclassroom.com/class/newtlaws/Lesson-2/Drawing-Free-Body-Diagrams)	

Physics: Steps for Drawing a Force Diagram

1. Identify the object(s). Each will require a separate diagram.
2. Select a coordinate system.
3. Identify all forces acting directly on the object.
4. Draw a dot or box to represent the object.
5. Draw a vector to represent each force, in the direction the force is being exerted, and clearly label each force.
6. Label as many angles as possible.
7. Set up a table and record all of the forces in the x and y directions, with the correct signs.
8. If the object is stationary or is moving at a constant velocity, the vectors should graphically add up to zero. If the object is accelerating, the sum of the vectors should produce a vector in the same direction as the acceleration.

Physics: Incline Free Body Diagram



(Image source: http://demos.smu.ca/index.php/demos/mechanics/141-free-body-diagram, Classroom Physics Demos , St. Mary's University)

Physics: Circular Motion (1)

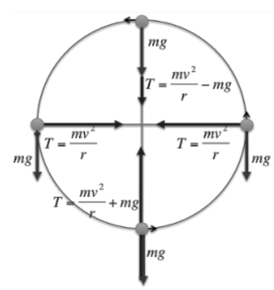
bottom of circle: $F_{c1} = F_{N1} - mg = \dfrac{mv_1^2}{r}$ $\quad F_{N1} = mg + \dfrac{mv_1^2}{r}$

$F_1 = \dfrac{mv_1^2}{r}$ $\quad K_1 = \dfrac{1}{2}mv_1^2$ $\quad U_1 = 0$

right side of circle:

$F_{c2} = F_{N2} = \dfrac{mv_2^2}{r}$ $\quad F_2 = m\sqrt{\dfrac{v_2^4}{r^2} + g^2}$

$K_2 = \dfrac{1}{2}mv_2^2$ $\quad U_2 = mgr$



(Image source: https://sites.google.com/a/morgan.k12.ga.us/mr-johnson/2nd-period/topic-6/6-1-circular-motion)

Physics: Circular Motion (2)

top of circle: $F_{c3} = F_{N3} + mg = \dfrac{mv_3^2}{r}$ $\quad F_{N3} = \dfrac{mv_3^2}{r} - mg$

$F_3 = \dfrac{mv_3^2}{r}$ $\quad K_3 = \dfrac{1}{2}mv_3^2$ $\quad U_3 = 2mgr$

left side of circle:

$F_{c4} = F_{N4} = \dfrac{mv_4^2}{r}$ $\quad F_4 = m\sqrt{\dfrac{v_4^4}{r^2} + g^2}$

$K_4 = \dfrac{1}{2}mv_4^2$ $\quad U_4 = mgr$

Physics: Simple Machines

<u>lever</u>: beam or rigid rod pivoted at a fixed hinge, or fulcrum., which can rotate on a point on itself

<u>wheel and axle</u>: wheel attached to a smaller axle that rotate together in which a force is transferred from one to the other

<u>pulley</u>: wheel on an axle or shaft designed to support movement and change of direction of a cable, rope or belt

<u>inclined plane</u>: flat supporting surface tilted at an angle, with one end higher than the other

<u>wedge</u>: triangular shaped tool, portable inclined plane, used to separate two objects or portions of an object, lift up an object, or hold an object in place

<u>screw</u>: converts rotational motion to linear motion, and a torque (rotational force) to a linear force

Physics: Energy

kinetic energy $E_k = \dfrac{1}{2}mv^2$ $\quad m$ = mass $\quad v$ = velocity

g = 9.81 m/s^2

potential energy $E_p = mgh$ $\quad h$ = height

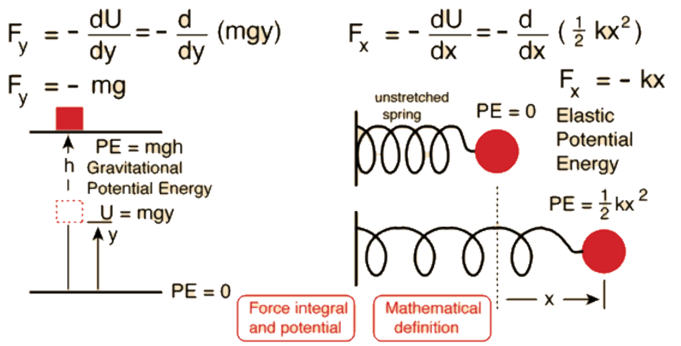
elastic energy $E_e = \dfrac{1}{2}kx^2$ $\quad k$ = spring constant

x = displacement

rotational energy $E_r = \dfrac{1}{2}I\omega^2$ $\quad I$ = rotational inertia

ω = angular velocity

Physics: Springs

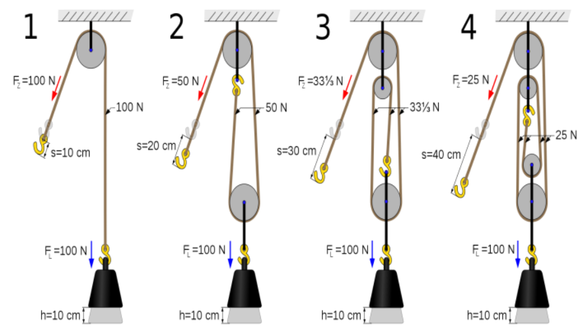


(Image source: http://hyperphysics.phy-astr.gsu.edu/hbase/pegrav.html, Author: R. Nave, Georgia State University, used with permission

Physics: Mechanical Advantage of Pulleys (1)

to calculate mechanical advantage MA: count the number of rope sections that support whatever object is being lifted (not counting the rope that is attached to the effort). For example, in a one pulley system the MA is 1; in a two pulley system the MA is 2. The more compound the pulley is the easier the load is to lift; lifting a 600 kg object with 2 pulleys would require use enough effort to pull 300 kg to lift the 600 kg object, meaning that the mechanical advantage = 2 (600/300)

Physics: Mechanical Advantage of Pulleys (2)



(Image source: https://en.wikipedia.org/wiki/Mechanical_advantage_device#/media/File:Four_pulleys.svg, Authors: Prolineserver, Tomia, CC BY 2.5)

Physics: Mechanical Advantage of Screws and Inclined Planes

theoretical mechanical advantage for a screw $MA = \frac{\pi d_m}{\ell}$

d_m = mean diameter of the screw thread

ℓ =lead of the screw thread

actual mechanical advantage of a screw system is greater, as a screwdriver or other screw driving system has a mechanical advantage

inclined plane MA = length of slope ÷ height of the slope

Physics: Mechanical Advantage of Gears

velocity $v = r_A\omega_A = r_B\omega_B$

r_A = radius of input gear *A* r_B = radius of output gear *B*

ω_A = angular velocity of gear *A* ω_B = angular velocity of gear *B*

$$\frac{r_A}{r_B} = \frac{\omega_B}{\omega_A} = \frac{N_B}{N_A}$$

N_A = number of teeth on gear *A* N_B = number of teeth on gear *B*

mechanical advantage $MAv = \frac{T_B}{T_A} = \frac{N_B}{N_A}$

T_A = torque of gear *A* T_B = torque of gear *B*

Physics: Momentum

conservation of linear momentum

$$m_1v_{i1} + m_2v_{i2} = m_1v_{f1} + m_2v_{f2}$$

velocity after elastic collision

$$v_{f1} = \frac{v_{i1}(m_1 - m_2) + 2m_2v_{i2}}{m_1 + m_2}$$

$$v_{f2} = \frac{v_{i2}(m_2 - m_1) + 2m_1v_{i1}}{m_1 + m_2}$$

velocity after inelastic collision $v_{f1} = v_{f2} = \frac{m_1v_{i1} + m_2v_{i2}}{m_1 + m_2}$

Physics: Center of Mass

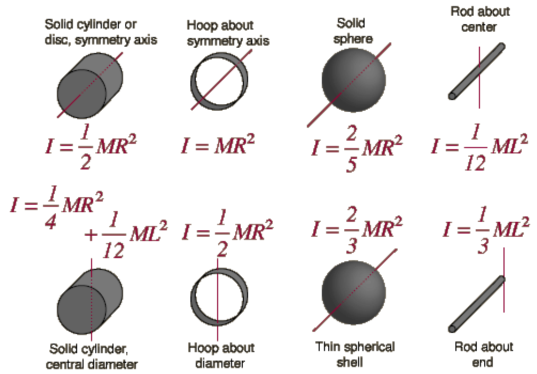
center of mass

$$X_{cm} = \frac{m_1x_1 + m_2x_2 + \dots}{m_1 + m_2 + \dots} = \frac{\sum mx}{M}$$

velocity of center of mass

$$V_{cm} = \frac{m_1\vec{v}_1 + m_2\vec{v}_2 + \dots}{m_1 + m_2 + \dots} = \frac{\sum m\vec{v}}{M}$$

Physics: Moment of Inertia



(Image source: http://hyperphysics.phy-astr.gsu.edu/hbase/mi.html, Author: R. Nave, Georgia State University, used with permission)

Physics: Pendulums

period of a mass on a spring $T = 2\pi\sqrt{\frac{m}{k}}$

period of a simple pendulum $T = 2\pi\sqrt{\frac{L}{g}}$ L = length

period of a compound pendulum $T = 2\pi\sqrt{\frac{I}{mgR}}$

R = distance between pivot point and center of mass

I = moment of inertia

Foucault pendulum angular speed $\omega = 360^0 \sin\varphi / day$

φ = latitude

Physics: Circular and Harmonic Motion Equations

tangential velocity $v_T = r\omega$

tangential acceleration $a_T = r\alpha$

centripetal acceleration $a_c = \frac{v_T^2}{r} = r\omega^2$

total acceleration $a_{total} = \sqrt{a_T^2 + a_C^2}$

$v = -A\omega\sin(\omega t)$ $v_{\max} = A\omega$

$a = -A\omega^2\cos(\omega t)$ $a_{\max} = A\omega^2$

Physics: Waves

transverse waves: the displacement of individual particles is at right angles to the direction of wave propagation

longitudinal waves: the displacement of individual particles is parallel to the direction of wave propagation

frequency $f = \frac{1}{T}$ period $T = 2\pi/\omega$ velocity $v = f\lambda$

λ = wavelength

speed of a wave on a string $v = \sqrt{\frac{F}{m/L}}$ L = string length

vertical displacement in a wave $y(t) = A\cos\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t\right)$

Physics: Speed of Sound

speed of sound: is the distance travelled per unit time by a sound wave as it propagates through an elastic medium; in dry air at 20°C (68°F), the speed of sound is 1,130 feet per second / 343.2 meters per second (1,236 km/h; 768 mph; 667 kn), or a kilometer in 2.914 s or a mile in 4.689 s

speed of sound in dry air $v_S = 20.05\sqrt{T + 27.3.15}$ m/s

T = temperature in ^{0}C

speed of sound in an ideal gas $v_S = \sqrt{\frac{\gamma\, p}{\rho}} = \sqrt{\frac{\gamma\, RT}{M}} = \sqrt{\frac{\gamma\, kT}{m}}$

γ = ratio of specific heats c_P / c_V

p = pressure ρ = density R = 8.314 J/ mol K

T = temperature in K M = molar mass

k = Boltzmann constant 5.67 x 10^{-8} W/m^2 K^4 m = molecular mass

(Source: https://en.wikipedia.org/wiki/Speed_of_sound)

Physics: Sound Intensity and Doppler Effect

sound intensity $I = \frac{P}{A}$ P = pressure A = area

intensity level $\beta = (10\ db)\log(I/I_0)$ I_0 = 10^{-12} W/m^2

Doppler effect:

moving observer $f\,' = (1 \pm u/v)f$, f = frequency

plus observer approaching source, minus observer receding

moving source $f\,' = \left(\frac{1}{1 \mp u/v}\right)f$, $f\,'$ = change in frequency

minus source approaching observer, plus source receding

Physics: Archimedes Principle

1. The buoyant force exerted on a submerged or floating body is equal to the weight of the fluid displaced by the body.
2. A floating body displaces a weight of fluid equal to its own weight; i.e., a floating body is in equilibrium. The center of buoyancy is located at the centroid of the displaced fluid volume. In the case of a body lying at the interface of two immiscible fluids, the buoyant force equals the sum of the weights of the fluids displaced by the body.

Physics: Fluids

density $\rho = \frac{m}{V}$ specific volume $V = \frac{1}{\rho}$

specific gravity $SG = \frac{\rho_{liquid}}{\rho_{water}}$, $SG = \frac{\rho_{gas}}{\rho_{air}}$

atmospheric pressure P_{atm} = 1.01 x 10^5 N/m^2 1 bar = 10^5 pascals

pressure $P = \frac{F}{A}$ A = area F = force

fluid pressure $P = P_0 + \rho gh$

buoyant force $F_B = \rho_{fluid} gV$ V = displaced fluid volume

Physics: Equation of Continuity and Bernoulli's Equation

equation of continuity: $\rho_1 A_1 v_1 = \rho_2 A_2 v_2$

ρ_1 and ρ_2 = fluid densities

A_1 and A_2 = cross-sectional areas

v_1 and v_2 = velocities

Bernoulli's equation:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + pgy_2$$

P_1 and P_2 = pressures

y_1 and y_2 = heights

Physics: Terminal Velocity in a Fluid

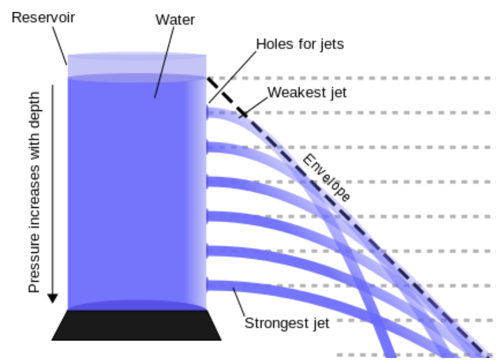
terminal velocity $v = \sqrt{\frac{2Dg(\rho_{sphere} - \rho_{fluid})}{3C_D \rho_{fluid}}}$

D = sphere diameter $C_D = \frac{24}{\mathrm{Re}}$ Re = Reynolds number

if the spherical particle is very small use Stoke's law

$$v = \frac{D^2(\rho_{sphere} - \rho_{fluid})}{18\mu} x \frac{g}{g_c}$$

Physics: Toricelli's Law



the speed of efflux, v, of a fluid through a sharp-edged hole at the bottom of a tank filled to a depth h is the same as the speed that a body would acquire in falling freely from a height h

$v = \sqrt{2gh}$

(Image source: https://en.wikipedia.org/wiki/Torricelli%27s_law#/media/File:TorricelliLawDiagram.svg, Author: Matt Cook, CC BY-SA 4.0)

Physics: Linear and Volumetric Expansion

linear expansion $\Delta L = \alpha L_0 \Delta T$

α = coefficient of linear expansion L_0 = initial length

area expansion $\Delta A = 2\alpha A_0 \Delta T$

volume expansion $\Delta V = \beta V_0 \Delta T$ $\beta = 3\alpha$

β = coefficient of volume expansion V_0 = initial volume

specific heat $c = \frac{Q}{m\Delta T}$ Q = heat m = mass

Physics: Conduction and Convection

conduction: transfer of heat (internal energy) by microscopic collisions of particles and movement of electrons within a body rather than between bodies.

$Q = kA\left(\frac{\Delta T}{L}\right)t$ Q = heat k = thermal conductivity

ΔT = change in temperature L = length

convection: movement of groups of molecules within fluids such as liquids or gases, and within non-molten solid that deforms by viscous flow; takes place through advection, diffusion, or both

Physics: Carnot Cycle and Entropy

efficiency $e = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H} = 1 - \frac{Q_C}{Q_H}$

Q_H = hot reservoir heat Q_C = cold reservoir heat

coefficient of performance $COP = \frac{Q_C}{W}$

change in entropy $\Delta S = \frac{Q}{T}$

Physics: Conservation of Energy

Conservation of Energy: in a system with no heat exchange with the surroundings, the heat that flows out of one object equals the heat that flows into a second object

Physics: Radiation and Newton's Law of Cooling

radiation: electromagnetic radiation generated by the thermal motion of charged particles in matter; all matter with a temperature greater than absolute zero emits thermal radiation.

Stefan-Boltzmann constant σ = 5.67 x 10^{-8} W/m^2 K^4

$P_{net} = e\sigma A(T^4 - T_s^4)$ $\quad P_{net}$ = net radiated power

e = emissivity $\quad A$ = area

T = object temperature $\quad T_s$ = temperature of surroundings

temperatures in K

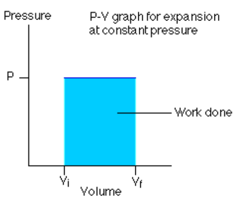
Newton's law of cooling $T(t) = T_s + (T(0) - T_s)e^{-rt}$

Physics: Laws of Thermodynamics

- Zeroth law: If two systems are in thermal equilibrium with a third system, they are in thermal equilibrium with each other.
- First law: When energy passes, as work, as heat, or with matter, into or out from a system, the system's internal energy changes in accordance with the law of conservation of energy.
- Second law: In a natural thermodynamic process, the sum of the entropies of the interacting thermodynamic systems increases.
- Third law: The entropy of a system approaches a constant value as the temperature approaches absolute zero. With the exception of non-crystalline solids (glasses) the entropy of a system at absolute zero is typically close to zero, and is equal to the logarithm of the product of the quantum ground states.

Physics: Isobaric Thermodynamics

isobaric (constant pressure) $\quad W = P\Delta V = nR\Delta T$



$$\Delta U = Q - P\Delta V = \frac{3}{2}nR\Delta T$$

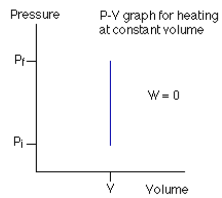
$$Q = \Delta U + P\Delta V = \frac{5}{2}nR\Delta T$$

W = work $\quad \Delta U$ = change in internal energy $\quad Q$ = heat

(Image source: http://physics.bu.edu/~duffy/py105/Firstlaw.html, Author : A. Duffy)

Physics: Isochoric Thermodynamics

isochoric (constant volume) $\quad W = 0$



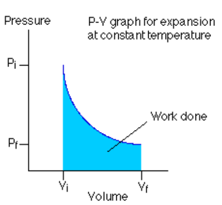
$$\Delta U = Q = \frac{3}{2}nR\Delta T$$

$$Q = \Delta U = \frac{3}{2}nR\Delta T$$

(Image source: http://physics.bu.edu/~duffy/py105/Firstlaw.html, Author: A. Duffy)

Physics: Isothermal Thermodynamics

isothermal (constant temperature) $\quad P_iV_i = P_fV_f = nRT$



$$W = Q = nRT\ln\left(\frac{V_f}{V_i}\right) = P_iV_i\ln\left(\frac{V_f}{V_i}\right)$$

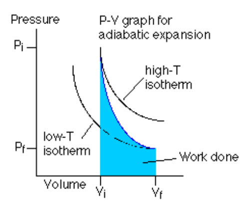
$$\Delta U = 0$$

$$Q = W = nRT\ln\left(\frac{V_f}{V_i}\right) = P_iV_i\ln\left(\frac{V_f}{V_i}\right)$$

(Image source: http://physics.bu.edu/~duffy/py105/Firstlaw.html, Author: A. Duffy)

Physics: Adiabatic Thermodynamics

adiabatic (no heat flow) $\quad P_iV_i^{\gamma} = P_fV_f^{\gamma}$,



$\gamma = \frac{5}{3}$ for monatomic ideal gas

$$W = -\Delta U = \frac{-3}{2}nR\Delta T$$

$$\Delta U = -W = \frac{3}{2}nR\Delta T \qquad Q = 0$$

(Image source: http://physics.bu.edu/~duffy/py105/Firstlaw.html, Author : A. Duffy)

Physics: Spherical Mirrors

spherical mirrors:

convex $\quad F = -\frac{1}{R}$

concave $\quad F = \frac{1}{R}$

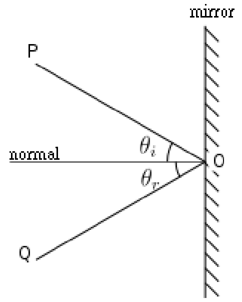
F = focal length $\quad R$ = mirror radius $\quad C$ = center of curvature

Physics: Mirrors

convex mirror object location	image orientation	image size	image type
arbitrary	upright	reduced	virtual
concave mirror object location	**image orientation**	**image size**	**image type**
beyond *C*	inverted	reduced	real
at *C*	inverted	same as object	real
between *F* and *C*	inverted	enlarged	real
just beyond *F*	inverted	approaching infinity	real
just inside *F*	upright	approaching infinity	virtual
between mirror and *F*	upright	enlarged	virtual

Physics: Reflection

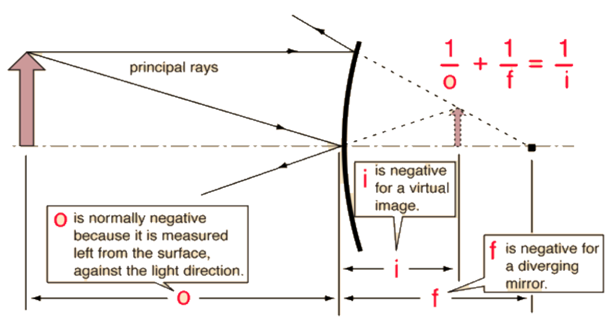
reflection: change in direction of a wavefront at an interface between two different media so that wavefront returns into the medium from which it originated; includes reflection of light, sound and water waves; law of reflection states that for specular reflection angle of incidence equals angle of reflection



(Image source: https://en.wikipedia.org/wiki/Reflection_(physics)#/media/File:Reflection_angles.svg, Author: Arvelius, CC BY-SA 3.0)

Physics: Convex Mirrors

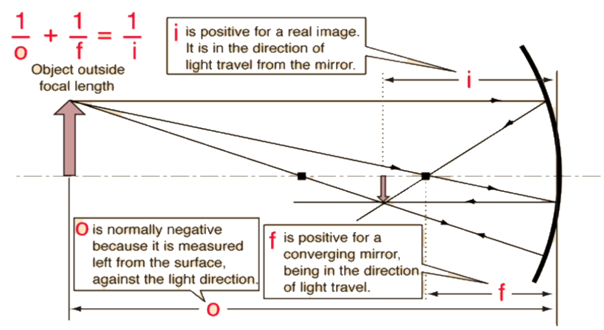
convex mirrors:



(Image source: http://hyperphysics.phyastr.gsu.edu/hbase/geoopt/mirray.html, Author: R. Nave, Georgia State University, used with permission)

Physics: Concave Mirrors

concave mirrors:



(Image source: http://hyperphysics.phyastr.gsu.edu/hbase/geoopt/mirray.html, Author: R. Nave, Georgia State University, used with permission)

Physics: Refraction and Snell's Law

index of refraction $v = \frac{c}{n}$ v = velocity of light through a substance

n = substance index of refraction c = 3.00 x 10^8 meters/second

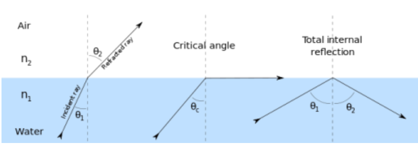
Snell's law $n_1 \sin\theta_1 = n_2 \sin\theta_2$

n_1 and n_2 = indexes of refraction of the two substances

θ_1 = angle of incidence

θ_2 = angle of refraction

critical angle for total internal reflection $\theta_C = \frac{n_2}{n_1}$

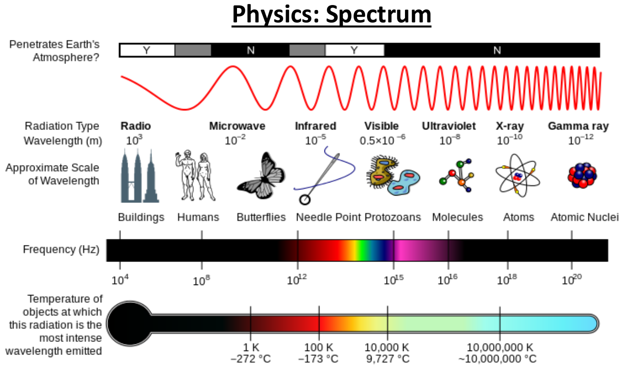


(Image source: https://en.wikipedia.org/wiki/Reflection_(physics)#/media/File:RefractionReflextion.svg, Author : Josell7, CC BY-SA 3.0))

Physics: Lenses

convcave lens object location	image orientation	image size	image type
arbitrary	upright	reduced	virtual
convex lens object location	**image orientation**	**image size**	**image type**
beyond *F*	inverted	reduced or enlarged	real
just beyond *F*	inverted	approaching infinity	real
just inside *F*	upright	approaching infinity	virtual
between lens and *F*	upright	enlarged	virtual

Physics: Spectrum



(Image source: https://en.wikipedia.org/wiki/Spectrum#/media/File:EM_Spectrum_Properties_edit.svg, Authors: Inductiveload, NASA, CC BY-SA 4.0)

Physics: Energy Quanta and Photoelectric Effect

energy $E = h\upsilon = \frac{hc}{\lambda}$

Planck's constant h = 6.626196 x 10^{-34} J s

υ = frequency of electromagnetic radiation

c = speed of light

λ = wavelength of electromagnetic radiation

photoelectric effect: $h\upsilon = \phi + \frac{1}{2}mv^2$

Physics: Heisenberg Uncertainty Principle, Schrödinger Wave Equation, De Broglie Equation

Heisenberg uncertainty principle: $\Delta x \Delta p \geq \frac{h}{4\pi}$

Δx = change in location Δp = change in momentum

h = Planck's constant

Schrödinger wave equation: $\Psi = A \exp\left[2\pi i\left(\frac{x}{\lambda} - vt\right)\right]$

De Broglie equation: relationship between particle and wave properties $\lambda = \frac{h}{p}$

Physics: Atomic Particles

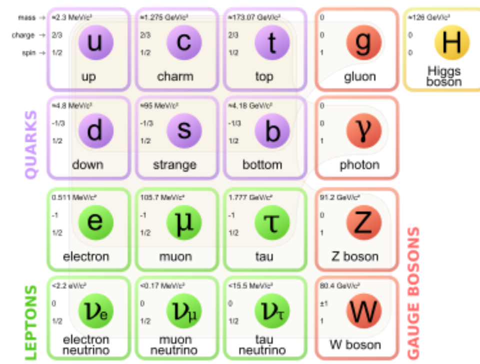
particle	kg	u	charge
alpha, α	6.6416×10^{-27}	4.00153	+2
beta, β	9.1091×10^{-31}	5.48597×10^{-4}	-1
deuteron, d	3.3421×10^{-27}	2.01355	+1
electron, e	9.1091×10^{-31}	5.48597×10^{-4}	-1
gamma ray, γ	0	0	0
neutrino, v	0	0	0
neutron, n	1.6748×10^{-27}	1.0086654	0
positron, +e	9.1091×10^{-31}	5.48597×10^{-4}	+1
proton, p	1.6725×10^{-27}	1.00727663	+1

Physics: Fundamental Forces

		weak	electro-magnetic	strong	
property/ interaction	gravitation	(electroweak)		fundamental	residual
acts on	mass - energy	flavor	electric charge	color charge	atomic nuclei
particles experiencing	all	quarks, leptons	charged particles	quarks, gluons	hadrons
particles mediating	gravitons (theoretical)	W and Z bosons	photons	gluons	mesons
strength in the scale of quarks	10^{-41}	10^{-4}	1	60	N/A to quarks
strength in the scale of protons/ neutrons	10^{-36}	10^{-7}	1	N/A to hadrons	20

(Source: https://en.wikipedia.org/wiki/Standard_Model)

Physics: Standard Model of Particle Physics



(Image source: https://en.wikipedia.org/wiki/Standard_Model#/media/File:Standard_Model_of_Elementary_Particles.svg, Author: MIssMJ, public domain)

Science

Science: Scientific Method

- Ask a question. What do you want to know about the world? Why do you want to know it? How can science answer the question?
- Do research. Has this question been asked before? Are there related questions? Can others provide information?
- Form a hypothesis. What do you think is the answer? Why do you think so? Can your prediction be tested?
- Test the hypothesis. Design an experiment. Perform the experiment carefully. Record the data.
- Analyze the data. Make a chart or graph. Compare your data to others' data. See if your data fits your hypothesis.
- Draw conclusions. What was learned from the experiment? Was the hypothesis correct? What questions remain?

Science: Scientific Notation and Significant Figures

scientific notation: $m \ x10^n$, where m is written with only one non-zero digit to the left of the decimal point and n is an integer

significant figure rules:

1. non-zero digits are always significant
2. any zeros between two significant digits are significant.
3. a final zero or trailing zeros in the decimal portion ONLY are significant

(Source: http://chemistry.bd.psu.edu/jircitano/sigfigs.html)

Science: Fundamental Units of the International System

quantity	unit	abbreviation
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
amount	mole	mol
luminosity	candela	cd

Science: Derived Units of the International System

quantity	unit	abbreviation
temperature	degree celsius	^{0}C
force	newton (kg m/s^2)	N
energy, work, heat	joule (N m)	J
pressure	pascal (N/m^2)	Pa
frequency	hertz (cycle/s)	Hz
electric potential	volt	V
resistance	ohm	Ω
power, heat flow	watt (J/s)	W

Science: Divisions of the International System

factor	prefix	symbol
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a
10^{-21}	zepto	z
10^{-24}	yocto	y

Science: Divisions of the International System

factor	prefix	symbol
10^{1}	deca	da
10^{2}	hecto	h
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E
10^{21}	zetta	Z
10^{24}	yotta	Y

Science: Metric and American Conversions

distance 1 kilometer (km) = 1000 meters (m) 1 meter (m) = 100 centimeters (cm) 1 centimeter (cm) = 10 millilters(mm) 1 yard (yd) = 0.914 meters (m) 1 mile (mi) = 1.609 kilometers (km)	**force** 1 newton (N) = 10^5 dynes
mass and weight 1 kilogram (kg) = 1000 grams (gm) 1 pound (lb) = 0.454 kilograms (kg) **volume** 1 liter (L) = 1000 milliliters (mL) 1 gallon (gal) = 3.785 liters (L)	**energy** 1 joule (J) = 10^7 ergs

Science: Temperature Conversion

Fahrenheit to Celsius: $^0C = \frac{5}{9}(^0F - 32)$

Celsius to Fahrenheit: $^0F = \frac{9}{5}(^0C) + 32$

Celsius to Kelvin: $K = {^0C} + 273$

Kelvin to Celsius: $^0C = K - 273$

Science: Angular Conversions

$$(1\ radian)\frac{360^0}{2\pi\ radians} = 57.3^0$$

$$(1^0)\frac{2\pi\ radians}{360^0} = 0.0174\ radians$$

$$\theta\ (in\ radians) = \frac{s}{r}$$

Science: Areas and Volumes

object	area	volume
regular polygon	$A = \frac{nsr}{2}$, n = number of sides, s = side length, r = radius	
sphere	$A = 4\pi r^2$	$V = \frac{4}{3}\pi r^3$
right circular cylinder	$A = 2\pi r^2 + 2\pi rh$	$V = \frac{4}{3}\pi r^2 h$

Technology

Technology: Base 2 and Base 10

IEC prefix		representations				customary prefix	
name	symbol	base 2	base 1024	value	base 10	name	symbol
kibi	Ki	2^{10}	1024^{1}	1024	$\approx 1.02\times10^{3}$	kilo	k or K
mebi	Mi	2^{20}	1024^{2}	1048576	$\approx 1.05\times10^{6}$	mega	M
gibi	Gi	2^{30}	1024^{3}	1073741824	$\approx 1.07\times10^{9}$	giga	G
tebi	Ti	2^{40}	1024^{4}	1099511627776	$\approx 1.10\times10^{12}$	tera	T
pebi	Pi	2^{50}	1024^{5}	1125899906842624	$\approx 1.13\times10^{15}$	peta	P
exbi	Ei	2^{60}	1024^{6}	1152921504606846976	$\approx 1.15\times10^{18}$	exa	E
zebi	Zi	2^{70}	1024^{7}	1180591620717411303424	$\approx 1.18\times10^{21}$	zetta	Z
yobi	Yi	2^{80}	1024^{8}	1208925819614629174706176	$\approx 1.21\times10^{24}$	yotta	Y

Technology: Electric Force and Charge

q_1/q_2 charges	force on q_1 charge	force on q_2 charge	result
- / -	←⊖	⊖→	repulsion
+ / +	←⊕	⊕→	repulsion
- / +	⊖→	←⊕	attraction
+ / -	⊕→	←⊖	attraction

particle	charge (C)	charge (e)
Electron	1.602×10^{-19} C	*-e*
Proton	1.602×10^{-19} C	*+e*
Neutron	0 C	0

Technology: Coulomb's Law

Coulomb's law $F = \dfrac{kq_1q_2}{r^2}$

F = force in newtons (N)

k = 8.988×10^{9} N·m^2/C^2

q_1 = first charge in coulombs (C).

q_2 = second charge in coulombs (C).

r = distance between the 2 charges in meters (m)

1 C = 6.242×10^{18} electrons

Technology: Ohm's Law, Power, and DC Circuits

Direct current (DC) is used to power electronics and other digital equipment, smartphones, tablets, electric vehicles, LED and LCD TVs, and is generated by a constant voltage source like a battery or other DC voltage source.

$V_R = I_R x R$ power $P = IV = I^2 R$

V_R = voltage drop in volts (V)

I_R = current in amps (A)

R = resistance in ohms (Ω)

Technology: Voltage and Current in DC Circuits

voltage in series $V_S = V_1 + V_2 + V_3 + \ldots$

voltage in parallel $V_P = V_1 = V_2 = V_3 = \ldots$

voltage divider for loads in series $V_i = V_{total} \dfrac{R_i}{R_{total}}$

current in series $I_S = I_1 = I_2 = I_3 = \ldots$

current in parallel $I_P = I_1 + I_2 + I_3 + \ldots$

current divider of resistors in parallel $I_i = I_P \dfrac{R_P}{R_i + R_P}$

Technology: Resistance and Capacitance in DC Circuits

resistance in series $R_{total} = R_1 + R_2 + R_3 + \ldots$

resistance in parallel $R_{total} = \dfrac{1}{1/R_1 + 1/R_2 + 1/R_3 + \ldots}$

capacitance in parallel $C_P = C_1 + C_2 + C_3 + \ldots$

capacitance in series $C_S = \dfrac{1}{1/C_1 + 1/C_2 + 1/C_3 + \ldots}$

inductance in parallel $L_P = \dfrac{1}{1/L_1 + 1/L_2 + 1/L_3 + \ldots}$

inductance in series $L_S = L_1 + L_2 + L_3 + \ldots$

Technology: Capacitance in DC Circuits

charge on a capacitor $q_{flow}(t) = Q_{\max}(1 - e^{-tRC})$

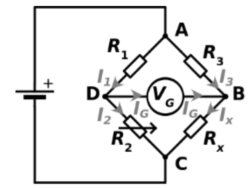
$Q_{\max} = CV_0$ $\qquad C = \dfrac{Q}{V_c}$

capacitors in series $\dfrac{1}{C_{total}} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3} + \ldots$

capacitors in parallel $C_{total} = C_1 + C_2 + C_3 + \ldots$

Technology: Wheatstone Bridge

$R_x = \dfrac{R_2}{R_1} x R_3$



$I_3 - I_x + I_G = 0 \qquad I_1 - I_2 - I_G = 0$

$I_3 R_3 - I_G R_G - I_1 R_1 = 0$

$I_x R_x - I_2 R_2 + I_G R_G = 0$

when bridge balanced $I_G = 0 \qquad I_3 R_3 = I_1 R_1 \qquad I_x R_x = I_2 R_2$

$V_G = \left(\dfrac{R_2}{R_1 + R_2} - \dfrac{R_x}{R_x + R_3} \right) V_S$

(Image source: https://en.wikipedia.org/wiki/Wheatstone_bridge#/media/File:Wheatstonebridge_current.svg, Authors: Rhdv and cmglee, CC BY SA 3.0)

Technology: RC Transient Response in DC Circuits with Switches

series, RC charging	series, RC discharging
$\tau = RC$	$\tau = RC$
$e^{-N} = e^{-t/\tau} = e^{-t/RC}$	$e^{-N} = e^{-t/\tau} = e^{-t/RC}$
$V_{bat} = V_R(t) + V_C(t)$	$0 = V_R(t) + V_C(t)$
$I(t) = \dfrac{V_{bat} - V_0}{R} e^{-N}$	$I(t) = \dfrac{V_0}{R} e^{-N}$
$V_R(t) = I(t)R = (V_{bat} - V_0)e^{-N}$	$V_R(t) = -V_0 e^{-N}$
$V_C(t) = V_0 + (V_{bat} - V_0)(1 - e^{-N})$	$V_C(t) = V_0 e^{-N}$
$Q_C(t) = C[V_0 + (V_{bat} - V_0)(1 - e^{-N})]$	$Q_C(t) = CV_0 e^{-N}$

Technology: RL Transient Response in DC Circuits with Switches

series, RL charging	series, RL discharging
$\tau = L/R$	$\tau = L/R$
$e^{-N} = e^{-t/\tau} = e^{-tR/L}$	$e^{-N} = e^{-t/\tau} = e^{-tR/L}$
$V_{bat} = V_R(t) + V_L(t)$	$0 = V_R(t) + V_L(t)$
$I(t) = I_0 e^{-N} + \dfrac{V_{bat}}{R}(1 - e^{-N})$	$I(t) = I_0 e^{-N}$
$V_R(t) = I(t)R = I_0 \mathrm{R} e^{-N} + V_{bat}(1 - e^{-N})$	$V_R(t) = I_0 \mathrm{R} e^{-N}$
$V_L(t) = (V_{bat} - I_0 R)e^{-N}$	$V_L(t) = -I_0 \mathrm{R} e^{-N}$

Technology: Voltage in AC Circuits

voltage $V(t) = V_{\max} \sin(\omega t) = \dfrac{I_{\max}}{\omega C} \sin(\omega t) = \dfrac{I_{\max}}{2\pi f} \sin(\omega t)$

$V(t)$ = voltage at time t (volts)

$V_{\max}$ = maximal voltage (amplitude of sine)

ω = angular frequency in radians per second (rad/s)

t = time in seconds (s)

f = frequency in Hz

$V_{RMS} = V_{\max} / \sqrt{2} = 0.707 V_{\max}$

peak-to-peak voltage $V_{P-P} = V_{\max}$

average power $P_{avg} = I_{RMS}^2 R$

Technology: Capacitors in AC Circuits

$I_{RMS} = \dfrac{V_{RMS}}{X_C}$

capacitive reactance $X_C = \dfrac{1}{\omega C} = \dfrac{1}{2\pi f C}$

f = frequency in Hz

ω = angular frequency in radians per second (rad/s)

C = capacitance in farads (F)

Technology: RC Circuits

capacitance reactance $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$ in ohms (Ω)

$$Z = \sqrt{R^2 + X_C^2} = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2} = \frac{V_{RMS}}{I_{RMS}}$$

phase angle $\cos\phi = \frac{R}{Z}$ $Z =$ impedence in ohms (Ω)

R = resistance in ohms (Ω) C = capacitance in farads (F)

$$V_{\max} = I_{\max}\sqrt{R^2 + X_C^2} = I_{\max} Z$$

$$V_{RMS} = I_{RMS}\sqrt{R^2 + X_C^2} = \sqrt{V_{RMS,R}^2 + V_{RMS,C}^2} = I_{RMS} Z$$

average power $P_{avg} = I_{RMS} V_{RMS} \cos\phi$

Technology: Inductors in AC Circuits

inductive reactance $X_L = \omega L = 2\pi f L$

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + (\omega L)^2} = \frac{V_{RMS}}{I_{RMS}}$$

phase angle $\cos\phi = \frac{R}{Z}$ $Z =$ impedence in ohms (Ω)

R = resistance in ohms (Ω) L = capacitance in farads (F)

$$V_{\max} = I_{\max}\sqrt{R^2 + X_L^2} = I_{\max} Z$$

$$V_{RMS} = I_{RMS}\sqrt{R^2 + X_L^2} = \sqrt{V_{RMS,R}^2 + V_{RMS,L}^2} = I_{RMS} Z$$

Technology: Current in AC Circuits

instantaneous current $I(t) = I_{\max}\sin(\omega t)$

$I(t)$ = current at time t in amps (A).

$I_{\max}$ = maximal current (amplitude of sine)

ω = angular frequency in radians per second (rad/s)

t = time in seconds (s)

RMS current $I_{RMS} = \frac{V_{RMS}}{X_C} = V_{RMS}\omega C$

peak-to-peak current $I_{P-P} = I_{peak}$

Technology: RLC Circuits and Resonance

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

$$\omega_0 = \frac{1}{\sqrt{LC}} = 2\pi f_0$$

f_0 = resonant frequency, frequency at which $X_L = X_C$

Technology: Resistivity

$$R = \frac{\rho L}{A}$$

for metallic conductors, the resistivity and resistance vary linearly with changes in temperature

$$\rho = \rho_0\left[1 + \alpha(T - T_0)\right]$$

$$R = R_0\left[1 + \alpha(T - T_0)\right]$$

ρ_0 = resistivity at T_0

R_0 = resistance at T_0

α = temperature coefficient

Technology: Boolean Algebra (1)

x	y	¬x	¬y	x^y	¬x^y	x^¬y	x˅y	¬x˅y	x˅¬y
0	0	1	1	0	0	0	0	1	1
1	0	0	1	0	0	1	1	0	1
0	1	1	0	0	1	0	1	1	0
1	1	0	0	1	0	0	1	1	1

x	y	x → y	x ⊕ y	¬x ⊕ ¬y	x≡y	¬x≡¬y
0	0	1	0	0	1	0
1	0	0	1	1	0	1
0	1	1	1	1	0	1
1	1	1	0	0	1	0

Technology: Boolean Algebra (2)

x^y = x AND y x˅y = x OR y x ⊕ y = x EXCLUSIVE OR y

¬x = NOT x x≡y = x EQUALS y

x^y = ¬(¬x˅¬y) = xy = min(x,y)

x˅y = ¬(¬x^¬y) = x + y – xy = max(x,y)

x → y = ¬x˅y x ⊕ y = (x˅y)^¬(x^y)

¬x = 1-x x≡y = ¬(x ⊕ y)

Demorgan's laws

¬x^¬y = ¬(x˅y)

¬x˅¬y = ¬(x^y)