Phil's Orderly Physics Curriculum Important Concepts List (POPCICL) 1C

[Warning : This list is NOT intended to be comprehensive, but rather to highlight a few key concepts]

Oscillatory Motion

A repeated back-and-forth motion is called an ___________.

Oscillations can arise when you have a system that provides a _________ force that tend to push the system back towards its equilibrium position.

______________________ is the name given to oscillations where the motion can be described mathematically by sinusoids (sines or cosines). A system that undergoes ___________(SHM) is called a ___________ ___________(SHO).

The time that it takes to complete one full oscillation is called the ______ of the motion. The number of full oscillations per second is call the ___________ and is given the symbol _____.

The position for the sinusoidal motion of a SHO can be written as ____(formula)_____ where A is the __________ of the oscillation, ω is the ____________ of the oscillation and ϕ is the ___________.

The ___________ is the positive maximal displacement of the object from its equilibrium position.

The angular frequency is measured in ___(units)______. It describes how the sinusoidal back-and-forth motion of a SHO is related to the projection (or "shadow") of ____________________ onto a 1-D axis.

The _____________determines shifts the sinusoidal function back-or-forward in time to allow for systems that are in a particular portion of their oscillatory cycle (peak, trough, or anywhere in between) at time t=0. [Note that cos (ωt + π/2) is identical to sin(ωt)]

The frequency and period of an oscillating mass on a spring depend on the _________ and the ________, but do not depend on the ______________________.

The velocity for the sinusoidal motion of a SHO is the time derivative of the position, and is also sinusoidal. ____(formula)_______

The acceleration for the sinusoidal motion of a SHO is the time derivative of the velocity, and is also sinusoidal. ____(formula)_______

An object undergoing SHM has a maximum speed, and hence maximum kinetic energy at _____(where?)______ where |Δx| = ___The speed and kinetic energy drop to zero at the _____(where?)______, where |Δx| = ___

An object undergoing SHM has a maximum net force, and hence the magnitude of the acceleration is also maximal at _____(where?)______ where |Δx| = ___. The net force on the object and its acceleration drop to zero at _____(where?)______ where |Δx| = ___

As the SHO oscillates, the total energy ______________ ; the distribution of that energy between potential energy and kinetic energy __________________.

At _____(where?)______ where |Δx| = ___, the kinetic energy of a SHO drops of to zero, and so all of the total energy is stored as potential energy; thus the total energy of the SHO is given by : ___(formula)_____.

A simple pendulum can be approximated as a SHO for __________ oscillations.

The frequency and period of an simple pendulum depend on the __________________ and the magnitude of the gravitational force (which is nearly constant anywhere on the surface of the Earth); but they are independent of both the ____________________, and the ____________________.

Mechanical Waves

A wave is a __________ that __________ (moves in a particular direction) away from its source.

A __________ wave is a wave that requires a physical medium through which to propagate. A non-mechanical wave (such as an electromagnetic wave) does not require a medium (it can propagate through empty space)

A __________ wave is a wave in which the direction of the local disturbance is perpendicular to the direction of the wave propagation

A __________ wave is a wave in which the direction of the local disturbance is parallel to the direction of the wave propagation.

A one-dimensional sinusoidal wave traveling in the positive x direction can be described by the wave function: _____(formula)_____, where A is the amplitude, k is the wave number, and ω is the angular frequency.

The wave number, k, is related to the wavelength, λ, by the relationship : ___(formula)___ .

The angular frequency, ω, is related to the frequency, f, and period, T, by the relationship : ___(formulas)___

The ________ is the separation (across space) of two identical points on a periodic (repeating) propagating wave.

The ________ is the separation (across time) of two identical points of a periodic propagating wave.

The __________ is a measure of the number of full cycles of the wave are completed per second.

The ______________ is a measure of the number of radians of phase are completed per second.

There are _____ radians of phase in a full cycle (compare to the circumference of a unit circle)

The speed of a wave is related to the velocity of that wave through a particular medium by the "wave speed relationship" : ___(formula)___.

The speed of a wave (including the speed of sound) is purely a property of the _______. It does not depend on the ________ or ________ of the wave. (In the same air, all sounds will travel at the same speed regardless of how loud they are or how high-or-low pitched they are).

In general, the speed of a wave in a material is proportional to the square-root of the ratio of the media's ________ properties to its ________ properties.

For a wave on a string, the wave speed is equal to the square-root of the ratio of the ________ of the string to the _________________ of the string.

For a sound wave, the wave speed is equal to the square-root of the ratio of the _________ of the medium to the ________________ of the medium.

The bulk modulus is a measure of "how difficult" it is to ________ the medium. A medium that is very difficult to ________ has a large bulk modulus, and thus a higher wave speed.

The density of a material (including air) depends on its __________, and so the speed of sound in the material will also depend on the _____(same as earlier)_____.

If the source of a sound and the observer of that sound are both stationary, then the observer will hear a frequency that is ____________ the frequency of the original source.

If the source or the observer are moving relative to each other, the observer will hear a different _________ than the original source. The observed frequency will be shifted _____ if the relative motion is bringing them closer together, and the observed frequency will shifted ______ if the relative motion is taking them further apart.

When a wave crosses a boundary from a lower density material to a higher density material (such as a rigid wall or a heavier string) then at least some of the wave will be reflected back with its amplitude ________.

When a wave crosses a boundary from a higher density material to a lower density material (such as a free end or a lighter string) then at least some of the wave will be reflected back with its amplitude ________.

When two traveling waves encounter each other, they can momentarily exhibit ________ or ________ interference, but then continue to propagate past their point of overlap ________.

Standing Waves

Two overlapping waves that are ___________ (moving in opposite directions) but have the same frequency can interfere to form a standing wave.

A sinusoidal standing wave has the form : _____(formula)_____, where A, k and ω are the ________,________ and __________________, of the two counter-propagating sine waves that created the standing wave.

While it is created from two propagating waves, the standing wave pattern itself __(does/doesn't)___ propagate. Each element of the medium (say, the string) oscillates locally as a ___________ : cos(ωt) with an amplitude that is fixed for all time at that location, x. But from location-to-location, the amplitude of the oscillation varies as ____(formula)____.

The location where the amplitude of the standing wave pattern is maximal is called an ________.

The location where the amplitude of the standing wave is zero is called a ________.

There are three types of boundary conditions that support standing wave patterns : ________, ________, and ________.

A string held fixed at both ends, as in a guitar or violin, exhibits the ________ boundary condition.

A tube that is open at both ends, as in a flute or a toilet-paper roll, exhibits the ________ boundary condition.

A tube that is closed at one end, as in a clarinet or an uncapped plastic bottle, exhibits the ________ condition.

A closed-closed condition requires a(n) ______ at each end. The lowest (fundamental) mode of oscillation that can be sustained (a.k.a the first harmonic) has one ________ in the middle and has a wavelength that is _____ the length of the string. The next higher mode has two antinodes and is called the second harmonic and is ___________ longer than the fundamental. Each higher harmonic adds an additional ________________.

The harmonic frequencies are described by the formula : _____(formula)_____.

An open-open condition requires a(n) ______ at each end. The fundamental mode has one ____ in the middle and has a wavelength that is _____ the tube length. The next higher mode has two internal nodes and is called the second harmonic and is ______________ longer than the fundamental. Each higher harmonic adds an additional ________________. The harmonic frequencies are described by : _____(formula)_____.

An open-closed condition requires a(n) ______ at the closed end and a(n) ______ at the open end. The fundamental mode has ____ internal nodes and ____ internal antinodes and has a wavelength that is ______ times the length of the tube. The next higher mode (second harmonic) is half a wavelength longer (tube length = _(fraction)___ wavelength). Each higher harmonic adds an additional ___________. The harmonic frequencies are described by the formula : _____(formula)_____.

When two traveling waves of slightly different frequencies are superimposed on each other, the phenomenon of ________________ can be observed as a result of the two waves gradually drifting in-and-out of phase with each other at the location of the observer. The rhythmic modulation of the overall sound amplitude has a frequency equal to the ________ of the two individual frequencies : _____(formula)_____

Electromagnetic (EM) Waves

Maxwell's Equations is a collection of ___ equations that form the basis of all electrical and magnetic phenomena and predict the propagation of electric or magnetic disturbances as an ________________________________.

Electromagnetic waves travel at the speed of _____ which is given by __(symbol)_ = ___(formula)__ = __(value)_

In an EM wave, the ratio of the amplitudes of the electric (E) and magnetic (B) fields is given by ________.

An EM wave consists of a(n) _______ electric field oscillating perpendicular to a(n) _______ magnetic field. Both fields are also perpendicular to the direction of wave propagation.

The intensity of an EM wave is proportional to the ___________________________ of either oscillating field.

An EM wave is an example of a _______________ transverse wave. It can travel through vacuum.

The intensity of an EM wave is equal to the _______ carried by the wave divided by the _______ of its wavefront.

Visible light is an example of an EM wave, and makes up a _______ portion of the full EM spectrum.

EM waves include (in order of decreasing increasing wavelength : Gamma rays, _______, _______ light, Visible light, _______ light, microwaves, and _______.

Visible light makes up a ___ fraction of the electromagnetic spectrum, and runs from ____ -____ nm wavelengths.

In a vacuum, all EM waves have the same ___________ but have different ___________ and ___________

Violet/Blue light is at the _____-wavelength end of the visible range. Red light is at the _____-wavelength end.

The ___________ of an EM wave describes the orientation of the electric field in the wave.

Light from thermal sources generally contain every ___________ of polarization. This light is call "___________".

Light in which all of the electric fields point along a single line is called ___________ polarized light.

Light of any polarization can be decomposed into a _______ electric field component and a _______ component.

A linear polarizer ________________ light that is polarized along the direction of its transmission axis.

A linear polarizer ________________ light that is polarized perpendicular to its transmission axis.

"Unpolarized Light" can be turned into linearly polarized light by passing it through a _________ _________.

When linearly polarized light is incident on a linear polarizer that has its transmission axis at an angle, θ, relative to the incident light's polarization, the transmitted fraction is given by __(name)___ : ____(formula)______.

Wave Optics

Young's double slit experiment demonstrated the ____ nature of light by producing __________ __________ on a screen when two closely spaced slits were illuminated by a ________ light source.

Two slit interference produces a ________ fringe at points on the screen that have a difference in path lengths from the two slits that are equal to an integer multiple of a wavelength of the illuminating light.

Two slit interference produces a ________ fringe at points on the screen that have a difference in path lengths from the two slits that are equal to a 1/2 (or 3/2 or 5/2) wavelength of the illuminating light.

In evaluating the positions of the fringes on the screen, we often use the ____ ______ approximation. If we also assume that the two slits are ________ _______, then the interference intensity pattern has the regularly-spaced form of a ________ function

Light passing through a single rectangular slit produce a ________ pattern, which is actually an _________ pattern between light waves passing through different parts of a rectangular slit of finite width, *a*.

The locations of the ____________________ of a single-slit diffraction pattern are difficult to calculate, but the exact center of the ____________ can be easily calculated to be at the angles : ____*(formula)*____

Light passing through a ____ ________ produces a circularly symmetric diffraction pattern called an Airy pattern. The width of the central _______ ____ determined by the angle to the first ____ fringe of the Airy pattern, which in turn determines the minimum angular ________ for imaging through a ________ opening.

The limiting resolution for imaging through a ________ ________ of width, *a*, is $\theta_{min} = \lambda / a$.

The limiting resolution for imaging through a ________ ________ of diameter, *D*, is $\theta_{min} = 1.22\cdot(\lambda / D)$.

A ____________________ consists of a series of rectangular slits (or lines) that are equally spaced with a spacing that is on the order of the ____________________________.

Light incident on a diffraction grating will produce bright ____ on a distant screen. The angle to these bright spots is the same as for the angle to the ______ ______ due to illumination of two slits with the same spacing.

Compared to the two-slit interference pattern, the bright spots of the diffraction grating are more ________________, and the dark bands are ________.

Thin Films

Light waves (or other EM waves) travels through vacuum at _______________________, c = __*(value)*___

When light waves (or other EM waves) travel through different media, the speed of the light is reduced by a factor, __(symbol)__, called the ____________________ of that material. ____*(formula)*____

When light waves (or other EM waves) travel through different media, the wavelength of the light is ________ by a factor of n (index of refraction) compared to its wavelength in vacuum. ____*(formula)*____.

When light transitions from one medium to another medium of a different refractive index, a ________________ occurs at the interface between the two media.

If light is moving from a medium with a ________ index of refraction to a medium with a ________ index of refraction, then the reflection will undergo a ____________________ phase shift upon reflection.

If light is moving from a medium with a ________ index of refraction to a medium with a ________ index of refraction, then the reflection will NOT undergo a phase shift.

Interference between the reflections off the front and back surfaces of a thin film of transparent material results in a ___________________ of a particular wavelength if the reflection off the second interface arrives back at the first interface exactly in phase with the reflection off the first interface.

The relative phase of the second-surface reflection depends on : the ____________ through the film, the ________ of the wavelength within the media, and the (possible) ________________ at the interfaces.

Ray Optics : Reflection and Refraction

In geometric optics, we ignore (most) of the ________ properties of light and treat light as a ________ that travels in straight lines through uniform media.

At an interface between two dissimilar media, light can undergo ________ or ________.

Reflection at a smooth interface obeys the law of reflection : the incident angle is _________ the reflected angle.

When light transmits from one medium to another medium, the light ray can _______ ("______") to a new _____.

The amount that the light bends at an interface is determined by the values of the ________________ of the two materials that make up the interface, and is given by ________ Law : ___(formula)___ , where the angle are measured relative to the ________________________.

Huygen's principle states that all points on a ________ (the points of constant phase of the wave) can be treated as ______________________________ that travel outward at the speed of the wave in the medium.

The new wavefront at some later time can be found by drawing the ________to these secondary wavelets

Huygen's principle, when applied to a wavefront incident (at an angle) on an interface between two media can explain the ________________ of light at that interface.

Although the index of refraction for a particular material is often given as a single number, it is actually a continuum of numbers that vary with the _____________________. The variation of refractive index with ___________ is called "________".

The angular spreading of different colors (wavelengths) of light through a prism is a combined result of ________ and ________________.

Most normal transparent materials have a dispersion curve in which the index of refraction is ________ for shorter wavelengths of light. Thus, ______ light "bends" more than _______ light as it transmits from air to glass.

When incident from a _(higher/lower)_ refractive index material (such as____) to a _(higher/lower)_ refractive index material (such as ____), all possible incident angles result in some real transmitted angle in the higher index media.

When incident from a _(higher/lower)_ refractive index material (such as ____) to a _(higher/lower)_ refractive index material (such as ____), there is a "_______ angle" (measured relative to the normal to the interface) beyond which no light is transmitted into the lower index media. This phenomenon is called ____________________.

The _______ angle occurs when the transmitted angle in the _(higher/lower)_ index media reaches 90 degrees relative to the normal to the interface. Beyond the _______ angle, Snell's Law does not result in a real angle solution for the transmitted beam, and thus _________________. All the light is _______ at the angle of _______.

Image Formation by Lenses and Mirrors

An _____ is form when many (or all) of the light rays that leave a particular point either _______ to another single point or appear to _______ from another single point that is at a different location from the object itself.

If the light rays actually converge to a point in space, then a _______ image of the original object is formed there.

If the light rays do not physically converge to a point, but appear to diverge from a common point that is separate from the original object, then a _______ image of the original object is formed at that point.

For a _______ image, a screen (piece of paper) placed at the image point of a glowing object would result in a sharp copy of that glowing object appearing on the screen.

For a _______ image, a screen (piece of paper) placed at the image point of a glowing object would NOT result in a sharp copy of that glowing object appearing on the screen.

Images can be produced by spherical _______ or spherical _______, both of which have surfaces that are a part of larger spherical surfaces with a particular radii of curvature.

The _______ axis (a.k.a., _______axis) of a mirror or lens is the line that runs through the symmetrical center of the front face of the mirror/lens and is perpendicular to the surface at that point.

The ______ length of a mirror or lens is the distance (from a lens or mirror) at which a sharp image will form when the object is infinitely far away so that the incident rays are parallel. If the parallel rays are also parallel to the principal axis, then the rays will converge to the ___________, which also lies on the principal axis.

For a spherical mirror, the focal length is exactly ____________ the radius of curvature of the mirror.

For a spherical lens, the focal length depends on both the ______________ and the ______________. For a lens surrounded by air, the focal length is given by the the _______ Formula : ___*(formula)*____.

The location of the image formed by spherical thin lenses or mirrors is given by the ____ Equation : __*(formula)*__

The magnification of an image formed by a thin lens or mirror is given by __*(formula)*__.

Glass or plastic shaped with a bi-convex or plano-convex shape acts as _______ lens (a.k.a. _______) lenses.

Glass or plastic shaped with a bi-concave or plano-concave shape acts as _______ (a.k.a. _______) lenses.

For light incident from the left on a lens, the positive object space is on the _(left/right)_ of the lens, the positive image space is on the _(left/right)_ of the lens, and the radius of curvature is positive if the center of curvature is to the right of the corresponding lens surface.

For a positive lens, an object out at infinity on the left of the lens produces an inverted, smaller, inverted real image to the right of the lens.

As the object moves toward a positive lens from infinity, the _____, _____ object moves __(away/towards)__the lens to the __(left/right)__, and _(grows/shrinks)_ in height. When the object reaches _____ the focal length, the real inverted image reaches the same height as the original and is located at a position of ______ the focal length to the right of the lens.

As the object move inside the focal length of the _______ lens, the image flips from being an larger, inverted, real image at the far right of the lens, to being a _______, _______, _______ image to the far left of the lens.

Image Formation by Lenses and Mirrors (cont)
[assume incident light is from the left]

Ray tracing of lenses and mirrors proceeds with the three following rules:

1) The ray leaving the object parallel to the principal axis passes through the _______________.
2) The ray leaving the object on a trajectory that passes through the ________ exits the lens parallel to the principal axis.
3) The ray leaving the object on a trajectory through the center point _______________________.

For a positive lens, the primary focal point is to the _____ of the lens and the secondary focal point is to the _____.

For a negative lens, the focal length is negative, and the primary focal point is to the ________ of the lens while the secondary focal point is to the ________ of the lens.

For a positive (concave) mirror, there is only one focal point, and it is to the ________ of the mirror surface.

For a negative (convex) mirror, there is only one focal point, and it is to the ________ of the mirror surface.

For all thin spherical lenses, the center point for ray tracing is the _______________________.

For all spherical mirrors, the center point for ray tracing is at the _______________________________.

For a system of two or more lenses, light from a light source on the left passing through a the first lens produces either a ________ image to the left of the lens or a _______ image to the right of the lens. This image then serves as a “second stage” ________ for the second lens, which also produces a real or virtual “image of the image”.

The Human Eye

Accommodation refers to the ability of the eye change the _______ _______ of the crystalline lens of the eye by adjusting its _______.

When the ciliary muscles of the eye are relaxed, the crystalline lens has a more ____ shape, and thus a _____ focal length. This relaxed state is the least accommodated, and is used for viewing objects located ________.

When the ciliary muscles of the eye are strained, the crystalline lens has a more _____ shape and thus a _____ focal length. This is the most accommodated state and is used for viewing objects located _______.

The ____ point of a person's eye is the furthest distance at which an object can be positioned and still form a sharp image on the retina with the unaided lens of the eye. The _[same]_ point of a healthy eye is at _____.

The ____ point of a person's eye is the nearest distance at which an object can be positioned and still form a sharp image on the retina with the unaided lens of the eye. The _[same]_ point of a healthy eye is ~ _____ cm

A person with myopia is ____-sighted. They can see ____ objects clearly, but cannot see clearly ______ their (myopic) far point. Their (myopic) far point is _*(closer/farther)*_than the far point of a healthy eye.

A person with hyperopia is ____-sighted. They can see ____ objects clearly, but cannot see clearly if an object is closer than their (hyperopic) near point. This (hyperopic) near point is _*(closer/farther)*_ than that of a healthy eye.

The prescription lens for a person with myopia (____-sightedness) is a _*(+) or (-)*_ focal length lens. Its job is to take an object at the "normal ___- point" (___cm) and make an image at the person's myopic far point.

The prescription lens for a person with hyperopia (____-sightedness) is a _*(+) or (-)* focal length lens. Its job is to take an object at the "normal ___- point" (___cm) and make an image at the person's hyperopic near point.

Compound Microscopes

A traditional microscope objective takes a sample placed just outside of its focal length and makes a ___ image of it at the "_________ image plane" (typically ~160 mm behind the objective). This "intermediate image" acts as the object for an ______ that produces a virtual image at $-\infty$ so it can be viewed with a ___ eye.

The resolution of a microscope is determined by the ____________ (abbreviated:___) of the microscope objective and is given by the Abbe resolution limit : ___*(formula)*___

The numerical aperture (___) of a microscope objective lens depends on the _______ half-angle (center-to-edge) of light acceptance and on the ____________ of the immersion medium . (___*(formula)*___**).**

Quantum Mechanics (QM)

____________________ describes the spectrum of electromagnetic emission given off by warm objects.

The first quantum mechanical model arose as a way to correctly model the observed shape of the blackbody spectrum. (The classical wave model incorrectly predicted an explosion of energy in the _____ portion of the spectrum - an inconsistency called the "_______________")

A key feature of the quantum mechanical model is the introduction of _______ energy states.

Quantum mechanical effects become significant at very small scales. At macroscopic (large) scales, quantum mechanical effects are too small to be noticed. The requirement that quantum mechanics must correctly reproduce classical results at macroscopic scales is called the correspondence principle.

In the quantum mechanical model of EM waves, light can be described as a stream of discrete particles called photons. Each photon has a specific wavelength, frequency, and energy, related by $E = hf = hc/\lambda$

An important application of the QM model of light is the accurate description of the ejection of electrons from a metal surface exposed to certain incident light, a phenomenon called the photoelectric effect.

In the photoelectric effect, electrons are only emitted from the metal if the energy of the incident photons exceed the metal's work function ϕ (the binding energy that holds the outermost valence electrons to the metal), with the excess energy going into the kinetic energy of the emitted electron.

The kinetic energy of the emitted electron in the photoelectric effect depends on the energy (and thus the frequency or wavelength) of the incident photon, but does not depend on the intensity of the light beam. Increasing the intensity of the light beam increases the number of emitted electrons, but not their kinetic energy.

In the wave picture, intensity relates to the square of the wave amplitude. In the particle picture, intensity relates to the number (or density) of particles.

Light can legitimately be thought of both as a wave or as a particle. In some situations, light behaves more like a wave, and it other situations, light behaves more like a particle.

Compton scattering of X-rays off of electrons provided proof of the particle nature of EM waves. The scattered X-rays were observed to have a positive wavelength shift that depends only on the angle of scattered X-ray, and does not depend on the incident wavelength of the EM wave.

Compton scattering provided evidence that a photon is a particle with a distinct energy and momentum.

De Broglie correctly hypothesized that if something classically considered a wave (like light) has a particle nature, then classical particles should also have a wave nature and thus an associated wavelength.

The De Broglie wavelength of a particle (e.g., an electron) is inversely related to its momentum : $\lambda = h/p$.

The Heisenberg uncertainty principle states that the particle's position along an particular axis and the particle's momentum along that same axis cannot be simultaneously known with infinite accuracy. The product of the uncertainties cannot be smaller than the constant value $h/4\pi$: $\Delta x \cdot \Delta p_x \geq h/4\pi$

At the quantum mechanical level, a particle is described by a wave function, Ψ, which has an associated probability amplitude, ψ. The square of the probability amplitude is called the probability density, $|\psi|^2$, and gives the probability of the particle being found in a particle point in space.

If a microscopic particle is placed in a one-dimensional box, then the wavefunction must obey the boundary conditions of the box : the probability of finding the particle outside the box must be zero, which implies that ψ must go to zeros at the edges of the box. These boundary conditions give rise to solutions that are sinusoids of discrete wavelengths. This is turn gives rise to a discrete set of possible energies states for the trapped particle. $E_n = (h^2n^2) / (8mL^2)$ $n = 1,2,3,...$

Atomic Physics

Prior to 1911, scientists (incorrectly) believed in a “Plum pudding” model of an atom.

In 1911, Ernest Rutherford discovered the atomic nucleus as a concentrated positive charge at the center of the atom; but his planetary model of the atom incorrectly imagined the electrons circling the nucleus in planet-like orbits.

The (incorrect) planetary model of the atom would exhibit continuous, gradual orbital decay of the electron orbit into the nucleus; this does not happen, and so the planetary model is incorrect.

The planetary model was replaced by Bohr's semi-classical (and semi-quantum-mechanical) model of the atom in which only specific, discrete electron orbits that were stable and did not decay or radiate except when jumping to another allowed discrete orbit.

The Bohr model of the atom was replaced with the (currently accepted) fully quantum mechanical model of the atom, which correctly predicts the splitting of spectral lines into doublets and triplets and also accurately populates the periodic table of elements.

In the full QM model of the atom, each electron occupies a unique electronic state that is described by four quantum numbers :

- n - principal quantum number : describes the energy level (or “shell”) of the electron
- ℓ - orbital quantum number : describes the orbital angular momentum (or “subshell”) of the electron
- m_ℓ - orbital magnetic quantum number : describes the azimuthal component of the angular momentum (or “orbital”) of the electron.
- m_s - spin magnetic quantum number : describes the intrinsic spin of the electron.

The quantum numbers only take on specific values, some depending on the value of other quantum numbers:

$n = 1,2,3,4,....$ traditional names : 1 = K , 2 = L , 3 = M , 4 = N , 5 = O , ….

$\ell = 0, 1, ...(n-1)$ traditional names : 0 = s , 1 = p , 2 = d , 3 = f

$m_\ell = -\ell, -\ell+1, \ldots 0, \ldots \ell-1, \ell$

$m_s = -½ , + ½$

The Pauli exclusion principle states that each unique quantum state can only be occupied by one electron.

For a hydrogen atom, the energy associated with a quantum state depends on its principal quantum number and is given by $E_n = -13.606 \text{ eV} / n^2$ $(n = 1, 2, 3, \ldots)$

The magnitude of the orbital angular momentum of the hydrogen atom is quantized and can only take on the discrete values : $L = \sqrt{l(l+1)}\hbar$ $(\ell = 0,1,2,\ldots n-1)$

The angle that the orbital angular momentum vector makes with respect to an external magnetic field is also quantized and can only take on discrete values (this effect is called space quantization). As a result, the azimuthal component (z-component) of the orbital angular momentum is also quantized : $L_z = m_l \hbar$

The lowest energy state (n=1) is called the ground state.

The ground state energy is negative, and its magnitude corresponds to the ionization energy for that atom.

When an electron in an atom moves from a higher energy state to a lower energy state, it emits a photon with an energy equal to the difference between the two energy states.

An electron can move from a lower energy state to a higher energy state in an atom by absorption of a photon with an energy equal to the difference between the two energy states.

The Lymann, Balmer, and Paschen spectral lines of hydrogen correspond to transitions from higher energy states to the n=1, n=2, and n=3 shells respectively. The transition wavelength is given by the (generalized) Rydberg formula : $\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$, where R is the Rydberg constant is $R = 1.097 \times 10^7 m^{-1}$