15/05/2023 to 21/05/2023

1. What are the basic laws in astrophysics

1.Kepler’s Laws of Planetary Motion

Kepler’s First Law(Law of orbits)
A planet orbits the Sun in an ellipse, with the Sun at one focus of the ellipse.

Kepler’s Second Law(Law of equalarea)
A line connecting a planet to the Sun sweeps out equal areas in equal time intervals

Kepler's Third Law(Law of periods)
The squares of the orbital periods of the planets are directly proportional to the cubes of the semi-major axes of their orbits.

2.Newton's law of universal gravitation

Is usually stated as that every particle attracts every other particle in the universe with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between their centers.

$$F = GMm/r2$$

where $G = 6.673 \times 10-11$ N m2 kg−2 (the Universal Gravitational Constant)

 # An ideal emitter(is an object that absorbs all of the light energy incident upon it and reradiates this energy with the characteristic spectrum) reflects no light, it is known as a blackbody, and the radiation it emits is called blackbody radiation. Stars and planets are blackbodies, at least to a rough first approximation.

Stefan's Law

The total radiant heat power emitted from a surface is proportional to the fourth power of its absolute temperature.

$$L = A\sigma T\^4$$

where σ = 5.670400×10^−8W m^−2K^−4

For a spherical star of radius R and surface area A = 4πR2, the Stefan–Boltzmann equation takes the form

$$L = 4\pi R^2 \sigma T_e^4$$

2.What are the different celestial coordinate systems

1.The Altitude–Azimuth Coordinate System

The altitude–azimuth (or horizon) coordinate system is based on the measurement of the azimuth angle along the horizon together with the altitude angle above the horizon.The altitude h is defined as that angle measured from the horizon to the object along a great circle2 that passes through that object and the point on the celestial sphere directly above the observer, a point known as the zenith. Equivalently, the zenith distance z is the angle measured from the zenith to the object, so $z + h = 90^\circ$. The azimuth A is simply the angle measured along the horizon eastward from north to the great circle used for the measure of altitude. (The meridian is another frequently used great circle; it is defined as passing through the observer's zenith and intersecting the horizon due north and south.)
Although simple to define, the altitude–azimuth system is difficult to use in practice. Coordinates of celestial objects in this system are specific to the local latitude and longitude of the observer and are difficult to transform to other locations on Earth. Also, since Earth is rotating, stars appear to move constantly across the sky, meaning that the coordinates of each object are constantly changing, even for the local observer. Complicating the problem still further, the stars rise approximately 4 minutes earlier on each successive night, so that even when viewed from the same location at a specified time, the coordinates change from day to day

Daily and Seasonal Changes in the Sky
To understand the problem of these day-to-day changes in altitude–azimuth coordinates, we must consider the orbital motion of Earth about the Sun (see Fig. 9). As Earth orbits the Sun, our view of the distant stars is constantly changing. Our line of sight to the Sun sweeps through the constellations during the seasons; consequently, we see the Sun apparently move through those constellations along a path referred to as the ecliptic.During the

spring the Sun appears to travel across the constellation of Virgo, in the summer it moves through Orion, during the autumn months it enters Aquarius, and in the winter the Sun is located near Scorpius. As a consequence, those constellations become obscured in the glare of daylight, and other constellations appear in our night sky. This seasonal change in the constellations is directly related to the fact that a given star rises approximately 4 minutes earlier each day. Since Earth completes one sidereal period in approximately 365.26 days,it moves slightly less than 1◦ around its orbit in 24 hours. Thus Earth must actually rotate nearly 361◦ to bring the Sun to the meridian on two successive days (Fig. 10). Because of the much greater distances to the stars, they do not shift their positions significantly as Earth orbits the Sun. As a result, placing a star on the meridian on successive nights requires only a 360◦ rotation. It takes approximately 4 minutes for Earth to rotate the extra 1◦. Therefore a given star rises 4 minutes earlier each night. Solar time is defined as an average interval of 24 hours between meridian crossings of the Sun, and sidereal time is based on consecutive meridian crossings of a star. Seasonal climatic variations are also due to the orbital motion of Earth, coupled with the approximately 23.5◦ tilt of its rotation axis. As a result of the tilt, the ecliptic moves north and south of the celestial equator (Fig. 11), which is defined by passing a plane through Earth at its equator and extending that plane out to the celestial sphere. The sinusoidal shape of the ecliptic occurs because the Northern Hemisphere alternately points toward and then away from the Sun during Earth's annual orbit. Twice during the year the Sun crosses the celestial equator, once moving northward along the ecliptic and later moving to the south. In the first case, the point of intersection is called the vernal equinox and the southern crossing occurs at the autumnal equinox. Spring officially begins when the center of the Sun is precisely on the vernal equinox; similarly, fall begins when the center of the Sun crosses the autumnal equinox. The most northern excursion of the Sun along the ecliptic occurs at the summer solstice, representing the official start of summer, and the southernmost position of the Sun is defined as the winter solstice.

The seasonal variations in weather are due to the position of the Sun relative to the celestial equator. During the summer months in the Northern Hemisphere, the Sun's northern declination causes it to appear higher in the sky, producing longer days and more intense sunlight. During the winter months the declination of the Sun is below the celestial equator,its path above the horizon is shorter, and its rays are less intense.The more direct the Sun's rays, the more energy per unit area strikes Earth's surface and the higher the resulting surface temperature.

2.The Equatorial Coordinate System

A coordinate system that results in nearly constant values for the positions of celestial objects, despite the complexities of diurnal and annual motions,is necessarily less straight forward than the altitude azimuth system. The equatorial coordinate system is based on the latitude–longitude system of Earth but does not participate in the planet's rotation. Declination δ is the equivalent of latitude and is measured in degrees north or The Celestial Sphere south of the celestial equator. Right ascension α is analogous to longitude and is measured eastward along the celestial equator from the vernal equinox (♈) to its intersection with the object's hour circle (the great circle passing through the object being considered and through the north celestial pole). Right ascension is traditionally measured in hours, minutes, and seconds; 24 hours of right ascension is equivalent to 360◦, or 1 hour = 15◦. The rationale for this unit of measure is based on the 24 hours (sidereal time) necessary for an object to make two successive crossings of the observer's local meridian. The coordinates of right ascension and declination are also indicated in Figs. 2 and 11. Since the equatorial coordinate system is based on the celestial equator and the vernal equinox, changes in the latitude and longitude of the observer do not affect the values of right ascension and declination. Values of α and δ are similarly unaffected by the annual motion of Earth around the Sun.The local sidereal time of the observer is defined as the amount of time that has elapsed since the vernal equinox last traversed the meridian. Local sidereal time is also equivalent to the hour angle H of the vernal equinox, where hour angle is defined as the angle between a celestial object and the observer's meridian, measured in the direction of the object's motion around the celestial sphere.

Precession

Despite referencing the equatorial coordinate system to the celestial equator and its intersection with the ecliptic (the vernal equinox), **precession causes the right ascension and declination** of celestial objects to change, albeit very slowly. Precession is the slow wobble of Earth's rotation axis due to our planet's nonspherical shape and its gravitational interaction with the Sun and the Moon. It was Hipparchus who first observed the effects of precession. Although we will not discuss the physical cause of this phenomenon in detail,it is completely analogous to the well-known precession of a child's toy top. Earth's precession period is 25,770 years and causes the north celestial pole to make a slow circle through the heavens. Although Polaris (the North Star) is currently within 1◦ of the north celestial pole, in 13,000 years it will be nearly 47◦ away from that point. The same effect also causes a 50.26″ yr−1 westward motion of the vernal equinox along the ecliptic.4 An additional precession effect due to Earth–planet interactions results in an eastward motion of the vernal equinox of 0.12″ yr−1.Because precession alters the position of the vernal equinox along the ecliptic, it is necessary to refer to a specific epoch (or reference date) when listing the right ascension and declination of a celestial object. The current values of α and δ may then be calculated,based on the amount of time elapsed since the reference epoch. The epoch commonly used today for astronomical catalogs of stars, galaxies, and other celestial phenomena refers to an object's position at noon in Greenwich, England (universal time, UT) on January 1, 2000.5 A catalog using this reference date is designated as J2000.0. The prefix, J, in the designation J2000.0 refers to the Julian calendar, which was introduced by Julius Caesar in 46 b.c.Approximate expressions for the changes in the coordinates relative to J2000.0 are

$\Delta\alpha = M + N \sin \alpha \tan \delta$
$\Delta\delta = N \cos \alpha$,

where M and N are given by
$M = 1°.2812323T + 0°.0003879T 2 + 0°.0000101T 3$
$N = 0°.5567530T - 0°.0001185T^2 - 0°.0000116T^3$
and T is defined as $T = (t - 2000.0)/100$
where t is the current date, specified in fractions of a year.

3.The Interaction of Light and Matter

Spectral Lines

The foundations of spectroscopy were established by Robert Bunsen, a German chemist, and by Gustav Kirchhoff, a Prussian theoretical physicist.Bunsen's burner produced a colorless flame that was ideal for studying the spectra of heated substances. He and Kirchhoff then designed a spectroscope that passed the light of a flame spectrum through a prism to be analyzed. The wavelengths of light absorbed and emitted by an element were found to be the same; Kirchhoff determined that 70 dark lines in the solar spectrum correspond to 70 bright lines emitted by iron vapor. In 1860 Kirchhoff and Bunsen published their classic work Chemical Analysis by Spectral Observations, in which they developed the idea that every element produces its own pattern of spectral lines and thus may be identified by its unique spectral line "fingerprint." **Kirchhoff summarized the production of spectral lines in three laws, which are now known as Kirchhoff's laws**:

1.A hot, dense gas or hot solid object produces a continuous spectrum with no dark spectral lines.

2. A hot, diffuse gas produces bright spectral lines (emission lines).

3.Acool, diffuse gas in front of a source of a continuous spectrum produces dark spectral lines (absorption lines) in the continuous spectrum.

Wavelengths of some of the stronger Fraunhofer lines measured in air near sea level:-

Wavelength Equivalent
(nm) Name Atom Width (nm)
385.992 Fe I 0.155
388.905 H8 0.235
393.368 K Ca II 2.025

396.849 H Ca II 1.547
404.582 Fe I 0.117
410.175 h, Hδ HI 0.313
422.674 g Ca I 0.148
434.048 G′
, Hγ HI 0.286
438.356 d Fe I 0.101
486.134 F, Hβ HI 0.368
516.733 b4 Mg I 0.065
517.270 b2 Mg I 0.126
518.362 b1 Mg I 0.158
588.997 D2 Na I 0.075
589.594 D1 Na I 0.056
656.281 C, Hα HI 0.40

PHOTONS

Despite Heinrich Hertz’s absolute certainty in the wave nature of light, the solution to the riddle of the continuous spectrum of blackbody radiation led to a complementary description, and ultimately to new conceptions of matter and energy. Planck’s constant h is the basis of the modern description of matter and energy known as quantum mechanics.

The Photoelectric Effect

When light shines on a metal surface, electrons are ejected from the surface, a result called the photoelectric effect. The electrons are emitted with a range of energies, but those originating closest to the surface have the maximum kinetic energy, Kmax. A surprising feature of the photoelectric effect is that the value of Kmax does not depend on the brightness of the light shining on the metal. Increasing the intensity of a monochromatic light source will eject more electrons but will not increase their maximum kinetic energy. Instead, Kmax varies with the frequency of the light illuminating the metal surface. In fact, each metal has a characteristic cutoff frequency vc and a corresponding cutoff wavelength λc = c/vc; electrons will be emitted only if the frequency v of the light satisfies v > vc (or the wavelength satisfies
λ < λc).

Einstein’s bold solution was to take seriously Planck’s assumption of the quantized energy of electromagnetic waves seriously. According to Einstein’s explanation of the photoelectric effect, the light striking the metal surface consists of a stream of massless particles called photons.The energy of a single photon of frequency v and wavelength λ is just the energyof Planck's quantum of energy:

$E_{photon} = hv = hc/\lambda$.

Einstein reasoned that when a photon strikes the metal surface in the photoelectric effect,its energy may be absorbed by a single electron. The electron uses the photon's energy to overcome the binding energy of the metal and so escape from the surface. If the minimum binding energy of electrons in a metal (called the work function of the metal, usually a few eV) is φ, then the maximum kinetic energy of the ejected electrons is

$K_{max} = E_{photon} - \varphi = hv - \varphi = hc/\lambda - \varphi$.

Setting $K_{max} = 0$, the cutoff frequency and wavelength for a metal are seen to be $v_c = \varphi/h$ and $\lambda_c = hc/\varphi$, respectively.

The photoelectric effect established the reality of Planck's quanta. Albert Einstein was awarded the 1921 Nobel Prize, not for his theories of special and general relativity, but "for his services to theoretical physics, and especially for his discovery of the law of the photoelectric effect." Today astronomers take advantage of the quantum nature of light in various instruments and detectors, such as CCDs (charge-coupled devices).

<u>The Compton Effect</u>

American physicist Arthur Holly Compton provided the most convincing evidence that light does in fact manifest its particle-like nature when interacting with matter. Compton measured the change in the wavelength of X-ray photons as they

were scattered by free electrons. Because photons are massless particles that move at the speed of light, the relativistic energy equation (with mass m = 0 for photons), shows that the energy of a photon is related to its momentum p by

$E_{photon} = hv = hc$

$\lambda = pc$.

The Compton effect: The scattering of a photon by a free electron. θ and φ are the scattering angles of the photon and electron, respectively.

wavelength, λ_i, by an amount

"$\lambda = \lambda_f - \lambda_i = h\ m_ec\ (1 - \cos\theta)$

where m_e is the mass of the electron. Today, this change in wavelength is known as the Compton effect. The term h/m_ec in Eq. is called the Compton wavelength, λ_C is the characteristic change in the wavelength of the scattered photon and has the value λ_C =0.00243 nm, 30 times smaller than the wavelength of the X-ray photons used by Compton. Compton's experimental verification of this formula provided convincing evidence that photons are indeed massless particles that nonetheless carry momentum, as described by Eq. This is the physical basis for the force exerted by radiation upon matter.

THE BOHR MODEL OF THE ATOM

The pioneering work of Planck, Einstein, and others at the beginning of the twentieth century revealed the wave particle duality of light. Light exhibits its wave properties as it propagates through space, as demonstrated by its double-slit interference pattern. On the other hand, light manifests its particle nature when it interacts with matter, as in the photoelectric and Compton effects. Planck's formula describing the energy distribution of blackbody radiation explained many of the features of the continuous spectrum of light emitted by stars.

The Structure of the Atom

Joseph John Thomson discov-
ered the electron while working at Cambridge University's Cavendish Laboratory. Because bulk matter is electrically neutral, atoms were deduced to consist of negatively charged elec-
trons and an equal positive charge of uncertain distribution Ernest Rutherford working at England's University of Manchester, discovered in 1911 that
an atom's positive charge was concentrated in a tiny, massive nucleus. Rutherford directed high-speed alpha particles (now known to be helium nuclei) onto thin metal foils. He was amazed to observe that a few of the alpha particles were bounced backward by the foils instead of plowing through them with only a slight deviation. Rutherford later wrote: "It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you." Such an event could occur only as the result of a single collision of the alpha particle with a minute, massive, positively charged nucleus. Rutherford calculated that the radius of the nucleus was 10,000 times smaller than the radius of the atom itself, showing that ordinary matter is mostly empty space! He established that an electrically neutral atom consists of Z electrons (where Z is an integer), with Z positive elementary charges confined to the nucleus. Rutherford coined the term proton to refer to the nucleus of the hydrogen atom (Z =1), 1836 times more massive than the electron.

The Wavelengths of Hydrogen

The experimental data were abundant. The wavelengths of 14 spectral lines of hydrogen had been precisely determined.

The wavelengths of selected hydrogen spectral lines in air.

Series Name Symbol Transition Wavelength (nm)
Lyman Lyα 2 ↔ 1 121.567
Lyβ 3 ↔ 1 102.572
Lyγ 4 ↔ 1 79.254
Lylimit ∞ ↔ 1 91.18
Balmer Hα 3 ↔ 2 656.281
Hβ 4 ↔ 2 486.134
Hγ 5 ↔ 2 434.048
Hδ 6 ↔ 2 410.175
Hϵ 7 ↔ 2 397.007
H8 8 ↔ 2 388.905
Hlimit ∞ ↔ 3 364.6
Paschen Paα 4 ↔ 3 1875.10
Paβ 5 ↔ 3 1281.81
Paγ 6 ↔ 3 1093.81
Palimit ∞ ↔ 3 820.4

Bohr's Semiclassical Atom

The dimensions of Planck's constant, J×s are equivalent to kg × m s^{-1} × m, the units of angular momentum. Perhaps the angular momentum of the orbiting electron was quantized. This quantization had been previously introduced into atomic models by the British astronomer J. W. Nicholson. Although Bohr knew that Nicholson's models were flawed, he recognized the possible significance of the quantization of angular momentum. Just as an electromagnetic wave of frequency v could
have the energy of only an integral number of quanta, E = nhv, suppose that the value
of the angular momentum of the hydrogen atom could assume only integral multiples of
Planck's constant divided by

2π: L = nh/2π = n!.

Bohr hypothesized that in orbits with precisely these allowed values of the angular momentum, the electron would be stable and would not radiate in spite of its centripetal acceleration.

h/2π = 1.054571596 × 10^{-34} J s and is pronounced "h-bar."

Coulomb's law

$F = 1/4\pi\epsilon^\circ \times q_1q_2/r^2 * \hat{r}$,

$\mu = m_em_p/m_e + m_p$

$F = \mu a$

$1/4\pi\epsilon^\circ \times q_1q_2/r^2 * \hat{r} = -\mu v^2/r * \hat{r}$

0 is defined as $\epsilon^\circ \equiv 1/\mu_0c^2$, where $\mu_0 \equiv 4\pi \times 10^{-7}$ N A^{-2} is the permeability of free space and $c \equiv 2.99792458 \times 10^8$ m s^{-1} is the defined speed of light.

$K = ½ \mu v^2 = 1/8\pi\epsilon_0 \times e^2/r$

$U = -1/4\pi\epsilon_0 \times e^2/r = -2K$.

$E = K + U = K - 2K = -K = - 1/8\pi\epsilon_0 \times e^2/r$

$L = \mu vr = n$

Solving this equation for the radius r shows that the only values allowed by Bohr's quantization condition are

$r_n = 4\pi\epsilon_0 h^2/\mu e^2 \times n^2 = a_0n^2$

$a_0 = 5.291772083 \times 10^{-11}$
m = 0.0529 nm is known as the Bohr radius.

$E_n = - \mu e^4/32\pi^2\epsilon_0^2h^2 \, 1/n^2 = -13.6 \text{ eV} \times 1/n^2$.

The integer n, known as the principal quantum number, completely determines the characteristics of each orbit of the Bohr atom.

E = −13.6 eV.

The electron loses energy "E =Ehigh−Elow

$E_{photon} = E_{high} - E_{low}$

$$hc/\lambda = \left(-\mu e^4/32\pi2\epsilon20h^2 \times 1/n^2high\right) - \left(-\mu e^4/32\pi2\epsilon20h^2 \times 1/n2low\right)$$

$$1/\lambda = \mu e^4/64\pi3\epsilon0^2h^3C(1/n2low - 1/n^2high$$

$R_H = \mu e^4/64\pi3\epsilon0^2h^3C=10967758.3m^{-1}$

The reverse process may also occur. If a photon has an energy equal to the differencein energy between two orbits (with the electron in the lower orbit), the photon may be absorbed by the atom. The electron uses the photon’s energy to make an upward transition from the lower orbit to the higher orbit. The relation between the photon’s wavelength and the quantum numbers of the two orbits is again given by Eq.

$$1/\lambda = \mu e^4/64\pi3\epsilon0^2h^3C(1/n2low - 1/n^2high$$

After the quantum revolution, the physical processes responsible for Kirchhoff’s laws (discussed in Section 1) finally became clear.

• A hot, dense gas or hot solid object produces a continuous spectrum with no dark spectral lines. This is the continuous spectrum of blackbody radiation emitted at any temperature above absolute zero and described by the Planck functions $B_\lambda(T)$ and $B_v(T)$. The wavelength λ_{max} at which the Planck function$B_\lambda(T)$ obtains its maximumvalue is given by Wien’s displacement law

• A hot, diffuse gas produces bright emission lines. Emission lines are produced whenan electron makes a downward transition from a higher orbit to a lower orbit. The energy lost by the electron is carried away by a singlephoton. For example, the hydrogen Balmer emission lines are produced by electrons “falling” from higher orbits down to the $n = 2$ orbit

• A cool, diffuse gas in front of a source of a continuous spectrum produces dark absorption lines in the continuous spectrum. Absorption lines are produced whenan electron makes a transition from a lower orbit to a higher orbit. If an incident photon in the continuous spectrum has exactly the right amount of energy, equal to the difference in energy between a higher orbit and the electron’s initial orbit, the photon is absorbed by the atom and the electron makes an upward transition to that higher orbit. For example, the hydrogen Balmer absorption lines are produced by atoms absorbing photons that cause electrons to make transitions from the n = 2 orbit to higher orbits

Despite the spectacular successes of Bohr's model of the hydrogen atom, it is not quite correct. Although angular momentum is quantized, it does not have the values assigned by Bohr. Bohr painted a semiclassical picture of the hydrogen atom, a miniature Solar System with an electron circling the proton in a classical circular orbit. In fact, the electron orbits are not circular. They are not even orbits at all, in the classical sense of an electron at a precise location moving with a precise velocity. Instead, on an atomic level,nature is "fuzzy," with an attendant uncertainty that cannot be avoided. It was fortunate that Bohr's model, with all of its faults, led to the correct values for the energies of the orbits and to a correct interpretation of the formation of spectral lines. This intuitive, easily imagined model of the atom is what most physicists and astronomers have in mind when they visualize atomic processes.

QUANTUM MECHANICS AND WAVE–PARTICLE DUALITY

The last act of the quantum revolution began with the musings of a French prince, Louis de Broglie. Wondering about the recently discovered wave–particle duality for light, he posed a profound question: If light (classically thought to be a wave) could exhibit the characteristics of particles, might not particles sometimes manifest the
properties of waves.

de Broglie's Wavelength and Frequency

In his 1927 Ph.D. thesis, de Broglie extended the wave–particle duality to all of nature.Photons carry both energy E and momentum p, and these quantities are related to the frequency v and wavelength λ of the light wave by Eq.

$$v = E/h$$
$$\lambda = h/p$$

de Broglie proposed that these equations be used to define a frequency and a wavelength for all particles. The de Broglie wavelength and frequency describe not only massless photons but massive electrons, protons, neutrons, atoms, molecules, people, planets, stars, and galaxies as well. This seemingly outrageous proposal of matter waves has been confirmed in countless experiments. Figure 9 shows the interference pattern produced by electrons in a double-slit experiment. Just as Thomas Young's double-slit experiment established the wave properties of light, the electron double-slit experiment can be explained only by the wave-like behavior of electrons, with each electron propagating through both slits.14 The wave–particle duality applies to everything in the physical world; everything exhibits its wave properties in its propagation and manifests its particle nature in its interactions.

Just what are the waves that are involved in the wave–particle duality of nature? In a double-slit experiment, each photon or electron must pass through both slits, since the interference pattern is produced by the constructive and destructive interference of the two waves. Thus the wave cannot convey information about where the photon or electron is,but only about where it may be. The wave is one of probability, and its amplitude is denoted by the Greek letter - (psi). The square of the wave amplitude(psi^2) at a certain location describes the probability of finding the photon or electron at that location. In the double-slit experiment, photons or electrons are never found where the waves from slits 1 and 2 have destructively interfered—that is, where |psi1 + psi2^2|=0

$$\Delta x \, \Delta p \geq 1/2h$$

This is known as Heisenberg's uncertainty principle.

The equality is rarely realized
in nature, and the form often employed for making estimates is

$$\Delta x \, \Delta p \approx h$$

similar statement relates the uncertainty of an energy measurement, "E, and the time interval, "t, over which the energy measurement is taken:

$$\Delta E \, \Delta t \approx h$$

<u>Quantum Mechanical Tunneling</u>

When a ray of light attempts to travel from a glass prism into air, it may undergo total internal reflection if it strikes the surface at an angle greater than the critical angle θc, where the critical angle is related to the indices of refraction of the glass and air by
sin θc = nair/nglass

This familiar result is nonetheless surprising because, even though the ray of light is totally reflected, the index of refraction of the outside air appears in this formula. In fact, the electromagnetic wave does enter the air, but it ceases to be oscillatory and instead dies away exponentially. In general, when a classical wave such as a water or light wave enters a medium through which it cannot propagate, it becomes evanescent and its amplitude decays exponentially with distance wave once again becomes oscillatory upon entering the glass, and so the ray of light has traveled from one prism to another without passing through the air gap between the prisms. In the language of particles, photons have tunneled from one prism to another without traveling in the space between them.

Barrier penetration is extremely important in radioactive decay, where alpha particles tunnel out of an atom's nucleus; in modern electronics, where it is the basis for the "tunnel diode"; and inside stars, where the rates of nuclear fusion reactions depend upon tunneling.

Schrödinger's Equation and the Quantum Mechanical Atom

Heisenberg's uncertainty principle does not allow classical orbits, with their simultaneously precise values of the electron's position and momentum. Instead, the electron orbitals must be imagined as fuzzy clouds of probability, with the clouds being more "dense" in regions where the electron is more likely to be found. In 1925 a complete break from classical physics was imminent, one that would fully incorporate de Broglie's matter waves. Maxwell's the Interaction of Light and Matter equations of electricity andmagnetismcan bemanipulated to produce a wave equation for the electromagnetic waves that describe the propagation of photons. Similarly, a wave equation discovered in 1926 by Erwin Schrödinger, an Austrian physicist, led to a true quantum mechanics, the quantum analog of the classical mechanics that originated with Galileo and Newton. The Schrödinger equation can be solved for the probability waves that describe the allowed values of a particle's energy, momentum, and so on, as well as the particle's propagation through space.

In particular, the Schrödinger equation can be solved analytically for the hydrogen atom,giving exactly the same set of allowed energies as those obtained by Bohr. However, in addition to the principal quantum number n, Schrödinger found that two additional quantum numbers, ℓ and m_ℓ, are required for a complete description of the electronorbitals. These additional numbers describe the angular momentum vector, L, of the atom.Instead of the quantization used by Bohr, L = n!, the solution to the Schrödinger equation shows that the permitted values of the magnitude of the angular momentum L are actually

$$\mathbf{L = \sqrt{\ell(\ell + 1)}h}$$

where $\ell = 0, 1, 2, \ldots, n - 1$, and n is the principal quantum number that determines the energy.

m_ℓ equal to any of the $2\ell + 1$ integers between $-\ell$ and $+\ell$

Different orbitals, labeled by different values of ℓ and m_ℓ are said to be degenerate if they have the same value of the principal quantum number n and so have the same energy. Electrons making a transition from a given orbital to one of several degenerate orbitals will produce the same spectral line, because they experience the same change in energy.

Zeemaneffect

Electrons making a transition between

these formerly degenerate orbitals will thus produce spectral lines with slightly different frequencies. The splitting of spectral lines in a weak magnetic field is called the Zeeman effect.

$$v = v0 \text{ and } v0 \pm eB/4\pi\mu$$

Spin and the Pauli Exclusion Principle

Attempts to understand more complicated patterns of magnetic field splitting (the anomalous Zeeman effect), usually involving an even number of unequally spaced spectral lines,led physicists in 1925 to discover a fourth quantum number. In addition to its orbital motion, the electron possesses a spin. This is not a classical top-like rotation but purely a quantum effect that endows the electron with a spin angular momentum S.S is a vector of constant magnitude

$$S = \sqrt{1/2(1/2 + 1)}\, h = \sqrt{3}/2\, h$$

No two electrons can occupy the same quantum state is called Pauli's exclusion principle.

It also explained and extended the Pauli exclusion principle by dividing the world of particles into two fundamental groups: fermions and bosons. Fermions are particles such as electrons,protons, and neutrons that have a spin of 1/2h (or an odd integer times 1/2h, such as 3/2h,5/2h,...). Fermions obey the Pauli exclusion principle, so no two fermions of the same type can have the same set of quantum numbers. The exclusion principle for fermions, along with Heisenberg's uncertainty relation, explains the structure of white dwarfs and neutron stars Bosons are particles such as photons that have an integral spin of 0,h,2h,3h, ...
Bosons do not obey the Pauli exclusion principle, so any number of bosons can occupy the same quantum state.

As a final bonus, the Dirac equation predicted the existence of antiparticles.Aparticle and its antiparticle are identical except for their opposite electric charges and magnetic moments. Pairs of particles and antiparticles may be created from the energy of gamma-ray photons (according to $E = mc2$). Conversely particle–antiparticle pairs may annihilate each other with their mass converted back into the energy of two gamma-ray photon.

Pair creation and annihilation play a major role in the evaporation of black holes.

The Complex Spectra of Atoms

With the full list of four quantum numbers (n, ℓ, mℓ, and ms) that describe the detailed state an each electron in an atom, the number of possible energy levels increases rapidly with the number of electrons. When we take into account the additional complications of external magnetic fields, and the electromagnetic interactions between the electrons them-
selves and between the electrons and the nucleus, the spectra can become very complicated indeed.

Telescopes

GALILEOS USE OF THE NEW OPTICAL DEVICE KNOWN AS THE TELESCOPE GREATLY IMPROVED OUR ABILITY TO OBSERVE THE UNIVERSE.

Refraction and Reflection

GALILEO'S TELESCOPE WAS A refracting TELESCOPE THAT MADE USE OF LENSES THROUGH WHICH LIGHT
WOULD PASS ULTIMATELY FORMING AN IMAGE ,ATER .NEWTON DESIGNED AND BUILT A reflecting
TELESCOPE THAT MADE USE OF MIRRORS AS THE PRINCIPAL OPTICAL COMPONENT "OTHER REFRACTORS AND
REmECTORS REMAIN IN USE TODAY

4HE PATH OF A LIGHT RAY THROUGH A LENS
CAN BE UNDERSTOOD USING Snell's law OF REFRACTION 2ECALL THAT AS A LIGHT RAY TRAVELS FROM
ONE TRANSPARENT MEDIUM TO ANOTHER ITS PATH IS BENT AT THE INTERFACE 4HE AMOUNT THAT THE RAY
IS BENT DEPENDS ON THE RATIO OF THE WAVELENGTHDEPENDENT INDICES OF REFRACTION $n\lambda \equiv c/v\lambda$
OF EACH MATERIAL WHERE $v\lambda$ REPRESENTS THE SPEED OF LIGHT WITHIN THE SPECIIC MEDIUM)F θ

IS THE ANGLE OF INCIDENCE MEASURED WITH RESPECT TO THE NORMAL TO THE INTERFACE BETWEEN THE
TWO MEDIA AND θ IS THE ANGLE OF REFRACTION ALSO MEASURED RELATIVE TO THE NORMAL TO THE
INTERFACE SEE &IG THEN 3NELLS LAW IS GIVEN BY
$n\lambda \text{ SIN } \theta = n\lambda \text{ SIN } \theta$.

IF THE SURFACES OF THE LENS ARE SHAPED PROPERLY A BEAM OF LIGHT RAYS OF A GIVEN WAVELENGTH
ORIGINALLY TRAVELING PARALLEL TO THE AXIS OF SYMMETRY OF THE LENS CALLED THE optical axis

4HE UNIQUE
POINT IN EITHER CASE IS REFERRED TO AS THE focal point OF THE LENS AND THE DISTANCE TO THAT POINT
FROM THE CENTER OF THE LENS IS KNOWN AS THE focal length f &OR A CONVERGING LENS THE FOCAL
LENGTH IS TAKEN TO BE POSITIVE AND FOR A DIVERGING LENS THE FOCAL LENGTH IS NEGATIVE

4HE FOCAL LENGTH OF A GIVEN THIN LENS CAN BE CALCULATED DIRECTLY FROM ITS INDEX OF REFRACTION
AND GEOMETRY)F WE ASSUME THAT BOTH SURFACES OF THE LENS ARE SPHEROIDAL THEN IT CAN BE SHOWN
THAT THE FOCAL LENGTH fλ IS GIVEN BY THE lensmaker's formula

fλ
= (nλ −)
!
R
+

R
"

The Focal Plane

4HE focal plane IS DElNED AS THE PLANE PASSING THROUGH THE FOCAL
POINT AND ORIENTED PERPENDICULAR TO THE OPTICAL AXIS OF THE SYSTEM

OPTICAL TELESCOPES

angular magnification
m = fOBJ
fEYE

Refracting Telescopes
Reflecting Telescopes

Telescope Mounts

In order to account for %arths rotation perhaps the most common types of telescope mount especially for smaller telescope is the equatorial mount

Large-Aperture Telescopes
Adaptive Optics
Space-Based Observatories
Electronic Detectors

RADIO TELESCOPES

INFRARED, ULTRAVIOLET, X-RAY, AND GAMMA-RAY ASTRONOMY

Atmospheric Windows in the Electromagnetic Spectrum

Reference: An introduction to Modern Astrophysics: Bradley W Carrol and Dale A Ostile