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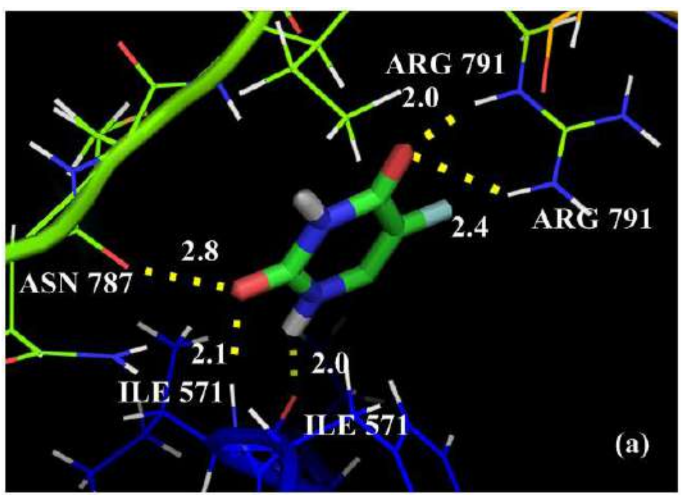

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Shades and Reflections of Light

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The paper endeavours the history of light and optics from the early Greek period and discusses the contributions made by philosophers and later by scientists in understanding the properties of light. Many of the thoughts expressed by Philosophers and Scientists about the nature of light have been taken from the Internet.

Keywords: EM spectrum, Rectilinear propagation, Reflection, Refraction

1. Introduction

Light is a small part of EM spectrum to which the human eye is sensitive but also includes the juxtaposed ultraviolet and infrared portions. Optics is defined as the science and technology of generation, amplification, propagation, manipulation and detection of light. Optics pervades all branches of science, engineering, medicine, agriculture etc. and enables technologies in the respective fields. Optics is an enabling technology. The article traces our understanding of light and development of the field of optics.

2. Early Period (~6th – 1st Century BCE)

Our comprehension of light, from Greek's period till the 17th Century, was governed by (i) rectilinear propagation and (ii) vision both seeing and colour perception. The source of light was the fire - a sacred element for the ancients. There has been large number of convoluted theories of light and vision from the Greek period till middle ages.

Two schools of thought, Samkhya and Vaisheshika, developed theories of light during 6th-5th century BCE in India [1]. Light was considered as one of the five fundamental subtle elements by Samkhya School. Light rays were considered as a stream of high velocity fire atoms, which can exhibit different characteristics depending on the speed and arrangement of these fire atoms. Like the ancient Greeks, early Indian philosophers assumed the eye to be the source of light. Susruta in 1st century BC posited that the light was arriving from the external sources. Aryabhatta also considered the source of light to be outside the eye. Chakrapani suggested that light traveled in waves with high speed. Mimamsakas imagined light to comprise of minute particles in constant motion and spreading through radiation and diffusion from the original sources. Varahmihira in 6th century BC discussed reflection as being caused by light particles arriving at an object and then back scattering (*kiranavighattana*, *murcchana*). Vatsyayana called this phenomenon as *rasmiparavartana* and explained the occurrence of shadows and opacity. Refraction was explained as the ability of light to penetrate the inner spaces of translucent and transparent materials. Uddyotakara considered refraction similar to the fluid moving through the porous materials (*tatra parispandah tiryaggamanam parisravah pata iti*).

Since the light travels in a straight line, it was considered as stream of particles. Further the sense of light would disappear as soon as the fire is extinguished irrespective of its location from the observer. Therefore the particles were believed to originate from the eye. This was the Pythagorean view. According

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to Democritus (460 - 370 BC), light rays were considered to be a flux of light particles traveling in straight lines and freely through empty space and which could penetrate transparent bodies. Plato (428/427 - 348/347 BCE) invented a theory of vision involving three streams of light: one from what is being seen, one from the eyes, and one from the illuminating source. This theory, however, did not hold long.

Aristotle (384 - 322 BCE) opined that light was not a substance or body but a quality of the transparent. Light is a kind of colour of the transparent, in so far as this is actualized by fire or something similar to the celestial body. The mere potentiality of the transparent is darkness. The transition from the potentially transparent to the actually transparent happens under the influence of fire or the shining bodies of Heaven. The primarily visible quality of objects is their color. Colors are qualities, which, like light, become actual in bodies that are not completely transparent but only participate in the nature of transparency to a certain degree. Therefore, it seems natural that Aristotle calls light the "color of the transparent".

Mo Zi also Mo Di (470 - 391 BCE) was a Chinese philosopher who described basic optical knowledge that includes rectilinear propagation, relationship between object and image in plane mirror, convex mirror and concave mirror, imaging in pinhole camera and vision.

Euclid (325 - 265 BCE) wrote a book that contains the geometry of vision. Euclid's optics is the earliest surviving manuscript of optics written in Greek. It deals almost entirely with the geometry of vision, with little reference to either the physical or psychological aspects of sight. Euclid's *Optics* influenced the work of later Greek, Islamic, and Western European Renaissance scientists and artists.

Subsequently, Archimedes (287- 212 BCE) was familiar with the working of concave mirror as he used a number of them collectively as a parabolic reflector to focus the sunrays on the enemy ship: the arrangement is known as Archimedes heat ray.

3. Middle Age Era

Lucretius (99 - 55 BCE) wrote that 'The light and heat of the sun are composed of minute atoms which, when they are shoved off, lose no time in shooting right across the interspace of air in the direction imparted by the shove'. Despite being similar to later particle theories, Lucretius's views were not generally accepted; light was still theorized as emanating from the eye.

Heron of Alexandria (10 - 70 CE) formulated the principle of shortest path of light in reflection: if a ray of light propagates from point A to point B within the same medium, the path-length followed is the shortest possible.

Ptolemy (100-170 CE) wrote about the refraction of light and developed a theory of vision that objects are seen by rays of light emanating from the eyes. He also studied refraction of light and suggested that the angle of refraction is proportional to angle of incidence.

Al-Kindi (801 - 873 CE) developed a theory that 'everything in the world emits rays in every direction, which fill the whole world'. This theory of the active power of rays had an influence on later scholars.

Thereafter, Ibn Sahl (940 - 1000 CE) was Persian mathematician and optics engineer. He wrote a treatise on 'On Burning Mirrors and Lenses' which deals with the optical properties of curved mirrors and lenses. He derived the laws of refraction and used these to derive lens shapes that focus light. Ibn Sahl is the first Muslim scholar known to have studied Ptolemy's Optics, and as such an important precursor to the Book of Optics by Ibn Al-Haytham (Alhazen), written some thirty years later.

Hassan Ibn Al-Haytham also known as Alhazan (965 - 1040 CE) wrote 7-volume book on optics, *Kitab al-Manazir*. He carried out various experiments with lenses and mirrors and described refraction, and reflection. Alhazen showed through experiments that light travels in straight line. His work also contained the first clear description of camera obscura. Alhazen studied the process of sight, the structure of the eye, image formation in the eye, and the visual system. Alhazen, who may have been familiar with the writings of Aryabhatta, proposed that light moves with a finite velocity, and it moves more slowly in dense medium. He made mathematical descriptions of the properties of light. He is considered the father of optics. Some parts of his book appeared in Europe around 1200CE, and were translated into Latin. The Latin translation of the Book of Optics exerted a great influence on Roger Bacon, Kepler and Fermat. Alhazen's book was considered the most important book on optics until Johannes Kepler's book 'Astronomiae Pars Optica' published in 1604.

Johannes Kepler (1571 - 1630 CE), best known for Kepler's laws of planetary motion, wrote many works: one of the manuscripts published as *Astronomiae Pars Optica* (The Optical Part of Astronomy) in 1604 described the inverse-square law governing the intensity of light, reflection by flat and curved mirrors, and principles of pinhole cameras, as well as the astronomical implications of optics such as parallax and the apparent sizes of heavenly bodies. He also extended his study of optics to the human eye and was the first to recognize that images are projected inverted and reversed by the eye's lens onto the retina. Today, *Astronomiae Pars Optica* is generally recognized as the foundation of modern optics though the law of refraction is conspicuously absent in the book.

Willibrord Snellius (1580 – 1620 CE) also known as Snell is known for the laws of refraction called Snell's laws of refraction. However, the Persian scientist, Ibn Sahl, first accurately described refraction law in 984 and used it to derive the lens shapes.

Rene Descartes (1596 -1650 CE), considered father of modern philosophy, derived the law of refraction independently using heuristic momentum conservation arguments in terms of *sines* of angles. Descartes assumed the speed of light was infinite, yet in his derivation of Snell's law he also assumed that the denser the medium, the greater the speed of light. He used this law to find the angle of the rainbow (42^{o}). He also independently discovered the law of reflection.

4. 17th Century

Pierre de Fermat (1607- 1665 CE) derived the law of refraction solely based on his principle of least time. He assumed that the speed of light is finite, and his derivation depended upon the speed of light being slower in a denser medium.

Robert Hooke (1635 - 1703 CE) held light to be mechanical: pulses of motion transmitted through a material medium. He did not examine the theory in detail but the mere proposal suffices to include him in the forebears of the wave theory of light. Hooke examined phenomena of colors in thin-transparent films, initially with mica, and then soap bubbles and air films between sheets of glass. He recognized that the colors are periodic, with the spectrum repeating itself as the thickness of the film increases. His theory of light intended specifically to account for such phenomena. Except in the most general terms, the theory has not survived. Yet his observations of thin films did exert an extensive influence. Both Huygens and Newton saw that the thickness of the films could be calculated from the diameters of rings formed in the layer of air between a flat sheet of glass and a lens of known curvature.

Christiaan Huygens (1629 - 1695 CE) is best known for his wave theory of light, which he proposed in 1678 and described in 1690 in *Treatise on Light*, which is regarded as the first mathematical theory of light. The nature of light was the longitudinal wave that propagates through ever pervading aether. His theory was initially rejected in favor of Isaac Newton's corpuscular theory of light, until Augustin-Jean Fresnel adopted Huygens' principle in 1818 and showed that it could explain the rectilinear propagation and diffraction effects of light. Today this principle is known as the Huygens–Fresnel principle. He assumed the velocity of light to be finite. He also experimented with double refraction in Icelandic spar (calcite). He also investigated the use of lenses in projectors and is credited as the inventor of magic lantern.

Isaac Newton (1643 - 1727 CE) performed a number of experiments on the composition of light using a prism and showed that prism separates white light rather than modifies it. A circular beam of white light incident on a prism emerges out as coloured oblong beam suggesting that different colours have different degree of refrangibility. His most remarkable observation was that light passing through a convex lens pressed against a flat glass plate produces concentric colored rings (Newton's rings) with alternating dark rings. Newton attempted to explain this phenomenon by employing the particle theory in conjunction with his hypothesis of 'fits of easy transmission (refraction) and reflection.' Newton's book, *Opticks* published in 1704 is most comprehensive and readily accessible work on light and color. Newton's theory of light was essentially corpuscular, or particulate.

Ole Roemer (1644 - 1710) made observation of the eclipses of the moon Io of Jupiter and announced in 1676 that the speed of light was finite. By timings the eclipses of Io he calculated the speed of light to be approximately 220,000km/s. Using stellar aberration to calculate the speed of light, Bradley in 1728 obtained the speed of light to be 301,000km/s in vacuum.

5. 18th Century

Etienne-Louis Malus (1775 - 1812 CE) conducted experiments to verify Huygens' theories of light and rewrote the theory in analytical form. His discovery of the polarization of light by reflection was published in 1809 and his theory of double refraction of light in crystals in 1810. Malus is probably best remembered for Malus' law that describes the irradiance of a polarized beam when it passes through a polarizer.

Thomas Young (1773 - 1829 CE) has been called the founder of physiological optics. He explained the mode in which the eye accommodates itself to vision at different distances depending on change of the curvature of the crystalline lens. He was the first to describe astigmatism. He also presented the theory of colour vision known as Young-Helmholtz tri-colour theory. He is however best known for the double-slit experiment to prove the wave theory of light. Young performed and analyzed a number of experiments, including interference of light from reflection off nearby pairs of micrometer grooves, from reflection off thin films of soap and oil, and formation of Newton's rings. His theory, however, could not be accepted against the Newton's corpuscular theory.

David Brewster (1781 - 1868 CE) is remembered for his pioneering work in experimental physical optics, mostly in the study of polarization of light and in particular the discovery of Brewster angle. He studied birefringence of crystals under pressure and hence the discovery of photoelasticity.

Joseph von Fraunhofer (1787 - 1826 CE) made optical glasses and measured their dispersion; made achromatic telescope objective lenses; invented the spectroscope; and developed diffraction grating. He observed the absorption lines, known as Fraunhofer lines, in the spectrum of sun. Though Fraunhofer was not involved with diffraction theory, a region known as Fraunhofer diffraction region is named to honour him. The equation $L= D^2/\lambda$, is known as Fraunhofer equation, where D is the diameter of the aperture, L is the Fraunhofer distance measured from the aperture and λ is the wavelength of light that illuminates the aperture. Fraunhofer region of diffraction extends beyond L.

6. 19th Century Evolution

Augustin-Jean Fresnel (1788 - 1827 CE) was both an experimentalist and a theoretician. He experimented with diffraction and polarization of light. He made several important contributions to optics. He put forward theory of diffraction based on Huygens principle known as Huygens-Fresnel diffraction theory. He carried out many experiments in polarization and confirmed that light waves are transverse waves and derived the reflection coefficients known as Fresnel reflection coefficients when light is reflected and transmitted at a dielectric interface. He also gave the theory of double refraction and propagations of waves in a birefringent medium. Fresnel's diffraction theory and observation of Poisson's spot as conceptualized by Arago put the wave theory on a firmer ground.

Michael Faraday (1791-1867 CE) discovered that a magnetic field influenced polarized light – a phenomenon known as the magneto-optical effect or Faraday effect. To be precise, he found that the plane of vibration of a beam of linearly polarized light incident on a piece of glass rotated when a magnetic field was applied in the direction of propagation of the beam. This was one of the first indications that electromagnetism and light were related. He also made a prophetic speculation that light could be a vibration of the electric and magnetic lines of force.

George Gabriel Stokes (1819 - 1903 CE) made several contributions in physical optics notably in polarization and fluorescence. Stokes relations in physical optics describe the relative phase of light reflected at a boundary between materials of different refractive indices. They also relate the transmission and reflection coefficients. For describing the polarization state of an incoherent light, he introduced the parameters known as Stokes parameters, which can be experimentally measured. The Stokes parameters are often combined to form a vector known as Stokes vector. The Stokes vector spans the space of unpolarized, partially polarized, and fully polarized light. Stokes shift is the difference (in wavelength or frequency units) between positions of the band maxima of the absorption and emission spectra (fluorescence and Raman being two examples) of the same electronic transition.

Most notable achievement of James Clerk Maxwell (1831 - 1879 CE) was to formulate the classical theory of electromagnetic radiation, bringing together for the first time electricity, magnetism, and light as different manifestations of the same phenomenon. Maxwell calculated that the speed of propagation of an electromagnetic field is approximately that of the speed of light and commented '*We can scarcely avoid the conclusion that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena*'. His work in geometrical optics led to the discovery of the fish-eye lens.

Ernst Abbe (1840 - 1905) is best known for the theory of image formation in a microscope. He, however, carried out scientific work in the design of microscope objectives. In order to make an image in the microscope free from coma he formulated sine condition. He invented apochromatic objectives and Abbe condenser for the microscope. He developed numerous optical instruments like Abbe refractometer, focimeter, apertometer, spectrometer, spherometer, etc. He, for the first time, defined the numerical aperture of an objective.

John William Strutt (1842 – 1919) also known as Lord Rayleigh is well recognized as a pioneer in light scattering and other areas of optics. He showed that the intensity of light in the sky, if scattered from particles much smaller than the wavelength of incident light, should vary as λ^{-4}. Therefore, blue light should be scattered 16× more than red light; this explained the blue sky. Rayleigh derived the law of blackbody radiation by assuming that all the standing waves in a cavity have the same energy. This law, known as Rayleigh-Jeans law, is valid at long wavelengths. Rayleigh made seminal contributions to theoretically defining the resolving power of gratings, prisms, telescopes and microscopes.

Albert A Michelson (1852 - 1931) had a passion to measure the speed of light accurately. He along with Morley carried out the famous Michelson-Morley experiment that failed to detect evidence of the existence of luminiferous ether. He is known for the invention of Michelson interferometer, definition of visibility and invention of Stellar Michelson interferometer for measuring heavenly bodies.

Heinrich Hertz (1857 - 1894) discovered radio waves and established that Maxwell's theory of electromagnetism is correct. He also determined the velocity of radio waves and found it equal to that of light as Maxwell predicted. Hertz also discovered the photoelectric effect, providing one of the first clues to the existence of the quantum world.

Max Planck (1858 - 1947) is best known for blackbody radiation law known as Planck's law, which describes the experimentally observed blackbody spectrum very well. It is based on the assumption that the electromagnetic energy could be emitted in quantized form, i.e. multiple of the elementary unit $h\nu$, where h is known as Planck's constant and ν is the frequency of electromagnetic radiation. The exchange of energy between matter and radiation is discreet. Planck is the originator of the quantum theory.

7. 20th Century and beginning of 21st Century

Albert Einstein (1879 – 1955) considered the radiation as a gas composed of independent 'quantum of energy', with each quantum proportional to the frequency of the radiation. According to Einstein, radiation is itself quantized. Einstein wrote "*When a light ray spreads out from a point source, the energy is not distributed continuously over an increasing volume (wave theory of light), but consists of a finite number of energy quanta that are localized at points in space, move without dividing, and can only be absorbed or generated as complete units*." Einstein quantum of energy, later called photon, is very much different from the corpuscle of Newton. With this assumption he explained the photoelectric effect. The origins of the wave-particle duality of light are found in Einstein's 1909 paper on energy fluctuations [2]. He derived Planck's law in 1916 by considering absorption, emission and stimulated emission as the processes taking place when the atom is in thermal equilibrium.

Neils Bohr (1885 - 1962) adapted Rutherford's nuclear structure to Planck's quantum theory to create model of the atom known as Bohr model. He proposed that the electrons revolve in stable orbits around the atomic nucleus, and their energy levels are discrete and they can jump from one energy level (or orbit) to another emitting or absorbing a quantum of energy. With his model, he explained the formation of Balmer series of H_2 atom.

Chandrashekhara Venkata Raman (1888 - 1970) carried out groundbreaking work in the field of light scattering that led to Raman effect, and for which Raman was awarded Nobel Prize in 1930. Raman along with Nath provided correct explanation for the acousto-optic effect [3]. He was interested in the physiology of vision and carried out intense research on colour.

Fritz Zernike (1888 - 1966) invented the phase contrast microscope. His next contribution to optics was the orthogonal circle polynomials, which provided a solution to the long-standing problem of the optimum 'balancing' of the various aberrations of an optical instrument. He proposed a simpler version of the theorem first derived by van Cittert: this is now known as van Cittert-Zernike theorem in coherent optics.

Narinder Singh Kapany (1926 -) showed that the images could be transmitted through glass fibers: essentially he can be considered founder of fiber optics.

8. Coherent Light

Until this period, the experiments were conducted with light either from sun or a candle, or white light sources and/or spectral lamps. The coherence properties were modified using spatial and colour filters. Though the concept of stimulated emission was put forward in 1916 by Einstein [4], it was not until 1951 when Townes conceived a new way to create intense, precise beams of coherent radiation, for which he invented the acronym maser (Microwave Amplification by Stimulated Emission of Radiation). During 1953, Townes, Gordon, and Zeiger built the first ammonia maser at Columbia University [5]. This device used stimulated emission in a stream of energized ammonia molecules to produce amplification of microwaves at a frequency of about 24.0 gigahertz. Moving the microwave frequency of ammonia maser up the electromagnetic spectrum (~20,000 times) to the frequency of light would require finding a feasible lasing medium and excitation source, and designing the system. The device will be known as laser (Light Amplification by Stimulated Emission of Radiation). In 1960, Maiman's solid-state pink ruby laser emitted mankind's first coherent light, with all rays of the same wavelength and fully in phase [6]. Ali Javan, Bennett, Jr. and Herriot obtained laser action in a mixture of He and Ne gases at the wavelength of 1.152μm in the same year [7]. White and Ridgen demonstrated the laser action in He-Ne mixture in the visible in 1962 [8]. Once the method of making stimulated emission stronger than the spontaneous emission was understood, laser action was obtained in variety of materials: gases, solids, liquids, semiconductors.

Therefore the lasers were classified as (i) gas lasers, (ii) liquid lasers, (iii) solid-state lasers, (iv) semiconductor lasers etc. They cover a vast spectral range from ultraviolet to far infrared. In the beginning a laser was considered **a solution in search of a problem.** To day it is very difficult to find an application that does not involve a laser.

Dennis Gabor (1900 - 1979) is known for the invention of holography. Though the basic principle of holography was invented in 1948, it had no appeal until the arrival of laser. Holograms made with laser light could be reconstructed with the same light used for recording or with white light depending on the geometry used for recording. For the first time, it was possible to see a three-dimensional image of an object suspended in space. Holography opened many other research areas, particularly hologram interferometry and vibration analysis. For the first time it was possible to carry out interferometry on real objects as was demonstrated by Stetson and Powell in 1965 [9]. Book 'Holographic Interferometry' by Vest is an excellent book on this topic. In 1966, Lohmann revolutionized holography by introducing the first computer generated hologram (CGH) using a cell oriented encoding adapted to the limited power of the computers available at this time [10]. All hologram reconstructions were immersed in a speckle pattern, a starry appearance: the speckle pattern was considered a nuisance, a bane of holography, and methods were discovered to reduce or eliminate its effects. At the same time efforts were made to utilize this phenomenon for measurements: the research work done by Burch is noteworthy [11]. Book 'Speckle Phenomenon and Related topics' by Dainty is the earliest book on this topic. A research area, known as Speckle Interferometry and later Digital Speckle Pattern Interferometry (DSPI), emerged from the efforts of many researchers and has applications in classical mechanics for stress analysis and vibration analysis. Both hologram interferometry and DSPI have been used for art conservation.

Like holography, the development of optical image processing was limited until the invention of a coherent source of light, the laser, in 1960. Optical processing makes use of the properties of parallelism and speed of light. There was flurry of activities in this area during 1980-2000, when innovative designs of processors for real applications were invented [12]. Unfortunately activity in optical processing waned thereafter.

Though Kapany transported images through a bundle of optical fibers way back in 1953, the transmission loss was very high. In 1966, Kao and Hockham published their now famous work, which evaluated material and loss mechanisms in waveguides and determined that a dielectric fiber represents a possible medium for the guided transmission of energy at optical frequencies [13]. Charles Kuen Kao (1933 - 2018) received the Nobel Prize in 2009.

A laser beam can be focused to a very small size creating electrical field that can change the polarizability of the medium. Peter Franken (1928 - 1999) is considered the father of nonlinear optics. In 1961 when Franken focused a high-powered ruby laser onto a quartz crystal the ultraviolet light that resulted was generated from a process known as second- harmonic generation [14]. Nonlinear optics moved from a laboratory curiosity to a tool critical for biomedical applications, spectroscopy, and metrology. Nicolaas Bloembergen (1920 - 2017) expanded the field of nonlinear optics theoretically and found the ways in which two or more intense pulses of visible laser radiations incident on an optical material produce intense pulses in the infrared and the ultraviolet regions.

Brillouin's prediction of light and sound interaction in 1922 and subsequent experimental demonstration in 1932 by Lucas and Biquard in France, and Debye and Sears in USA may be considered as the beginning of a new branch of Science and Technology called *Acousto-Optics* [15]. Raman and Nath developed a general ideal model of interaction in 1935. The laser invention has led the development of *Acousto-optics* and its applications, mainly for deflection, modulation and signal processing.

Roy Jay Glauber (1925 - 2018) developed a theory that merged the field of optics with quantum mechanics and thus created a new field of quantum optics: he is considered the father of quantum optics, which has many practical applications.

Theodor W Haensch (1941 -) made seminal contributions and landmark advances in optical science and atomic physics, including narrow-band dye lasers, Doppler-free laser spectroscopy, laser cooling of atomic gases, precision spectroscopy of atomic hydrogen, frequency metrology with optical combs, and new physics with cold atoms in optical lattices.

Red LED was developed in 1962 by Nick Holonyak (Jr), which was extensively used in display devices [16]. Later yellow, green and blue LEDs were developed. However these LEDs were highly inefficient and expensive. High brightness LEDs for fiber optic communication were developed in 1976. Nakamura demonstrated blue LEDs of high brightness whose commercial production began in 1993 [17]. Though white light can be produced by a combination of red, green and blue LEDs, it does not provide the correct colour rendering. Development of white light LEDs followed immediately after the high brightness blue LEDs were developed. White light LEDs are used for illumination and replacing the fluorescent tubes and incandescent bulbs as these have many advantages over them such as lower energy consumption, longer lifetime, improved physical robustness, smaller size, and faster switching.

Donna Theo Strickland (1959 -) is known for her work on chirped pulse amplification, generating ultra short pulse of terawatt to petawatt power. Chirped pulse amplification allowed smaller high-power laser systems to be built on a typical laboratory optical table, as 'table-top terawatt lasers'.

Developments in the field of optics required concurrent development in the area of detection. There were two streams of development: one for the development of point detectors and other for the area detectors. Starting with the development of the phototubes, the photomultipliers, and then the photodiodes, there had been considerable improvement in sensitivity and time response over the whole visible range. Area detectors include photographic emulsions, dichromatic gelatin, thermoplastics, photorefractives, photopolymers and photoresists: these have different spectral responses and sensitivities. With the advent of CCDs and CMOS, the other area detectors are seldom used or used for highly specialized applications. Boyle and Smith invented the CCD in 1969 for which they received the Nobel Prize in 2009. First practical linear device with 500 elements, and a 2-D device with 100 x 100 pixel were produced in 1974 [18]. Since then there has been enormous increase in the number of pixels and CCDs have completely replaced the photo-emulsions. There is very little difference between the performances of CCD and CMOS devices but their technologies of production are different, and their read out mechanisms are different.

Having presented the views of philosophers and scientists about the nature of light, and describing the development that have taken place in optics, still it is not obvious what light is ?. One way to describe light is with waves following Maxwell's equations. Another way is to describe light with photons following quantum electrodynamics. For some one with no knowledge of these subjects, it is best to say that light behaves both like a wave and like a particle. For a monochromatic wave, photon exists everywhere and for all times. A photon can interfere with itself even though the two paths could be kilometers apart. For polychromatic light, say an extended visible light, the photon appears to be localized and can only interfere with itself if the paths are nearly same.

9. Conclusion

This write-up places on record some of the breakthroughs in the development of the field of optics and our understanding of light. It renders the phases of evolution of light over time. It is quite likely that some events may have been missed but that is unintentional. Quite a bit of information is gathered from the Internet, which is in public domain. However, the usage of Internet is gratefully acknowledged.

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