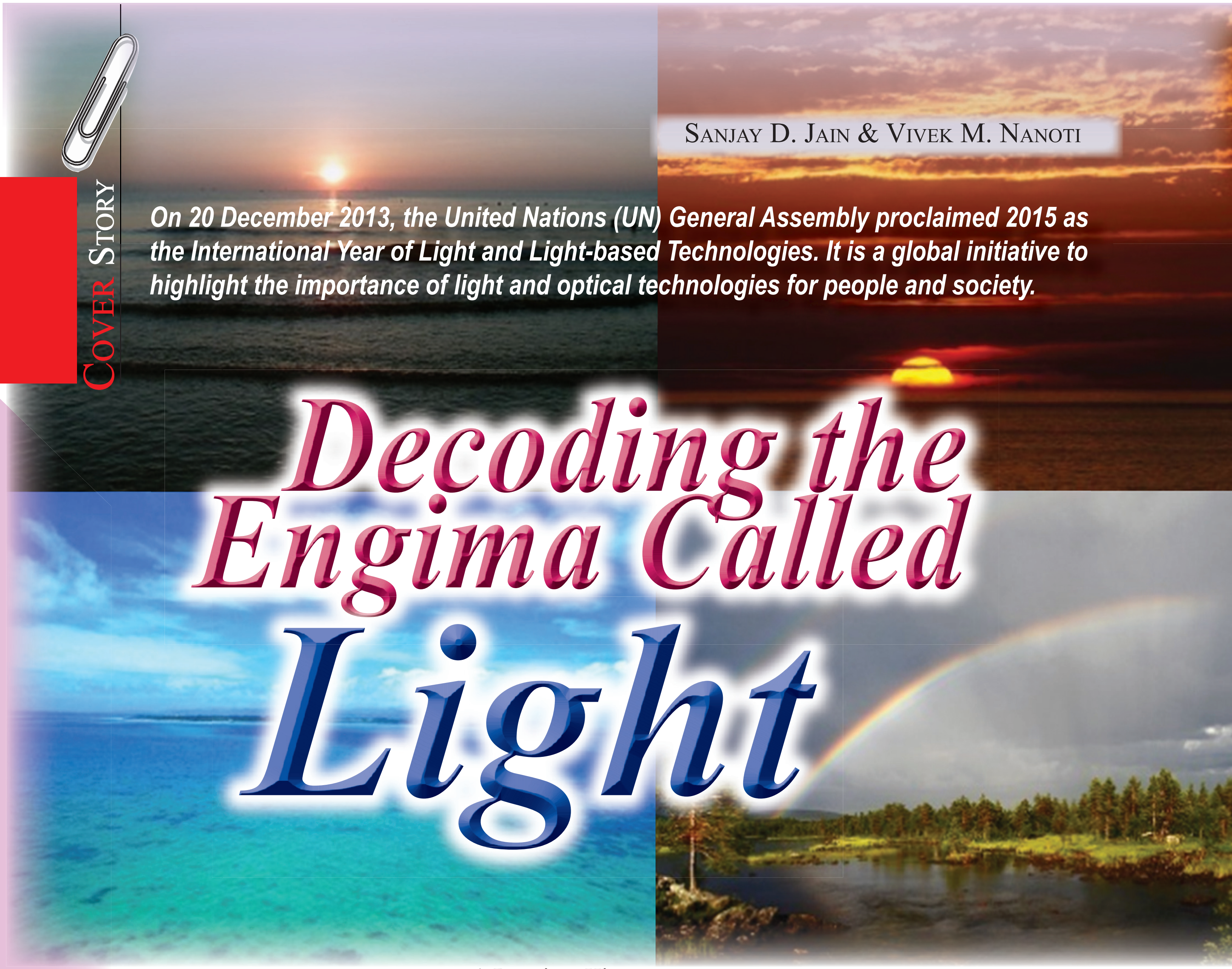
COVER STORY



SANJAY D. JAIN & VIVEK M. NANOTI

On 20 December 2013, the United Nations (UN) General Assembly proclaimed 2015 as the International Year of Light and Light-based Technologies. It is a global initiative to highlight the importance of light and optical technologies for people and society.

Decoding the Engima Called Light

WE see light and we see through light every day, everywhere. Over the years, scientists researching in optics – the science of light – have amassed a repository of knowledge, thanks to their myriad discoveries, which have provided us an insight into the enigma that is light. This quest to unravel the enigma can be depicted in the form of an 'optics knowledge spiral' shown on the next page.

As we travel along the depth (height) of this spiral we unravel the nature of light through various theoretical models and experimental discoveries. As we travel along the breadth of the spiral, we appreciate how the knowledge at that depth is useful to us in several ways.

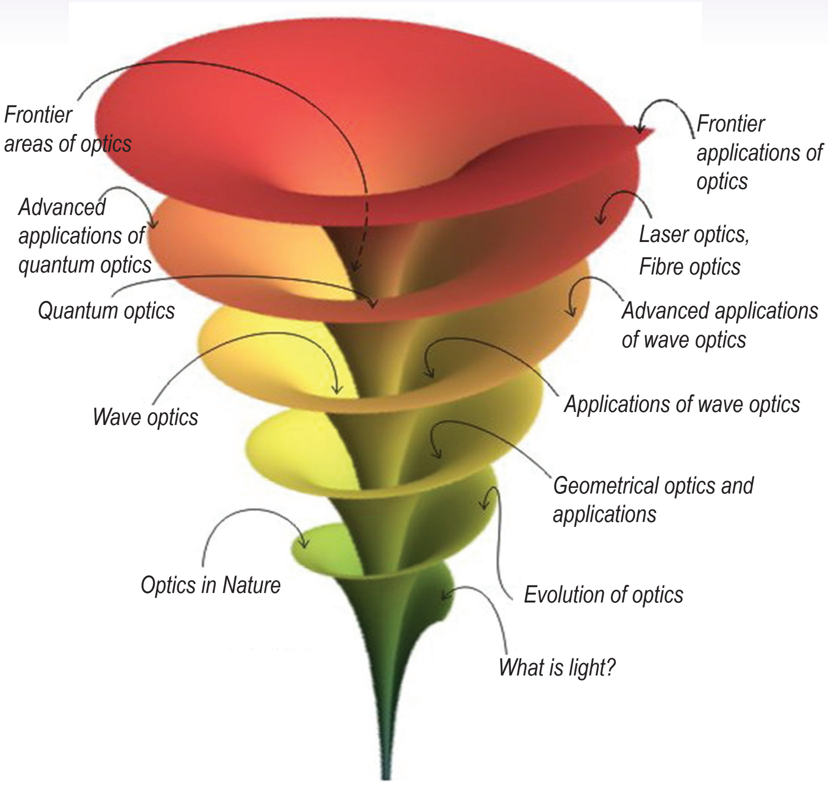
A Peep into History

The journey of light dates back to antiquity. Our journey of the optics knowledge spiral may begin through simple, light hearted queries like what is light and wondering how various phenomena in nature involving light occur such as sunrise and sunset, blues of sky and sea, rainbow, and the remarkable range of colors of plants and animals. It is estimated that since about 4.5 billion years the sun has been constantly lighting our earth by converting mass into energy. Life is believed to have originated by cyanobacteria in ocean because of light by the process of photosynthesis about 2 billion years ago.

Our effort to understand the 'nature of light' and 'light in nature' leads us to the historical evolution of optics dealing with aspects like origin and propagation of light and effects and phenomena associated with light. The early Greek philosophers held different beliefs about light.

Pythagoras (582-500 BC) thought of light as particles that produce the sensation of vision upon entering the eye. Plato (427-347 BC), on the other hand, supposed that vision was produced by rays of light that originate in the eye and then strike the object being viewed. Aristotle (384-322 BC) considered light in the form of waves and Euclid (320-275 BC) postulated that light rays travel in a straight line and applied the knowledge of geometry to study paths of light. Hero of Alexandria (150 BC) is often credited with discovering the properties of reflection of light whereas Claudius Ptolemy (100-170 AD) performed elaborate experiments to measure the bending of a light beam as it passed from air into water or glass.

Optics Knowledge Spiral



In the medieval period, Ibn al-Haytham or Alhazan (965-1039), an Arabian scientist, developed the theory of optics and published a seven-volume treatise, 'Kitab al-Manazir' *(Book of Optics)* that dealt with refraction and dispersion of light, the nature of vision, shadows, rainbows and eclipses. Leonardo da Vinci (1452-1519) also investigated the nature of light and studied reflection, refraction and anatomy of the human eye.

In 1554, Franciscus Maurolycus wrote the book, *'Light on the Subject of Light'*. In 1621, Willebrod Snell, a Dutch physicist, derived a relation between the angle of incidence and the angle of refraction for a ray of light moving from one medium to another. In 1637, Rene Descartes, a French scientist, published *'Les Meteores'* in which he offered an explanation of the rainbow by using geometric construction and the law of refraction. He also discovered the fundamental law of reflection that the angle of incidence is equal to the angle of reflection.

This early understanding of light had corresponding applications in different times. The simplest application of light is lighting. Fire constituted early man's first use of artificial lighting in the form of flaming torch and campfire. It was followed by the use of primitive lamps made from natural sources like rocks and shells by prehistoric humans. Fireflies have also been used for illumination in the West Indian Islands and Japan. The invention of the candle dates back to about 400 A.D.

Another application of light relates to controlling light using glass. This unites the knowledge of light with the knowledge of glass. The oldest types of glass are based on silica, the primary constituent of sand. As mirrors and lenses, glass can divert light and magnify images. Assyrian lenses, dated as early as 700 BC, are the earliest known lenses made from quartz. The confluence of these two worlds led to development of several instruments such as camera (Mozi, a Chinese philosopher, 400 BC and Alhazan), magnifying glass, eyeglasses, concave and convex lenses [Roger Bacon (1214-1294)].

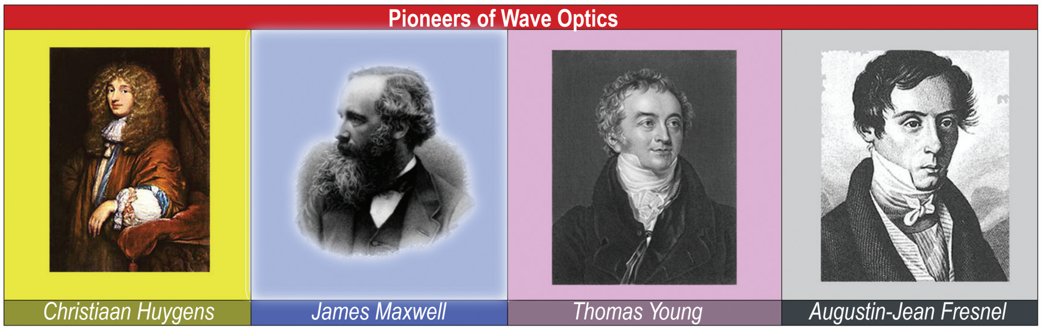
In the 18th century several physicists, including Newton, studied light. In Newton's time (1642-1727) almost all the scientists enquired into the nature of light. Newton himself devoted considerable time to the study of light and proposed the corpuscular theory of light in his famous book, *Optiks*, published in 1704. This theory assumes light to consist of particles that travel in straight lines and produce the sensation of vision upon falling on the eye. Newton's theory failed because it could not explain anything beyond reflection and some aspects of refraction of light. Newton's theory predicted that light should travel faster in denser media which was found to be against the experimental observation of Focault in 1850 who found the speed of light in water to be lesser than its speed in air.

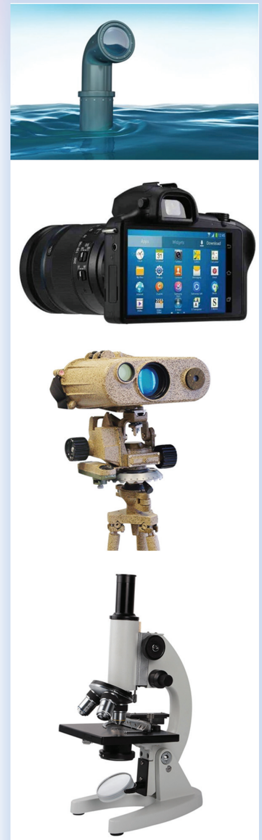
Light as Rays

Optics since the time of the Greeks up to the end of the 18th century was based mainly on the assumption that light consists of rays that obey the geometrical laws of reflection and refraction and thus came to be known as ray optics or geometrical optics. It dealt mainly with the effect of instruments such as prisms, lenses and mirrors on the paths traced by light rays. Theory and applications of geometrical optics thus constituted the depth and breadth of the optics knowledge spiral till this time. The breadth kept expanding with aims of improving the fidelity of images produced by the optical instruments.

The first microscope was developed around 1595 by the Dutch eyeglass makers, Hans Lippershey, Hans Janssen and his son, Zacharias. The earliest known telescopes were developed in 1608 in Netherlands by Hans Lippershey, Zacharias Janssen and Jacob Metius. Galileo (beginning of 17th century) and Kepler (1610) made pioneering contributions to the refinement of a telescope. The bifocals were developed by Benjamin Franklin, an American scientist, in 1784. The pioneering research of Leeuwenhoek, a Dutch microscopist who developed the theory of aberration-free lenses by about 1830, led to improvement in magnification of lenses. By the end of the 19th century microscopes with large magnifying power were available.

Camera was improved through the pioneering work of Joseph-Nicephore Niepce and Louis Jacques Mande Daguerre of France (1820-30). The word 'photography' was coined by Sir John Herschel in 1839 and in 1847 Claude Niepce invented the photographic glass plate. In 1888, Eastman coined the word 'Kodak' and started marketing a hand-held camera, using his new film. In 1861,





Knowledge of geometrical optics helped in improving the fidelity of images produced by the optical instruments

the Scottish physicist, James Maxwell demonstrated the first color photographs. The development of zoom lens and telephoto lens helped to refine the design and performance of the camera.

By the 20th century a variety of cameras for specific purposes such as aerial photography, document copying, movie, TV and video were developed. In addition to these many other optical instruments such as tracking instruments, gunsights, periscopes and rangefinders have been developed for different uses. Today geometrical optics has been relegated to background due to further developments in our understanding of light. However, its importance as a tool in solving practical problems is still unabated.

Light as Waves

In 1678, a Dutch physicist, Christian Huygens, suggested the wave theory of light, which assumes light to be a wave, similar to a water wave or a sound wave. This theory was highly successful due to its close agreement with experiments. The Wave Theory was substantiated in 1873 by James Maxwell who propounded that light is not only a wave but that it is a transverse, electromagnetic wave (wave of oscillating electric and magnetic fields) which can travel through vacuum.

Using the equations of electromagnetism Maxwell obtained the theoretical value of speed of light that was in close agreement with the experimental value measured by Fizeau. Coincidence of these two numbers is considered to be a major milestone in the history of physics. Maxwell exclaimed after his discovery: "Let there be electricity and magnetism, and there is light!"

Thomas Young, an English physician who researched on the human eye and Augustin Fresnel, an engineer of bridges and roads for the French government, provided strong experimental proofs in support of the wave theory by demonstrating interference of light waves. Young demonstrated it using light coming out of two pinholes in 1801 and Fresnel did it using a biprism in 1814. Young reported the first experimental determination of the wavelength of light that agrees well with that obtained using today's sophisticated instruments. He is called the founder of wave theory for his valuable contribution to this field.

In 1802, Young proposed the superposition principle, which forms the conceptual basis for explanation of properties of light such as interference, diffraction and polarisation. Superposition of light waves leads to many beautiful patterns of different light intensities.

Optics based on the assumption of light as waves came to be known as wave optics. It deals with phenomena involving light interacting with dimensions of the order of its wavelength. Theory and applications of wave optics mainly constituted the depth and breadth of the optics knowledge spiral in the 19th century. Theory concerned with the study of the patterns formed due to interference, diffraction and polarisation and applications were based on the use of this knowledge. Thus the sciences of interferometry, diffractometry and polarimetry enriched the depth, and applications of interferometric, diffractometric and polarimetric techniques (using instruments such as interferometers, diffractometers and polarimeters) augmented the breadth of the spiral.

TABLE 1. CONCEPTS AND THEIR APPLICATIONS

Concepts	Applications
Interference Interference means redistribution of light intensity due to superposition of two or more light waves. Interference pattern thus consists of bright and dark fringes. In a typical interferometric setup the light beam is first divided and then reunited with some path difference to form such a pattern. The fringe pattern so formed thus contains information about the source of light and geometry of the film in which interference takes place.	Interference studies are useful in several applications such as reducing or enhancing the reflection of light from glass using films called anti-reflection/high reflection films, testing how flat or spherical a particular glass surface is and determination of properties like refractive index and elastic constant of different media. Interferometric techniques also find applications in measurement of the diameters of stars, study of the hyperfine structure of spectral lines, study of transparent or reflecting specimens using interference microscopes and detection of minute variations in the surface finish of videotapes, photographic films, computer discs and ball bearings. Sophisticated techniques like 'computer analysed optical interferometry' have been developed that can detect variations in the surface texture of the order of few A° (A° means angstrom, the unit of wavelength equivalent to 100 millionth part of a centimeter).
Diffraction Diffraction means bending of light round sharp obstacles. The diffraction pattern produced by an obstacle contains information about the characteristics of the light used and of the diffracting obstacle. Grating (an arrangement formed by ruling a large number of lines on a small glass plate so that the separation between adjacent lines is of the order of wavelength of light) became popular for diffraction studies.	A grating diffracts different wavelengths along different directions – a property useful for determination of unknown wavelength and as a wavelength separator or a monochromator. Diffraction of light by gratings motivated studies of diffraction of x-rays by crystals that led to the development of x-ray crystallography, a technique that has been used to map many complex structures in the last century. Diffraction studies are also useful for measurement of stellar data and elastic properties of liquids. One of the interesting outcomes of diffraction studies was a deeper insight into the concept of resolution. It provided a clue that resolving power of an instrument can be enhanced by reducing the wavelength of the probing waves – a clue that gave a lot of impetus to the progress in the field of microscopy. It can be said that had diffraction not been discovered and subsequently researched into we would not have known about anything smaller than the wavelength of light!
Polarisation Polarized light is a special type of light – one in which the electric field is confined to a single plane as compared to ordinary light, which has field in all possible random orientations. That the state of polarisation of the light coming from a particular object is decided by the nature of that object is the basis of the spectroscopic investigation of matter based on polarisation. Research into how a desired polarisation can be achieved artificially led to the discovery of a large number of phenomena that include optical activity (rotation of the plane of polarisation) and photoelastic effect.	Polarisers are used in applications such as aeroplane windows, automobile headlights, visors, camera filters, laser windows, anti-glare sunglasses and stereoscopic (three-dimensional) viewing. Polariscope, which uses two polarisers in tandem, is used in viewing of colourless objects. Polarisation studies have revealed structures ranging from a galaxy (~ 10^{20} meters) to a nucleus (~10^{-14} meter). That the Saturn rings are made of ice crystals is borne out by polarisation studies. Photoelasticity, a field of paramount importance in civil and mechanical engineering, is used to check and optimise the designs of structures by simulating the stress distribution in transparent plastic models of these structures under application of a load. Photoelastic techniques enable engineers to 'see' stress in components such as gears, turbine blades, windshields, etc. An instrument called polarimeter is used in industries for measuring the concentration of optically active substances. For example, saccharimeters are used in sugar industries for determination of sugar concentrations and urinalysis tubes are used in pathology laboratories for detecting the sugar concentration in urine specimens. One of the most remarkable applications of optical activity is in the liquid crystal display (LCD). LCD devices find wide applications in electronic and computer industry and in medical diagnostics.

Optics based on the assumption of light as waves came to be known as wave optics.

The first interferometer was developed in 1881 by A.A. Michelson, an American physicist who fetched the first Nobel Prize in Science for America in 1907 for his researches on light. After this several new and elegant designs of interferometers were developed. Diffraction was discovered by the Italian physicist, Francesco Grimaldi, in 1665. Special devices called gratings were developed by David Rittenhouse in 1787, Joseph von Fraunhofer in 1821 and Rowland in 1882 to study the diffraction of light in a laboratory.

Polarization was discovered by Huygens in 1678 and by Etienne Malus, a French military engineer, in 1808. Nicol prism, one of the most renowned polarisers based on the phenomenon of double refraction was built in 1828 by the Scottish physicist, William Nicol.

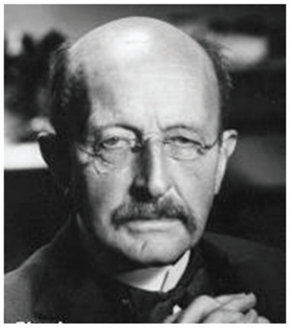
In 1932, Edwin Land, an American inventor, developed a polariser that could conveniently produce polarized light from ordinary light. Table 1 shows the basic concepts of interference, diffraction and polarisation and their corresponding applications.

Light as Quanta

The spectacular success of wave theory made scientists believe in the wave nature of light till the end of the nineteenth century. But the citadel of wave theory started showing cracks in the beginning of the twentieth century.

Experimental observations of black-body radiation, photoelectric effect and line spectra could not be explained by the wave theory and necessitated a fresh approach to the understanding of the physical nature of light. Max Planck (1900), Albert Einstein (1905) and Niels

Pioneers of Quantum Optics



Max Planck

Albert Einstein

Niels Bohr

Theodore Maiman developed the first operational laser

APPLICATIONS OF PHOTO DEVICES

- Photocells are used i) to measure a definite fixed amount of illumination, e.g., in photometry and colorimetry; ii) to reproduce rapid variations in light intensity, e.g., in sound track of a motion picture film or in scanning in TV tube, and iii) to detect a definite large change in light intensity, e.g., in ON-OFF switches, electric eye.
- Photomultiplier tube is used to measure very weak light intensities as in nuclear-radiation, television pickup devices many industrial processes.
- Photoelectric cells are used in systems such as perimeter guard systems to sense and control the movement of objects or intruders. They are also used in xerography and systems that read coded or printed information on data cards and packages. Photoconductivity is also used to examine the perfection of the interiors of large crystals of silicon. Silicon absorbs the visible light but transmits the IR radiation. Thus, radiation of variable frequency is incident on a simple and transmitted radiation detected by a detector providing information about the interior of the crystal.
- Solar cells are used as voltage sources. A large number of cells connected in series or parallel forms a solar panel. Solar panels are used as sources of power in satellites, spacecrafts and in large number of solar devices. Photodiodes and phototransistors are widely used in optoelectronic devices. For example, arrays of photodiodes, fabricated using modern IC techniques can be used to read printed information.
- Photo devices also find wide applications as sensors. Photoelectric sensors are used for sensing the presence, checking the position or counting any target material. They are widely used in industrial and machine tool applications and for personnel safeguarding around hazardous machinery.

Bohr (1913) pioneered this effort and offered successful explanations of these effects using a new theory – the quantum theory of light, which assumes light to be made of quantized bundles of energy called photons.

This theory gave birth to quantum optics – the study of the nature and effects of light as photons – a field of research that uses quantum theory to investigate interaction of light and matter at submicroscopic level. The theory and applications of quantum optics mainly constituted the depth and breadth of the optics knowledge spiral in the 20th century. Research in quantum optics enriched the depth and applications of this knowledge augmented the breadth of the spiral.

Research into photoelectric effect brought forth knowledge that aided the development of a large number of devices called photo devices. Their basis is categorized as photoemissive effect (ejection of electrons from the surface of a photosensitive metal; e.g., photocells and photomultiplier tubes), photoconductive (or photoresistive) effect [generation of free charge carriers inside a photosensitive semiconductor; as resistance of photoconductor changes with the extent of their illumination they are also referred to as photoresistors or light dependent resistors (LDR); e.g., photoelectric cells] and photovoltaic effect (generation of voltage due to absorption of light near a p-n junction diode, e.g., solar cells, photodiodes and phototransistors).

The crowning glory of quantum optics was the discovery and development of laser (light amplification by stimulated emission of radiation). The story of the development of lasers is the story of physicists' pursuits towards 'purifying' and 'strengthening' light. Natural light is unpolarised, incoherent, divergent and weak. Thus, research efforts aimed at obtaining light that is polarised, coherent, convergent and intense.

Einstein provided a breakthrough in the thinking in this direction when he suggested a new insight into the mechanism of emission of light. In 1917, Einstein made a theoretical speculation that much intense and coherent light can be obtained if the emission process can be stimulated instead of allowing it to take place spontaneously as in the case of ordinary light. However, due to the enormous practical difficulties involved in the fabrication of a real laser it took 43 years before the first operational laser source could see the light of the day in 1960 when it was developed by an American physicist, Theodore Maiman.

Optics before the advent of the laser is often called incoherent optics; the age of laser is the age of coherent optics.

Just as the discovery of transistor in 1947 gave birth to electronics that dominated the 20th century, the discovery

Serge Haroche and David Wineland

Photonics is at the base of technologies of daily life like smartphones, laptops, and medical instruments

Optics before the advent of the laser is often called incoherent optics; the age of laser is the age of coherent optics

of laser is at the base of photonics, the science and technology of generating, controlling, and detecting photons, which promises to dominate the 21st century. Interestingly both these discoveries are based on the quantum theory. Photonics is at the base of technologies of daily life like smartphones, laptops, Internet, medical instruments and lighting technology. The smartphones that are commonplace today are advanced photonic devices which handle both imaging and communication technologies.

The 2012 Nobel Prize in Physics was awarded to David Wineland, an American physicist and Serge Haroche, a French physicist, for their work based on quantum optics. They "independently invented and developed methods for measuring and manipulating individual particles while preserving their quantum-mechanical nature, in ways that were previously thought unattainable". Their work led to the development of one of the most precise clocks ever made, and could mark the first steps toward building a quantum computer, which would use tiny quantum systems to make calculations much quicker than normal computers.

Light as Wave-Particle

The success of the wave theory in explaining some of the properties of light and the success of quantum theory in explaining some others led to an intriguing question: What is light? Is it a wave? Or is it a particle? The answer was: it is both.

Bohr proposed a complementarity principle according to which the wave and the particle nature of radiation complement rather than contradict each other. This reconciliation came to be known as the wave-particle dualism of radiation. Light behaves like a wave in phenomena like interference, diffraction and polarisation and as a particle in others like photoelectric effect and black body radiation.

The wave-particle dualism of radiation titillated the curiosity of a young, brilliant French physicist, Louis de Broglie, who asked: if light, which was assumed to be a wave for the last two centuries, could behave like a particle, then why matter that was assumed as a particle could not have a wave nature? Taking cue from the inherent symmetry and simplicity of nature de Broglie extended the idea of wave-particle dualism of light to matter. He proposed the revolutionary idea of 'matter waves' in 1924 in his doctoral thesis. His bold suggestion was proved experimentally in 1927 when Davisson and Germer demonstrated the wave nature of electrons.

The discovery of matter waves opened up new vistas in the fields of microscopy. According to the wave theory, resolving power of a microscope is inversely proportional to the wavelength used. The resolving power achievable with optical microscopes was thus limited by the wavelength of visible light. De Broglie's theory offered an innovative solution to overcome this limitation. It suggested the use of microparticles as waves! As the wavelength of these waves could be decreased by increasing the voltage through which these particles are accelerated the resolving power could be improved drastically. This culminated in the development of an 'electron microscope' in 1932. In 1981, Gerd Binnig and Heinrich Rohrer developed the scanning tunnelling microscope (STM) that can achieve resolution comparable to an atomic size.

Optical Microscope and Scanning Electron Microscope

Light as a Lighting Source

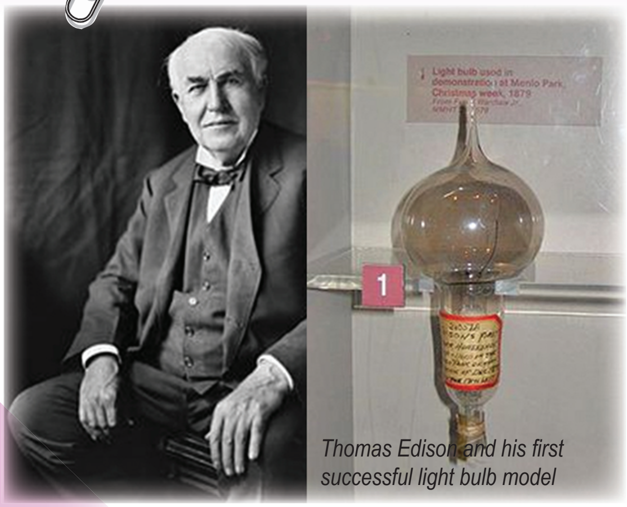
From fire, the earliest form of artificial lighting, to the modern light emitting diode (LED) lights, there have been several improvements in our use of light as a source of lighting. Light sources are historically divided into incandescent and luminescent.

An incandescent source based on the thermionic heating of the filament in the evacuated glass bulb was invented by Edison in 1879. Edison gave the first public demonstration of his invention at Menlo Park, New Jersey on New Year's Eve, December 31, 1879 by using about 100 lamps to light the streets, the laboratory, and the station at Menlo Park.

A luminescent source emits light not through heating but by other means such as chemical reactions (chemiluminescence), biochemical reactions (bioluminescence) or passing electric current through a substance (electroluminescence).

Fluorescence is emission caused by absorption of electromagnetic radiation, mostly high frequency radiation like UV. A fluorescent lamp is based on the use of fluorescent powders in a low pressure gas discharge tube which are activated by ultraviolet energy generated by a mercury arc. These sources thus give a 'cooler' light compared to that from an incandescent source.

The phenomenon of electro-luminescence discovered in 1907 by the British experimenter, H.J. Round of



Thomas Edison and his first successful light bulb model

TABLE 2. BRIEF CHRONOLOGY OF IMPROVEMENTS IN USE OF LIGHT AS A LIGHTING SOURCE

Year	Improvement
1898	Neon (the best known of the inert gases) discovered
1901	First high intensity discharge lamp (mercury lamp) introduced.
1907	First tungsten filament lamps used
1937	Fluorescent lamp first introduced to the public at New York World's Fair
1962	First visible-spectrum (red) LED developed
1968	Visible LEDs mass-produced by the Monsanto Company and introduced by Hewlett Packard
1972	First yellow and first blue-violet LED developed
1993	High-brightness blue LEDs demonstrated by Shuji Nakamura of Nichia Corporation
1994	Sulfur lamp developed by Fusion Lighting (USA), with support from U.S. Department of Energy

Marconi Labs, was ingeniously used by Oleg Losev (1927), James Biard (1961) and Nick Holonyak (1962) in the invention of LED, a new source of lighting for the modern world.

An LED is a semiconductor device (basically a p-n junction diode operated in a forward bias mode) which emits light when current is passed through it. LEDs are being increasingly used as lighting sources in such diverse applications as general lighting, display lighting, aviation lighting, stage lighting and medical lighting due to advantages of smaller size, lower energy consumption, longer lifetime, more robustness and faster switching.

On October 7, 2014, Japanese scientists, Isamu Akasaki, Hiroshi Amano and Shuji Nakamura were awarded the Nobel Prize in physics for "the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources".

In large scientific research facilities such as synchrotrons and free electron lasers the particle accelerators create light of an enormous intensity that can be used to undertake systematic investigations of the atomic and molecular detail of the world around us. Today there are more than 60 such advanced machines around the world that are being used for scientific research.

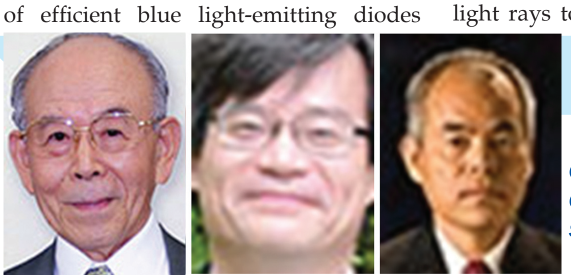
Light as a Mystery

Though our faculties for perception of light are highly evolved we can see only a very narrow range of the electromagnetic spectrum from 4000 A° to 7000 A°. Our eyes function like a sophisticated camera. The iris controls the amount of light entering the eye. Cornea and lens refract light rays to focus on the retina. Ciliary muscles control the thickness of the lens thus adjusting its focal length. The retina contains rods and cones – photoreceptors that are stimulated by light. They generate nerve impulses that travel along the optic nerves to the visual cortex of the brain where the image is perceived.

One of the most mysterious aspects of light that captured the imagination of many geniuses is its speed. It changed the fate of many theories. Newton's theory failed due to speed, Maxwell's theory triumphed due to speed and Einstein's theory is totally based on speed!

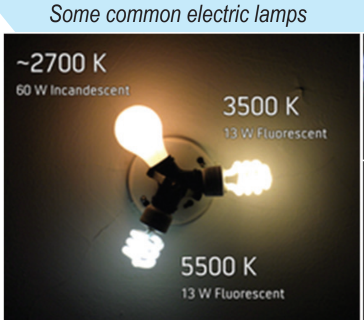
In 1905, Einstein based his special theory of relativity on the postulate that the speed of light is invariant, i.e., it is the same for everyone irrespective of one's state of motion and nothing in the universe travels faster than the speed of light. In 1915, he showed using his general theory of relativity how light was at the center of the very structure of space and time.

In 1983, the speed was precisely determined as 299792458 m/s by virtue of redefining the metre by the International System of Units (SI) as the distance travelled by light in vacuum in 1/299,792,458 of a second. Thus, light travels about 9 lakh, 10 thousand times


From left: *Isamu Akasaki, Hiroshi Amano and Shuji Nakamura*

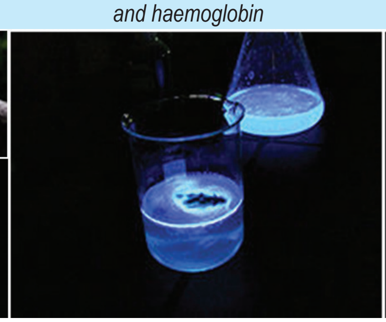
They invented blue light-emitting diodes which enabled bright and energy-saving white light sources

Some common electric lamps

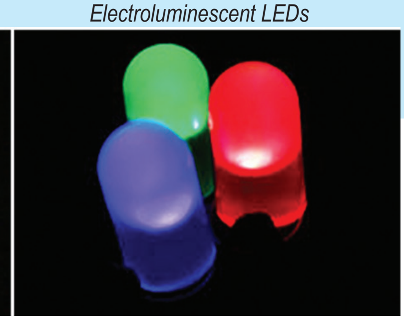


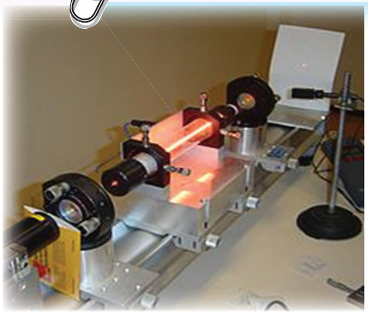
Bioluminescent fungus and firefly

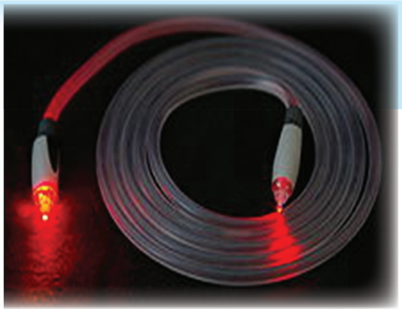
Chemiluminescent Luminol and haemoglobin



Electroluminescent LEDs







Extreme left: A Helium Neon Laser

Left: An optical Fibre

Optical fibres are thinner than hair tubular structures that can carry light from one place to another as light pipes or light guides.

faster than sound and about 1 crore, 8 lakh times faster than a train running at a speed of 100 kilometres per hour! It covers a distance of about one foot in 1 nanosecond and takes about 2.5 million years to reach from the Andromeda galaxy, our nearest galaxy, to earth. In 1964, Arno Penzias and Robert Wilson, scientists at the Bell-Labs, discovered the Cosmic Microwave Background, the oldest light in the universe that can be received today in the form of microwaves that have been traveling for over 13 billion years.

Another enigmatic aspect is colour. The process by which a human brain perceives colour is a mystery not properly understood. It is decided by both the physics of the object in its environment (absorption, reflection and emission of light) and the characteristics of the perceiving eye and brain (spectral sensitivities of the light receptors).

Some colours like the colours of peacock's feathers, called structural colors, are caused by interference effects rather than by pigments. This phenomenon, also called iridescence, is studied as a part of the field called thin-film optics. Newton performed his famous prism experiment in 1666 and recorded the spectrum of sunlight containing all the seven colors. Later it was found that sunlight contains not just seven colors. Aubert estimated about 1000 distinguishable hues in 1865 and Root found about 2 million tints and shades in the solar spectrum in 1881.

Fusion of Confusions: Light is All

What is light? Is it a ray, a wave or a particle? A fusion of confusions – it is all these together. The eye provides an excellent example of this complex unity where the gathering and focusing of light is understood in terms of rays and waves and the absorption of light by rods and cones is understood in terms of photons. Another example is laser in which light is treated as rays in the design of resonant cavity (made by a partially reflecting mirror optically parallel to a completely reflecting mirror), as waves in achieving amplification by forming standing wave patterns in the resonant cavity and as photons in achieving stimulated emission through desired quantum transitions.

As we further our journey of the optics knowledge spiral we can appreciate the complex unity of light in several recent advancements such as laser optics and fibre optics. The combination of lasers and fibres finds place in the United States National Academy's list of the twenty most important engineering developments of the twentieth century.

Laser was described as a solution looking for a problem by Theodore Maiman because of its extraordinary properties. It is evident today as lasers pervade virtually every sphere of human activity from scanning items at a grocery shop using barcode to lidars (light detection and ranging) that measure distant locations, from laser printers to industrial drilling, cutting and welding, from compact discs to surgical applications, from automated cloth cutting to optical communication and from entertainment lighting to production of high temperatures in fusion reactors. Lasers are used for precision long distance measurement due to their high degree of coherence. The distance between moon and earth was measured using a laser beam by the astronauts of Apollo mission to a probable error of less than 10 cm!

Optical fibres are thinner than hair tubular structures that can carry light from one place to another as light pipes or light guides. Fibre optic techniques are used by engineers to communicate telephone and data signals and by doctors to view internal organs (endoscopy). The invention of modern fiber optics is credited to Kapany (British) and Brian O'Brien Sr. at the American Optical Company in America in 1955. As the demand for more capacity, more speed and more clarity of communication increases, driven mainly by the phenomenal growth of the Internet, we are becoming increasingly dependent on fibre optic technologies. We are slowly moving from a wired society into a fibered society.

The optics knowledge spiral widens and deepens further as we reach frontier areas such as holography (a technique which enables three dimensional imaging), quantum information theory (a theory based on quantum information – the physical information held in the state of a quantum system), quantum dots (semiconductor nanocrystals that possess unique optical properties), optical traps and optical tweezers (tightly focused laser beam that holds microscopic particles stable in three dimensions), Bose-Einstein condensates [a new form of matter formed by trapping of atoms so that they are slowed and made to have the same energy level (coherent matter)], atom optics (area dealing with beams of cold, slowly moving neutral atoms, as a special case of a particle beam), photonic logic (use of photons in logic gates), optical computing (computing using photons for computation), and so on.

Light plays a vital role in almost all spheres of modern life. Apart from the scientific and technological aspects, light has also played a crucial role in art as is evident in paintings all over the world that show the aesthetic use of light and shades. Today artists and architects are increasingly using lighting technologies to enhance the aesthetics of their work.

Light has also been synonymous with knowledge and wisdom in all cultures of the world. Alexander Pope honoured Newton's work in his verse, "Nature and Nature's laws lay hid in Night: God said, Let Newton be, and all was Light." Pandit Nehru paid homage to Mahatma Gandhi in the words, "The light has gone out of our lives." Pope John Paul II remarked on his visit to Raj Ghat, "… the light is still shining, and the heritage of Mahatma Gandhi speaks to us still."

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