The Importance of Light in our Lives[1]

An overview of the fascinating history and current relevance of Optics and Photonics

Lecture Notes

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[1] This subject is included in the University of Cantabria's Senior Program.

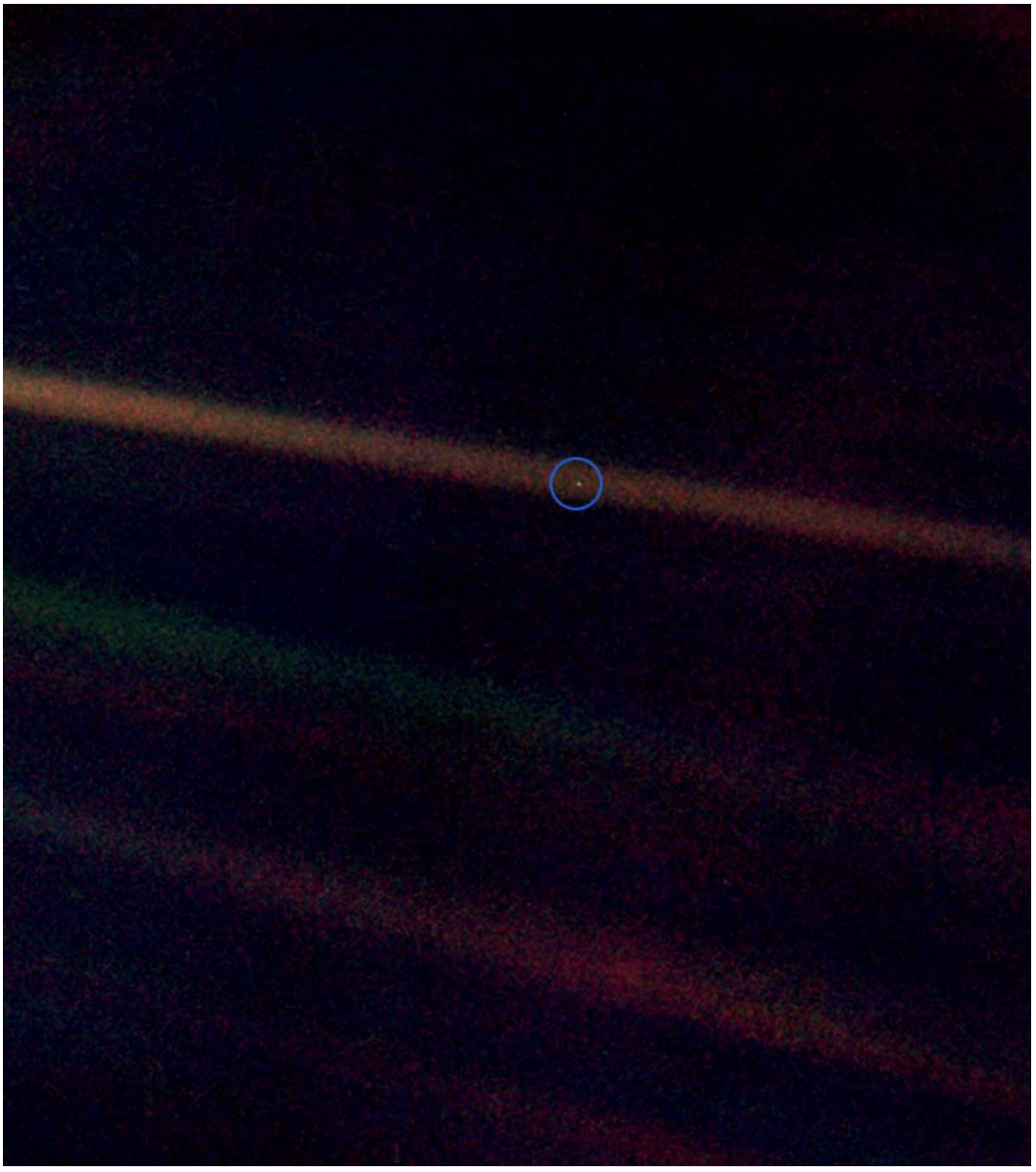

Figure 0. Image of the Earth captured by the probe Voyager-1 (first photograph taken of the Solar System). Source: NASA (Public Domain). https://bit.ly/240WEkU

From this distant vantage point, the Earth might not seem of particular interest. But for us, it's different. Consider again that dot. That's here, that's home, that's us. On it everyone you love, everyone you know, everyone you've ever heard of, every human being who ever was, lived out their lives.

The aggregate of our joy and suffering, thousands of confident religions, ideologies and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every "superstar", every "supreme leader", every saint and sinner in the history of our species lived there — on a mote of dust suspended in a sunbeam.

Carl Sagan: American astronomer, astrophysicist, cosmologist, author and science communicator.

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Prefacio

All professors, researchers or people who work in an area related to science, probably feel that their field of work is fundamental and more important than any other.

It goes without saying that the same happened to me and, although I must confess that I became involved in Photonics by chance, I feel that my field of work and study is, at the very least, of considerable importance to society.

This is precisely one of the main reasons why I am creating and giving this course, to explain to students not just what light is and how it behaves, but also the different applications and technologies that, using light as a basic element, surround us today both in our homes and in the hospitals that we visit, in the planes that we fly on or in the factories that manufacture the everyday objects we use.

The history of the evolution of Optics and Photonics is fascinating and begins several centuries before the current era, moving through legends that merge with history (Archimedes and his defense of Syracuse) and important people who have almost been forgotten (Al-Hazen), towards our day (almost) with names as familiar as Albert Einstein (who, for example, received the Novel Prize in Physics for his explanation of the photoelectric effect).

We will begin this course by looking back at the history of Optics and Photonics in order to put into context the current situation of this field of knowledge. We will then try to answer the difficult question: What is light? Following this, we will delve into the mysteries of the stars, in particular the Sun, to understand how it is capable of generating such large amounts of energy.

At this point, we will proceed towards the present day and take a close look at the operating principles of optical fiber, a key technology without which today's communications (for example the Internet) would be inconceivable. We will discover the connection between optical fiber and different applications that allow us to interact with our environment by means of photons, particularly in the development of sensors whose fields of application range from biomedicine to large civil infrastructures.

Not forgetting the phenomenon of vision, both human and animal, we will explain how we are capable of perceiving the world around us through this amazing sense. Finally, we will discuss some key advances in photonics and potential future prospects, offering a glimpse at the inventions that could mark our lives in the coming years.

I am sure that you will find this course fascinating: come on board and, in Einstein style, imagine yourself travelling on a beam of light to join this adventure.

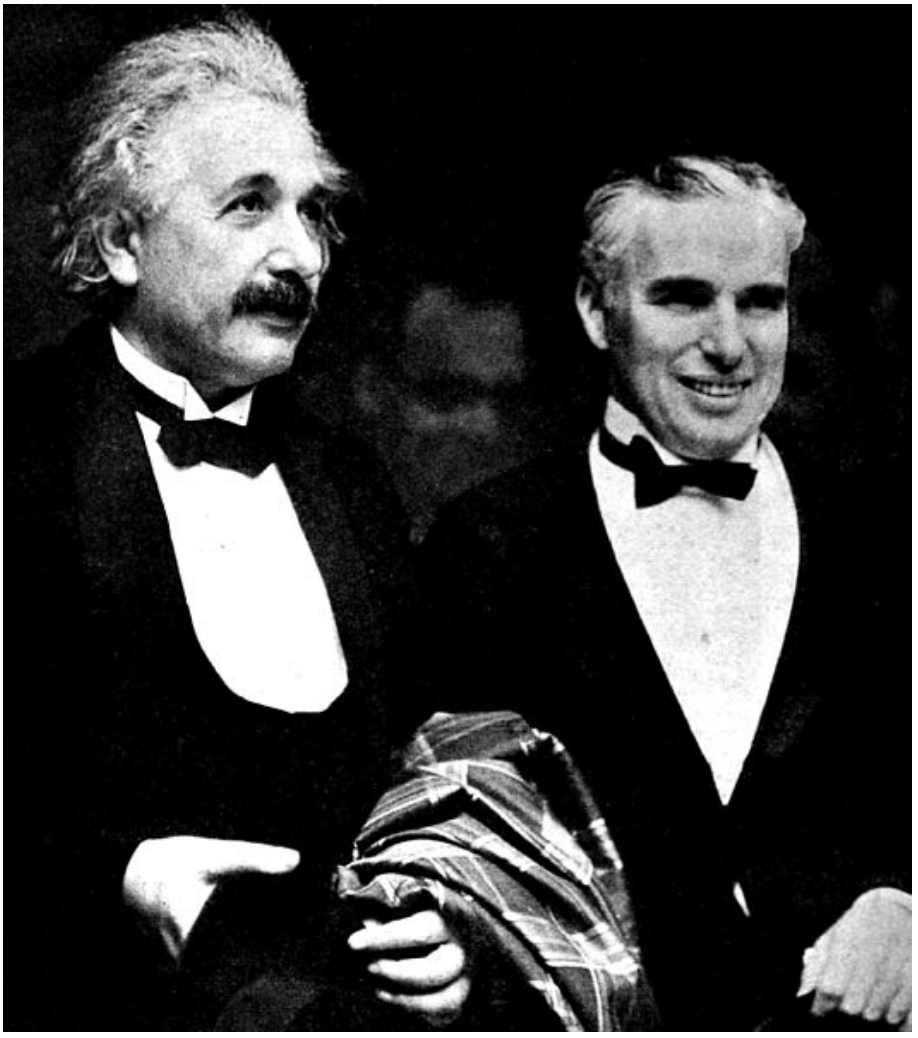

Figure 1. Photograph of Einstein and Charles Chaplin in Los Angeles in 1931 at the premiere of the movie "City Lights". Source: Photoplay magazine (Public Domain). https://bit.ly/2SjnwIE

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Course Structure

This course is divided into 8 chapters and aims to provide an introduction to the main concepts of optics and photonics: from the use of the first magnifying glasses to the use of laser in a multitude of present-day devices and applications.

- **Chapter 1: The Historical Evolution of Optics and Photonics**

  With reference to the discoveries of key personalities such as Archimedes, Newton or Einstein, this chapter traces the fascinating history of the evolution of Optics through to Photonics, with the invention of the omnipresent laser and optical fiber.

- **Chapter 2: What is Light? Waves and Particles**

  This chapter aims to provide a clear and simple explanation of one of the "mysteries" that have most greatly concerned and occupied hundreds of scientists throughout the centuries: What is Light? Is it a wave or a particle?

- **Chapter 3: Sun, Light and Life: how the Sun and photosynthesis work**

  Life on our planet would not exist without the Sun and the energy it provides every second. Likewise, photosynthesis or the conversion of inorganic substances to organic compounds in plants, takes place thanks to the energy of light.

- **Chapter 4: The light that revolutionized the digital era: the laser and optical fiber**

  Today's society would not be the same if, back in 1958, the laser had not been invented and, thereafter, optical fiber. The Internet, the great communications phenomenon that has revolutionized our lives, is simply light (laser) travelling around the world through optical fiber. We will briefly review the invention of the laser, optical fiber and their fundamentals.

- **Chapter 5: Measuring the world using light: from biomedicine to civil work**

  Light not only serves for high speed communication via the Internet, but can also help us in a variety of applications: from precisely delimiting cancer cells to real-time monitoring of a bridge or dam. This chapter provides a brief explanation of some important examples that help us to better understand this "hidden" facet of light.

- **Chapter 6: The phenomenon of vision: how humans and animals see**

  This introduction to the world of light would not be complete if we were not to explain how one of the most incredible parts of our body works: the eye and the sense of sight. Furthermore, we will explore the differences between our sense of sight and that of other members of the animal kingdom.

- **Chapter 7: Photonics: current situation and future perspectives**

  This final chapter reviews some of the most recent advances in the world of optics and photonics and other possible future applications of this field of knowledge, which is fundamentally important today and will undoubtedly continue to be so in future decades.

- **Chapter 8: Experiments with light that you can do at home**

  Finally, we suggest a series of simple experiments that students can do to help assimilate the concepts explained during the course.

Acronyms

A	amplitude of a wave
c	speed of light in vacuum
CD	compact disc
CSP	Concentrating Solar Power
dB	decibel
d_m	minimum distance (referring to the process of vision and lens accommodation)
E	energy
f	frequency of a wave
FBG	fiber Bragg grating
FTTH	fiber to the home
h	Planck's constant ($6{,}63 \cdot 10^{-34} J \cdot s$)
IR	infrared
λ	wavelength
LASER	light amplification by stimulated emission of radiation
LIBS	laser-induced breakdown spectroscopy
m	mass (referring to an object)
Mbps	Megabits (10^6 bits) per second (referring to data transfer speed)
n	refractive index (optical density of a medium)
UV	ultraviolet
v	speed of light in a medium
s	space (distance)
t	time (e.g. which elapses between two events)
T	period of a wave

Units

Hz hertz (frequency)
s second (time, period)
J Jule (energy, work and heat)
W Watt (power)

Glossary

Absorption of light the process whereby a photon of light is absorbed by an atom in which, using the photon's energy, an electron is elevated from a lower to a high energy level.

Amplitude (of a wave) indicates the intensity or energy associated with it.

Cones photoreceptors responsible for perceiving colors.

Cornea a hemispherical transparent structure located at the front of the eye that allows light to enter the eye and protects the iris.

Corpuscle in the context of this course, this term has been used as a synonym for "particle´´.

Crystalline lens a part of the eye that works like a biconvex lens and enables focusing objects situated at different distances.

Diffraction grating component that splits light into several beams of light travelling in different directions.

Dispersion phenomenon which occurs when light is broken down into different "colors´´ or wavelengths (not to be confused with the dispersion of light pulses in optical communications).

Distributed sensor sensor which enables making measurements of a certain physical magnitude over a certain distance, for example using optical fiber.

Energy ability to do work in the form of motion, light, heat, etc.

Fovea area of the retina where the rays of light are focused, particularly concerned with color vision.

Frequency (of a wave) refers to the number of waves that pass a fixed point in a given amount of time.

Fusion reactor energy-generating technology that attempts to imitate the nuclear fusion process in the stars.

Grating Bragg or diffraction grating that, normally inscribed in an optical fiber, enables measuring temperature and strain by means of variations in the wavelength of the reflected light.

Infrared thermography technology which enables capturing, normally with cameras, infrared radiation emitted by bodies, in order to estimate their temperature.

Iris structure that controls the amount of light that the eye receives.

Laser device capable of generating light with certain ”special´´ characteristics, as all the photons generated in the process share the same characteristics (phase, frequency, etc.). The field of knowledge known as ”photonics´´ came about with the invention of the laser.

Lens device capable of bending light rays which is transparent (normally made of glass) and consists of two surfaces.

LIDAR optical ”radar´´ for measuring distance by estimating the time it takes for a pulse of light to hit a target and return back.

Luminescence property of certain bodies to emit “cold” light whose origin is another type of electromagnetic radiation.

Microscope instrument that serves to observe very small objects using lenses that increase the image.

Myopia a visual defect in which distant objects appear blurred because their images are focused in front of the retina rather than on it.

Nuclear fusion process whereby energy is generated in the stars by fusing atoms together.

Optics the branch of physics that studies the properties of light, including its interaction with matter and the construction of elements that use it or enable its detection.

Particle constituent element of matter.

Period (of a wave) indicates how fast or slow a wave varies, to be precise the time that it takes one complete wave to pass a reference point.

Photoelectric effect the property whereby certain materials are capable of generating electric current when they receive electromagnetic radiation (light).

Photonics science that studies the generation, control and detection of light (photons) and links optics with electronics. It arises from the invention of the laser at the end of the fifties.

Photosynthesis process whereby plants, using the Sun’s energy, generate their own food in the form of sugars. In order to do this, plants also need water, minerals and CO2.

Photoreceptors retina cells that allow converting the images generated in the eye into electric impulses that will be interpreted by the brain.

Point sensor sensor which enables making measurements at a specific point.

Polarization orientation of the vibration of light.

Presbyopia difficulty in clearly seeing nearby objects due to a loss in the lens’ ability to adapt.

Quantum Physics (or Mechanics) branch of physics concerning the study of nature at very small scales (atoms, etc.).

Reflection change in the direction or path of light when it strikes an obstacle, for example a mirror.

Refraction change in the direction and speed of light when it travels from one medium to another one, with a different ”optical density´´ or ”refractive index´´.

Refractive index indicates the "optical density" of a material and, therefore, the speed at which light travels through it. The greater the refractive index, the greater the density and the lower the speed of light in that medium.

Retina sensor or transducer of the human eye, enabling the conversion of light into electric impulses which are then interpreted by the brain.

Rods photoreceptors responsible for perceiving images (details, forms, contours) in dimly lit conditions.

Scattering (dispersion) scattering processes are generated when light strikes random obstacles, being redirected in other directions.

Sensor device which converts a physical or chemical magnitude into another magnitude, normally electric, and makes a quantitative measurement of the phenomenon.

Solar photovoltaic energy renewable energy based on converting sunlight into electric energy by means of the photoelectric effect.

Solar thermoelectric energy renewable energy based on converting energy from the sun in the form of heat into electric energy by heating a fluid and using a conventional turbine.

Spectrum in optics, a spectrum is the representation of light broken down into its "colors" or wavelengths.

Spectroscopy science that studies the interaction between light and matter.

Spontaneous emission of light the light emitted by an atom when one of its electrons loses energy when moving from a higher lever to a lower one. This is the process which gives rise to the emission of light in the Sun or in an incandescent bulb.

Stimulated emission of light process whereby light is emitted in laser-type sources.

Strain tension or elongation, applied to optical fiber sensors.

Tapetum lucidum reflective membrane behind the retina which many animals have, like cats and dogs, which enables the reflection of light thus increasing the sensitivity of vision.

Telescope device containing an arrangement of mirrors and lenses, which serves to observe distant objects by magnifying the image.

Total internal reflection phenomenon which explains the propagation of light in optical fiber and which occurs, depending on the angle of the light entering, when there are two media with different refractive indexes.

Wave periodic movement that propagates through a physical medium or in vacuum transporting energy.

Wave-particle duality refers to the dual behavior of light (as a wave or as a particle) depending on the experiment used to observe it.