

# Preface

The evolution of light science has followed an irregular but progressive path through the efforts of many investigators—from about the fifth century BC to the current era. Early speculations on the nature of light were usually based on visual observations, leading to a philosophical conclusion, an imagined experiment, or a proposal and implementation of an actual experiment. Over the years, progress in light science has modified earlier widely held views, and future research will inevitably revise these views. Thoughts on the nature of light have led to the formation of theories, and new theories have also arisen from unexpected results of experiments. Often, original theories or proposals to describe the physics of light are rapidly followed by confirming or refuting arguments and experiments. Moreover, successful experiments have often led to practical applications that have generated major new industries. From the earliest recorded theories and experiments to the latest applications in photonic communication and computation, the ways in which light has been put to use are numerous and astounding. Some of the latest endeavors in light science are approaching the realm of science fiction.

Light consists of a broad spectrum of radiation, with only a small spectral region visible to the human eye. Although visible light has been a major factor in the development of photonic technology, much of the understanding of the nature of light was made possible by discoveries occurring outside the visible spectrum. Over the centuries, scientists have attempted to measure, generate, control, and utilize light over specific wavelength ranges. The spatial realm of this research encompasses an almost incomprehensible range—from the size of a photon to the infinite reaches of space. The continuous development of new engineering capabilities has provided a platform for many of these ideas to be realized.

Aided by the extensive communication networks available today, modern innovative experiments using light often involve cooperation between scientists and laboratories in different countries. The defining experiments described in this book have sufficient detail to illustrate the goals, procedures, and conclusions of the investigators and, when possible, are derived from original research papers and reports. The described concepts and experiments are supplemented with many annotated drawings.

Topics in this book include the foundational investigations on the nature of light and ongoing methods to measure its speed. Early experiments on electrodynamics, Maxwell's equations of electromagnetism, and Maxwell's wave equations identified light as an electromagnetic wave. Planck's radiation formula and Einstein's energy equations described light as a fundamental quantized light particle in the form of a packet of electromagnetic energy—the photon. The strong connections between light and relativity were established, and the quantum mechanical properties of photon particles have been experimentally validated.

A progression of electrically driven light sources has developed, including early sustainable arc lamps, modern solid-state lamps, and coherent laser light. The intensity range of light sources available today is remarkable—from intense vortex arc discharge lamps, synchrotron radiators, and petawatt lasers to weak single-photon light generators. The origins and operating principles of the main types of gas and solid-state lasers are described, along with current achievable levels in super-high power and ultra-short pulse duration lasers. In addition, several novel types of lasers have emerged, including dark pulse lasers, time-reversed lasers, and anti-lasers.

Engineering advances in nanotechnology have resulted in the fabrication of novel photonic metamaterials for controlling the propagation of light. Extreme reduction of light speed has been achieved in atomic gases and solid photonic crystal waveguides, along with the stoppage and time reversal of light. Photonic crystal metamaterials have been produced that exhibit negative and zero refractive indices. Structured metamaterial cloaks have enveloped opaque objects and rendered them invisible. Creative experiments and devices have demonstrated both subluminal and superluminal light speeds in free space.

The discovery, production, and utilization of photon quantum entanglement have enabled many new applications, including secure long-distance quantum communication and quantum teleportation. Delayed-choice experiments with entangled photons have been designed to observe the transition between particle and wave behavior of a photon. Quantum memory devices have been developed to receive, stop, store, and re-emit a photon, while preserving the quantum state of the light. Squeezed light at the quantum level was applied in the recent detection of gravitational waves. The photon has emerged as the preferred carrier of information in the rapidly developing field of quantum computing. Recent studies on hypothetical light-based time-like curves have opened new dialogues on time travel possibilities. Lastly, scientific evidence and speculation have produced several scenarios for the cosmological beginning of the photon and its expected fate in a fading universe.

Austin, USA

Dennis F. Vanderwerf

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Vanderwerf, D.F.

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