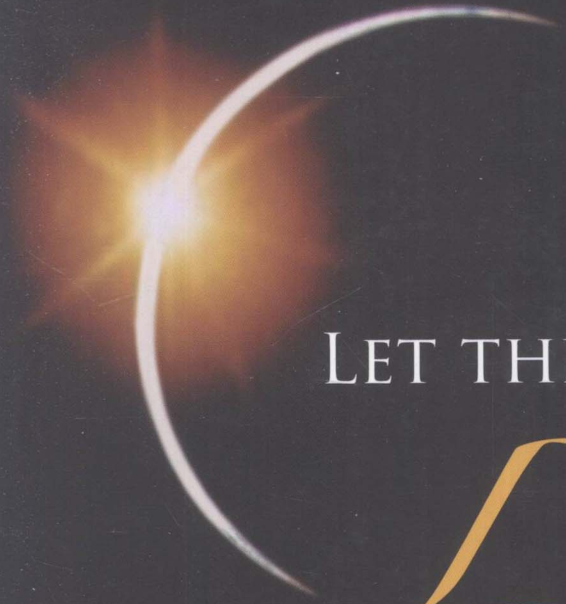

LET THERE BE *Light*

The Story of Light from Atoms to Galaxies

Alex Montwill
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Let There Be Light

The Story of Light
from Atoms to Galaxies

This book is dedicated to
Ann and Liam,
our life partners.

Preface

Physics is a complex subject. Students meet many concepts and phenomena; mass and energy, electric charge and magnetism, light and heat, atoms and molecules, stars and galaxies, to name just a few. Much time and effort is devoted to learning experimental methods and new mathematical techniques. There is often little opportunity to stand back and take an overall view.

As the overall picture begins to unfold and the various parts of the jigsaw come together, a deeper understanding develops. Apparently unrelated phenomena are seen to be different aspects of the same thing. It emerges that the many laws and formulae are derived from a small number of basic fundamental principles. The steps are logical and comprehensible, but often very subtle, and it is in following these steps that we discover the beauty and fascination of the subject.

As is implied by the title, the book focuses on light, or more generally, electromagnetic radiation. Many of the properties of light derive from the most fundamental principles and laws of physics. Fermat's principle of least time leads to the laws of reflection and refraction. Maxwell's logic leads to the propagation of electromagnetic radiation. Einstein derived his equation $E = mc^2$ by a logical path from the hypothesis of symmetry of empty space and the constancy of the speed of light in vacuum. Planck's discovery of light quanta leads to the apparent paradoxes of quantum mechanics! Nature, it would seem, is at the same time both comprehensible and incomprehensible.

The book is written in textbook style, at a level somewhere between the rigorous and the popular. We feel that it is suitable as background reading for third level students and may also be enjoyed by readers who have an interest in science and are comfortable with basic mathematics. Wherever possible, mathematical derivations are given in appendices rather than inserted into the main body of the text. These appendices may be consulted by readers who wish to delve more deeply into the subject.

Many of the topics in the book formed part of a number of series of science slots on Irish National radio (RTE1). Each series consisted of about 20 ten-minute slots on a common theme under titles such as *'From Greeks to Quarks'*, *'Forces at Work'*, *The Mind Laboratory'*, *'Portraits in Physics'*, *'Street Science'* and *'Letters from the Past'*. These programs continued over a period of almost 10 years attests to the fact that there were people out there listening!

To put the physics into a historical context and to show the human side of some of the 'main players' in the story, most chapters conclude with a biographical sketch. These sketches are, in the main, anecdotal and light hearted.

Chapter 1 Introducing Light. We give a historical synopsis of the perception of light through the ages, and the discovery of some extraordinary properties in the last two centuries. Sometimes light behaves as a wave, and sometimes as a stream of particles. When Max Planck, Niels Bohr and others looked more deeply into the puzzle, they opened a Pandora's box full of secrets of Nature.

Chapter 2 Geometrical Optics — Reflection. The path taken by light is always the one which takes the shortest time. This law (Fermat' principle), is applied to the change of direction of light when it is reflected. *Historical figure: Pierre de Fermat.*

Chapter 3 Geometrical Optics — Refraction. When light comes to the boundary between two media it has two choices; it can be reflected at the boundary or transmitted into the second medium. Fermat's law still applies, but such 'freedom of choice' gives a hint of non-predictability in the laws of Nature. We look at practical applications of refraction in lenses and treat the human eye as an optical instrument.

Chapter 4 Light from Afar — Astronomy. Starlight reaches us after a long, journey across the universe. The ancient astronomers showed remarkable ingenuity in their deductions on the size and distance from the earth of the moon and sun. Equally impressive were the measurements and calculations made in the Middle Ages, considering that they were carried out by observers on the earth which is both rotating and in orbital motion. *Historical figure: Galileo Galilei.*

Chapter 5 Light from the Past — Astrophysics. The laws of physics that apply on earth are seen to apply throughout the universe and do not appear to have changed with time. We can retrace the steps back to the birth of the universe. *Historical figure: Isaac Newton.*

Chapter 6 Introducing Waves. We look at the characteristics of waves in general. *Historical figure: Jean Baptiste Fourier.*

Chapter 7 Sound Waves. To most of us, the properties of sound are more familiar than those of light. Sound can be reflected, can bend around corners, can interfere constructively, and can resonate. This chapter draws on the wealth of human experience with sound to highlight the properties of waves. *Historical Interlude — The 'Sound Barrier'.*

Chapter 8 Light as a Wave. Armed with the knowledge of what we can expect from a wave we examine the wave properties of light, a very special wave which can exist in empty space independent of a material medium. Under certain conditions, light + light = darkness! *Historical figure: Thomas Young.*

Chapter 9 Making Images. From photographs to holograms.

Chapter 10 There was Electricity, There was Magnetism, and Then There was Light. Electric charges mysteriously attract and repel one another at a distance. New forces appear when these charges are in motion. It took the genius of Maxwell to combine the experimental laws of electromagnetism to predict the propagation of electromagnetic waves. *Historical figure: James Clerk Maxwell.*

Chapter 11 'Atoms of Light' — The Birth of Quantum Theory. Just when it seems that all is understood, a small problem with the spectrum of light emitted by hot surfaces turns out to be a symptom of something big. Max Planck put his head on the block by suggesting nature is not continuous... *Historical figure: Max Planck.*

Chapter 12 The Development of Quantum Mechanics. The consequences of Planck's hypothesis are studied from different angles. Surprisingly completely different mathematical approaches lead to the same final conclusions. Quantum mechanics leads to a new philosophy and physics changes beyond all recognition. *Historical figure: Niels Bohr.*

Chapter 13 Atoms of Light Acting as Particles. The evidence that light is like a stream of particles is conclusive. These 'Atoms of Light' are called *photons. Historical figure: Robert A. Millikan.*

Chapter 14 Atoms of Light Behaving as Waves. Nature seems to be playing a trick. Just when we have accepted photons as particles, and looked at individual photons one by one, they behave not as particles, but as waves! *Historical figure: Richard Feynman.*

Chapter 15 Relativity. Part 1: How It Began. We begin with the hypothesis of symmetry of space and time. Empty space has no preferred places, there is no universal clock. The speed of light is the same for everybody. Following logical steps of Einstein and others, we arrive at the startling result concerning the nature of time, contrary to natural instinct. *Historical figure: Hendrik A. Lorentz.*

Chapter 16 Relativity. Part 2: Verifiable Predictions. Continuing in the logical steps of the previous chapter, we arrive at a prediction with great practical consequences. Matter and energy are equivalent and related by the equation $E = mc^2$. From the hypotheses of symmetry of space and constancy of the speed of light comes the prediction that matter can be converted into energy and energy into matter. *Historical figure: Albert Einstein.*

Chapter 17 Epilogue. The creation of matter out of energy revealed a whole new world of fundamental particles, including the theoretically predicted or *'heavy atom of light'*, the W particle.

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