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With 385 Figures

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Preface

"Which area do you think I should go into?" or "Which are the areas that have the brightest future?" are questions that are frequently asked by students trying to decide on a field of specialization. My advice has always been to pick any field that combines two or more disciplines such as Nuclear Physics, Biomedical Engineering, Optoelectronics, or even Engineering Optics. With the ever growing complexity of today's science and technology, many a problem can be tackled only with the cooperative effort of more than one discipline.

Engineering Optics deals with the engineering aspects of optics, and its main emphasis is on applying the knowledge of optics to the solution of engineering problems. This book is intended both for the physics student who wants to apply his knowledge of optics to engineering problems and for the engineering student who wants to acquire the basic principles of optics.

The material in the book was arranged in an order that would progressively increase the student's comprehension of the subject. Basic tools and concepts presented in the earlier chapters are then developed more fully and applied in the later chapters. In many instances, the arrangement of the material differs from the true chronological order.

The following is intended to provide an overview of the organization of the book. In this book, the theory of the Fourier transforms was used whenever possible because it provides a simple and clear explanation for many phenomena in optics. Complicated mathematics have been completely eliminated.

Chapter 1 gives a historical prospective of the field of optics in general. It is amazing that, even though light has always been a source of immense curiosity for ancient peoples, most principles of modern optics had to wait until the late eighteenth century to be conceived, and it was only during the mid-nineteenth century with Maxwell's equations that modern optics was fully brought to birth. The century following that event has been an exciting time of learning and a tremendous growth which we have been witnessing today.

Chapter 2 summarizes the mathematical functions which very often appear in optics and it is intended as a basis for the subsequent chapters.

Chapter 3 develops diffraction theory and proves that the far field diffraction pattern is simply the Fourier transform of the source (or aperture) function. This Fourier-transform relationship is the building block of the entire book (Fourier optics).

Chapter 4 tests the knowledge obtained in Chaps. 2 and 3. A series of practical examples and their solutions are collected in this chapter.

Chapter 5 develops geometrical optics which is the counterpart of Fourier optics appearing in Chap. 3. The power of geometrical optics is convincingly demonstrated when working with inhomogeneous transmission media because, for this type of media, other methods are more complicated. Various practical examples related to fiber optics are presented so that the basic knowledge necessary for fiber optical communication in Chap. 13 is developed.

Chapter 6 deals with the Fourier *transformable and image formable* properties of a lens using Fourier optics. These properties of a lens are abundantly used in optical signal processing appearing in Chap. 11.

Chapter 7 explains the principle of the Fast Fourier Transform (FFT). In order to construct a versatile system, the merits of both analog and digital processing have to be cleverly amalgamated. Only through this hybrid approach can systems such as computer holography, computer tomography or a hologram matrix radar become possible.

Chapter 8 covers both coherent and white light holography. The fabrication of holograms by computer is also included. While holography is popularly identified with its ability to create three-dimensional images, the usefulness of holography as a measurement technique deserves equal recognition. Thus, holography is used for measuring minute changes and vibrations, as a machining tool, and for profiling the shape of an object.

Descriptions of microwave holography are given in Chap. 12 as a separate chapter. Knowledge about the diffraction field and FFT which are found in Chaps. 3 and 6 are used as the basis for many of the discussions on holography.

Chapter 9 shows a pictorial cook book for fabricating a hologram. Experience in fabricating a hologram could be a memorable initiation for a student who wishes to be a pioneer in the field of engineering optics.

Chapter 10 introduces analysis in the spatial frequency domain. The treatment of optics can be classified into two broad categories: one is the space domain, which has been used up to this chapter, and the other is the spatial frequency domain, which is newly introduced here. These two domains are related by the Fourier-transform relationship. The existence of such dual domains connected by Fourier transforms is also found in electronics and quantum physics. Needles to say, the final results are the same regardless of the choice of the domain of analysis. Examples dealing with the lens in Chap. 6 are used to explain the principle.

Chapter 11 covers optical signal processing of various sorts. Knowledge of diffraction, lenses, FFT and holography, covered in Chaps. 3, 6, 7 and 8, respectively, is used extensively in this chapter. In addition to coherent and incoherent optical processing, Chap. 11 also includes a section on tomography.

Many examples are given in this chapter with the hope that they will stimulate the reader's imagination to develop new techniques.

Chapter 12 is a separate chapter on microwave holography. While Chap. 8 concerns itself primarily with light wave holography, Chap. 12 extends the principles of holography to the microwave region. It should be pointed out that many of the techniques mentioned here are also applicable to acoustic holography.

Chapter 13 describes fiber-optical communication systems which combines the technologies of optics and those of communications. The treatment of the optical fiber is based upon the geometrical-optics point of view presented in Chap. 5. Many of the components developed for fiber-optical communication systems find applications in other areas as well.

Chapter 14 provides the basics necessary to fully understand integrated optics. Many an integrated optics device uses the fact that an electro- or acousto-optic material changes its refractive index according to the external electric field or mechanical strain. The index of refraction of these materials, however, depends upon the direction of the polarization of the light (anisotropic) and the analysis for the anisotropic material is different from that of isotropic material. This chapter deals with the propagation of light in such media.

Chapter 15 deals with integrated optics, which is still such a relatively young field that almost anyone with desire and imagination can contribute.

Mrs. Mary Jean Giliberto played an integral role in proof reading and styling the English of the entire book. Only through her devoted painstaking contribution was publication of this book possible. I would like to express my sincere appreciation to her.

Mr. Takamitsu Aoki of Sony Corporation gave me his abundant co-operation. He checked all the formulas, and solved all problem sets. He was thus the man behind the scenes who played all of these important roles.

I am thankful to Dr. Junichi Nakayama of Kyoto Institute of Technology for helping me to improve various parts of Chapter 10. I am also grateful to Professor Stefan Zukotynski and Mr. Dehuan He of The University of Toronto for their assistance. The author also wishes to thank Professor T. Tamir of The Polytechnic Institute of New York, Brooklyn and Dr. H. K. V. Lotsch of Springer Verlag for critical reading and correcting the manuscript. Mr. R. Michels of Springer-Verlag deserves praise for his painstaking efforts to convert the manuscript into book form. Megumi Iizuka helped to compile the Subject Index:

Toronto, August 1985 *Keigo Iizuka*

Contents

1. History of Optics

1.1 The Mysterious Rock Crystal Lens

It was as early as 4,000 B.C. that the Sumerians cultivated a high level civilization in a region of Mesopotamia which at present belongs to Iraq. The name Mesopotamia, meaning "between the rivers", [1.1] indicates that this area was of great fertility enjoying natural advantages from the Tigris and Euphrates rivers. They invented and developed the cuneiform script which is today considered to have been man's first usable writing.

Cuneiforms were written by pressing a stylus of bone or hard reed into a tablet of soft river mud. The tip was sharpened into a thin wedge and thus the cuneiform letters are made up of such wedge shaped strokes as shown in Fig. 1.1 [1.2]. These tablets were hardened by baking in the sun. Literally tens of thousands of the tablets were excavated in good condition and deciphered by curious archaeologists.

The inscriptions on the tablets have revealed education, religion, philosophy, romance, agriculture, legal procedure, pharmacology, taxation, and so on. It is astonishing to read all about them, and to discover that

Fig. 1.1. Cuneiform tablets excavated from Mesopotamia. The contents are devoted to the flood episode. (By courtesy of A. W. Sjörberg, University Museum, University of Pennsylvania)

they describe a highly sophisticated society more than five thousand years ago [1.3].

What is amazing about the tablets is that some of the cuneiform inscriptions are really tiny (less than a few millimeters in height) and cannot be easily read without some sort of a magnifying glass. Even more mysterious is how these inscriptions were made. A rock-crystal, which seemed to be cut and polished to the shape of a plano-convex lens, was excavated in the location of the tablets by an English archaeologist, Sir *Austen Layard*, in 1885 [1.4]. He could not agree with the opinion that the rock crystal was just another ornament. Judging from the contents of the tablet inscriptions, it is not hard to imagine that the Sumerians had already learned how to use the rock crystal as a magnifying glass. If indeed it were used as a lens, its focal length is about 11 cm and a magnification of two would be achieved with some distortion.

Another interesting theory is that these cuneiforms were fabricated by a group of nearsighted craftmen [1.5]. A myopic (nearsighted) eye can project a bigger image onto the retina than an emmetropic (normal) eye. If the distance b between the lens and the retina is fixed, the magnification m of the image projected onto the retina is

$$m = \frac{b}{f} - 1, \tag{1.1}$$

where f is the focal length of the eye lens. The image is therefore larger for shorter values of f. In some cases, the magnifying power of the myopic eye becomes 1.7 times of that of the emmetropic eye, which is almost as big a magnification as the rock crystal "lens" could provide. However, it is still a mystery today how these tiny tablet inscriptions were fabricated and read.

Two other significant developments in optics during this period, besides the questionable rock crystal lens, were the use of a lamp and a hand-held mirror. Palaeolithic wall paintings are often found in caves of almost total darkness. Such lamps, as shown in Fig. 1.2, were used by the artists and have been excavated from the area. Animal fat and grease were used as

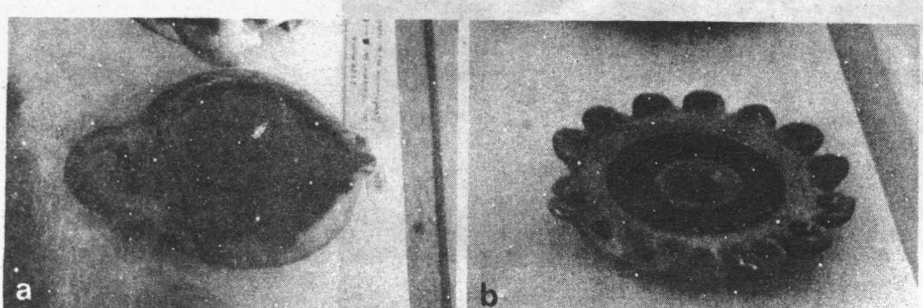

Fig. 1.2 a, b. One candle power at the beginning of Greek empire (**a**) evolved to 15 candle power (**b**) at the end of the empire

their fuel. The lamps were even equipped with wicks. The paintings themselves demonstrated a sophisticated knowledge about colour.

Other optical instruments of early discovery are metallic mirrors, which have been found inside an Egyptian mummy-case. By 2,000 B.C., the Egyptians had already mastered a technique of fabricating a metallic mirror. Except for the elaborate handle designs, the shape is similar to what might be found in the stores today.

1.2 Ideas Generated by Greek Philosophers

Greece started to shape up as a country around 750 B.C. as a collection of many small kingdoms. Greek colonies expanded all around the coast lines of the Mediterranean Sea and the Black Sea including Italy, Syria, Egypt, Persia and even northeast India [1.6].

A renowned Greek scientist, Thales (640–546 B.C.), was invited by Egyptian priests to measure the height of a pyramid [1.4]. For this big job, all that this brilliant man needed was a stick. He measured the height of the pyramid by using the proportion of the height of the stick to its shadow, as shown in Fig. 1.3. He also predicted the total solar eclipse that took place on May 28, 585 B.C.

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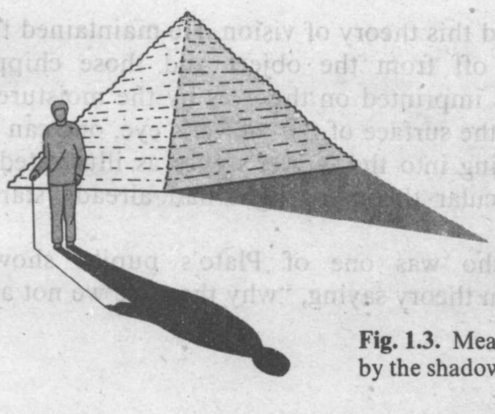

Fig. 1.3. Measurement of the height of a pyramid by the shadow of a stick

The greatest mathematician and physicist of all time, Euclid (315–250 B.C.), and his student Archimedes (287–212 B.C.) and many others were from the University of Alexandria in Egypt which was then a Greek colony. The "Elements of Geometry" written by Euclid has survived as a text book for at least twenty centuries. The progress of geometry has been inseparable from that of optics.

Democritus (460–370 B.C.), Plato (428–347 B.C.) and Euclid all shared similar ideas about vision. Their hypothesis was that the eyes emanate vision rays or eye rays and the returned rays create vision. Under

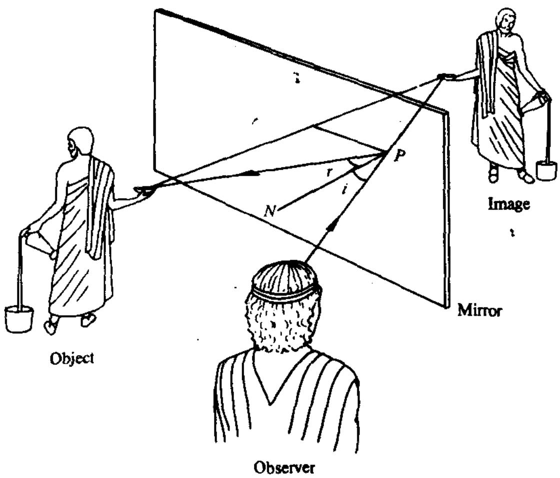

Fig. 1.4. Reversed direction of arrows as well as reversed designation of the incident and reflected angles

this hypothesis, vision operated on a principle similar to that of modern day radar or sonar. As a result of the concept of the eye ray, arrows indicating the direction of a ray always pointed away from the eye. Not only the direction of the arrows, but also the designation of the incident and reflected angles were reversed from what these are today, as illustrated in Fig. 1.4. As a matter of fact, it took fourteen hundred years before the direction of the arrows was reversed by Alhazen (around 965–1039) of Arabia in 1026.

Democritus further elaborated this theory of vision. He maintained that extremely small particles chip off from the object and those chipped particles form a replica which is imprinted on the eyes by the moisture in the eyes. His proof was that, on the surface of the viewer's eye, one can see a small replica of the object going into the viewer's eyes as illustrated in Fig. 1.5. The basis of a corpuscular theory of light had already started percolating at this early age.

Aristotle (384–322 B.C.), who was one of Plato's pupils, showed dissatisfaction about the emission theory saying, "why then are we not able to seen in the dark?" [1.4, 7, 8].

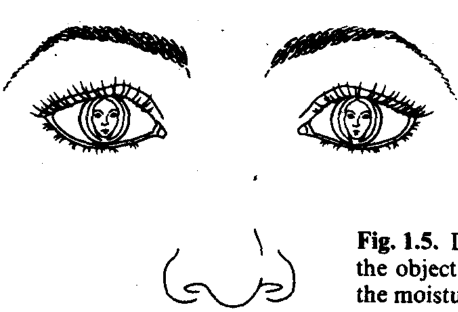

Fig. 1.5. Democritus (460–370 BC) said "a replica of the object is incident upon the eyes and is imprinted by the moisture of the eye"