38. A Philosophical Ode to Physical Optics

Brian J. Thompson

Most of us now believe that there is an integrated body of knowledge that constitutes the discipline of optical science and engineering. That discipline includes, of course, the technology and resultant systems that are associated with, and derived from, that science and engineering. This concept of a discipline comes from the definition that optical science and engineering is concerned with the generation, propagation, manipulation and detection of light from the ultraviolet to the infrared and the application of optics in a wide variety of commercial, industrial and military systems in pure optical form and perhaps more importantly as hybrid systems. Evidence of the acceptance of “optics” as a discipline as well as an enabling technology is apparent in the number of academic programs now available in many schools, colleges and universities around the world. It is interesting to recall that when The Institute of Optics was founded at The University of Rochester, it was one of a very small group of academic programs around the world and the first in the United States. Times have certainly changed!

The now broad field of optics can be examined in three major areas: geometrical optics, physical optics and quantum optics. Or, if you wish, as rays, waves, and photons. This separation into three areas has significant historical importance and each approach can be applied to optical problems and to the design of practical optical systems. The major impact on optical science and engineering is in the interconnection of the three approaches and their interdependence which provides critical insight into the generation, propagation, manipulation, and detection of light but critical insights into the limitation of the approaches and their range of validity.

It was the fundamental concept of rectilinear propagation that really led to the ray tracing techniques which became a very powerful tool for the design and analysis of optical systems including the effects of aberrations. There was, of course, no thought that rays really exist as such. From a physical optics point of view the “rays” are equivalent to the normals to the wave front as that wave front propagates through the optical system. Light waves do exist and electromagnetic wave theory is a particularly important and truly fundamental method in the analysis of the propagation of light and hence to the analysis of optical systems. Historically, geometrical optics was thought of in terms of so-called incoherent systems; physical optics and the phenomena of interference and diffraction were so-called coherent systems. With the development of wave optics the full range of problems could be included—that is, incoherent, partially coherent, and coherent systems, with the spatial and temporal coherence taken into consideration as well as the polarization. Just one example will suffice to make the point. The introduction of the “sine-wave response” of an optical system was a major step in the evaluation and characterization of optical systems, particularly imaging systems. Since the idea was for incoherent systems the “sine-wave” input was really 1 + sine in intensity as a spatial distribution. The ratio of the contrast of the output (image) as a function of the input (object) contrast was the measurement to be
made. A full “response function” could be obtained by varying the spatial frequency of the
“sine wave” input. This idea led in time to the concept of a spatial frequency response and
the Modulation Transfer Function (MTF), and the Optical Transfer Function (OTF).
These measures replaced the simple two-point resolution measurement and the somewhat
arbitrary three-bar target techniques (i.e., a three bar “square-wave” response). From a
wave optics point of view the fundamental parameter for an incoherent system is the inten-
sity distribution in the image (output) of a point object (input). The mathematical Fourier
transform of that intensity distribution is the OTF of the system. Hence, the fundamental
concept of the point spread function, or the intensity impulse response is to describe that
distribution in the image of a point object. In the language of diffraction the above output
is the intensity distribution in the diffraction pattern formed in the output plane of the
system for a point intensity input. So, in fact, the real fundamental function is the so-called
amplitude impulse response which characterizes the amplitude and phase of that output.
This then in turn allows a much more general evaluation of the performance and charac-
teristics of the system for any state of coherence of a generalized input.

Quantum optics has added yet a further dimension to our full understanding of optical
systems and today’s complex detection systems. Interactions of light with matter on the
atomic scale have become of paramount importance as have detection issues at very low
light levels. No longer is the photon just something to consider in association with the pho-
toelectric effect! The very word “photonics” has become a major part of our vocabulary.
(On a personal note, I think that it is very unfortunate for our discipline that people talk
about optics and photonics as if they were two distinct but connected fields—it’s all optics
to me!) I must say I enjoy the debate that is currently underway about photons. In what
sense do they exist? Do they exist only as a manifestation of the interaction of light with
matter, e.g., in the detection step? I leave the reader to ponder these questions.
In the meantime I will take comfort in the thought that physical optics remains a very important area both physically (i.e., for real . . . waves exist!) and philosophically (optical science is part of natural philosophy). In any event, it has been wonderful to work in the field at the very heart of optics and see and be a part of its development. It has been a rare privilege for me and my many colleagues over nearly fifty years (and counting) of which thirty-five have been in association with The Institute of Optics.

An interesting postscript: I had just finished drafting this “ode” on a plane ride headed to Rochester from Portland, Oregon, when I attended a very fine production of Michael Frayn’s 2000 Tony Award-winning play Copenhagen (also put on by our own Geva Theatre in Rochester). The play centers around conversations between Niels Bohr and Werner Heisenberg with contributions from Margrethe Bohr on political and scientific issues, including their thoughts about wave-particle duality and the uncertainty principle. I took great comfort in my fundamental belief in waves—whether right or wrong!