

CHAPTER 6

Ocular Damage from Laser Radiation

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1. INTRODUCTION

It is the purpose of this chapter to consider some simple models of damage to ocular tissues caused by exposure to laser radiation. The presentation stresses the interpretation of limited experimental data obtained in the last few years rather than the development of a comprehensive and physically more accurate model than has been proposed previously.

The fundamental interactions of optical radiation with matter, particularly biological material, are briefly discussed. The various mechanisms that can lead to damage of biological material are examined. At the threshold damage level, the level where minimal response can just be detected, the important mechanisms are apparently photochemical and thermal processes.

For lasers in the visible and infrared parts of the spectrum at levels associated with threshold damage, the primary mechanism for damage is thermal in nature. The thermal damage is believed to be associated with the denaturation of proteins and the inactivation of enzymes. Accordingly, the models considered include not only the solution of the heat conduction equation but also the rate equation for the inactivation process.

Simple models of ocular damage are considered for three distinct situations. First, corneal damage due to a CO₂ laser is discussed. Second, models
for retinal damage due to Q-switched laser pulses are presented. Finally, retinal damage from CW laser is considered.

2. INTERACTION OF RADIATION AND MATTER

2.1. Interactions at Low Levels of Radiation

The interactions of electromagnetic fields and matter are intimately related to our environment and fundamentally contribute to our understanding of it. These interactions involve some of the most challenging problems in present-day physics, chemistry, and biology. The solution of a typical problem must include the molecular or atomic systems as represented by Schroedinger’s equation, as well as the electromagnetic fields governed by Maxwell’s equations. Ideally, this overall system of equations must then be solved simultaneously.

The types of interactions that result depend on the wavelength and consequently the energy of the photons of the radiation field, on the intensity of the field, and on the characteristics of the molecules and their interactions with their neighbors.

2.1.1. A Simple Atom

The fundamental processes that can take place in the interaction of atoms and molecules with electromagnetic fields involve the absorption and re-emission of photons. Aside from effects that arise from high densities of photons and molecules, the interactions of an atom or molecule with the field involve single-photon processes that are associated with the characteristic energy levels of the atom or molecule and properties of the wave functions describing them.

As explained by the quantum theory of matter, the internal energy of an atom or molecule is limited to certain discrete values. Let use consider an extremely simple case of an atom where only two energy levels are involved. Let $E_1$ be the energy of the lower energy state, or ground state, and $E_2$ be the energy of the upper, or excited, state. The atom may change from one level to the other by either the absorption or the emission of a discrete amount of radiant energy, given by $h\nu = E_2 - E_1$, depending on whether the atom is initially in the upper or lower state. Here $h$ is Planck’s constant and $\nu$ is the frequency of the photon.

A qualitative discussion of these processes of absorption and emission is afforded most simply by the use of Einstein’s probability coefficients. If an atom is in the upper level, there is a finite probability $A_{21} \, dt$ that in a time $dt$ the atom will spontaneously jump to the lower level and emit a photon of