HANDBOOK of LASERS

with Selected Data on Optical Technology

Editor
ROBERT J. PRESSLEY, Ph.D.
Manager of Research and Development
Laser Products Division
Holobeam, Inc.

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PREFACE

The aim of this volume is to collect and present critically evaluated original data, both published and unpublished, that are relevant to laser research and development. The laser is close to its eleventh birthday. It has experienced a rapid growth, both in numbers and in complexity. Lasers of different types, frequencies, powers and energies have proliferated to such a degree that scientists are even becoming specialized in restricted fields within the general field of lasers.

The theory of the generation and control of coherent radiation is covered in various articles and texts. The experimental data, however, are being extended and enlarged much faster than the theory. To provide convenient access to this rapidly expanding volume of information is the goal of this handbook. The textual material is, in general, only that necessary to explain the data.

The data are the results of many different experimental arrangements. There has been little standardization between various laboratories in certain measurements such as threshold or efficiency. With this in mind, an important part of this handbook is the references to the original work, which should be consulted for details of how the various measurements were made. This referencing will become of less importance in later editions when there should be more standardization of measurement techniques.

The listings of the laser transitions for this first edition represent data available in late summer of 1970. There will undoubtedly be important additional data available between that date and the publication date, but this is an inevitable consequence of publishing in a current field of research.

The selection of data on related optical elements is not intended to be inclusive, but is meant to be a representative selection of some of the more useful items of considerable current interest. Both the American Institute of Physics and the Optical Society of America are currently preparing revised Handbooks, which will contain much more complete and detailed tabulations of topics covered peripherally in this handbook.

This handbook is intended for the use of active researchers in the field of lasers, and as such needs comments, criticisms and suggestions from these researchers if future editions are to be of maximum value. We welcome your cooperation in helping us to correct any errors or omissions.

The advisors to this handbook have contributed considerable time and effort toward the compilation of the data presented. That this Handbook could appear at all is due to their unstinting co-operation in collecting, collating, evaluating and referencing the data, in addition to their continuing normal scientific responsibilities.

I am personally indebted to both the David Sarnoff Research Center at Princeton, New Jersey, and Holobeam, Inc. at Paramus, New Jersey, for their cooperation during the compilation of this volume. I also wish to thank Mrs. Mary Lou Wu of the Chemical Rubber Company for her continuing enthusiasm and technical expertise in the editing of the book.

Hopewell, New Jersey
September 1, 1971

ROBERT J. PRESSLEY

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Section I
Laser Safety

Ocular Hazards

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Ocular hazards in the vicinity of laser devices include not only the laser itself, but the optical pumps used for excitation, the off-axis spontaneous radiation from gas discharge tubes, and occasionally the blackbody radiation of absorbers used to stop extremely intense beams. Geometrical considerations make the latter two cases a lesser hazard, but obviously do not remove them from inclusion in a safety protocol.

Ultraviolet devices of all types must be carefully controlled, as exposure of the cornea to even relatively low levels of irradiation at wavelengths less than 320 nm produces "sunburn" of the cornea, called "photophthalmia." Because a source in this region is not visible, has a cumulative effect, and the extremely dehabilitating "blepharospasm," or "sand in the eye" reaction to the corneal epithelium sloughing off and exposing the nerve tissue does not occur until 30 minutes to 24 hours following exposure (usually in the evening or night after exposure), any source which has a significant ultraviolet component must be used with caution. Figures 1-1 and 1-2, from the work of Pitts and his associates,[1,2] indicate the sensitivity of rabbits and primates to the ultraviolet.

The middle infrared (10.6 μ) portion of the spectrum also affects the corneal epithelium as the primary damage site. In this spectral region the damage mechanism is of thermal origin, not abiotic as in the case of the ultraviolet. Thus, the damage mechanism is a function of the time-temperature history within a single exposure interval. The threshold for a minimal irreversible lesion on the cornea is given in Figure 1-3.

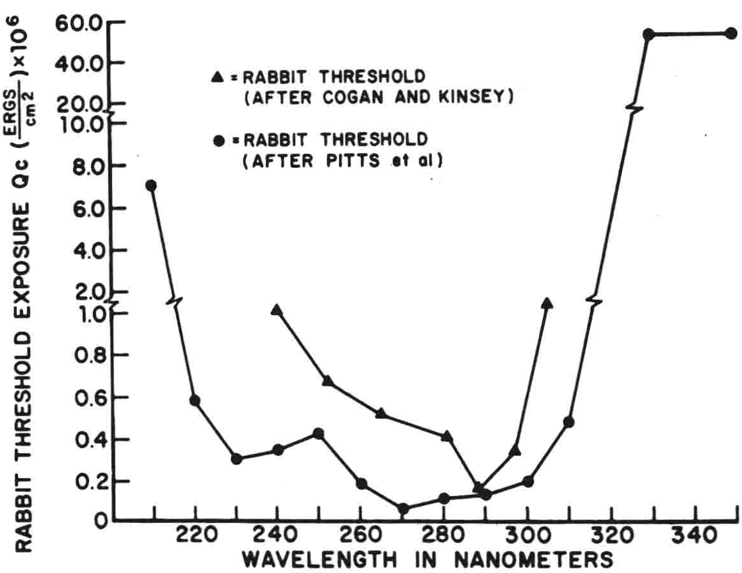

Fig. 1-1. Threshold exposure (Q_c) for the production of photophthalmia in rabbits versus wavelength of ultraviolet light. Each point on the curve is plotted at the peak wavelength of the various 10 nm wavebands. (From Pitts, D. G. and Kay, K. R., *Amer. J. Optom.*, *46*, 561, 1969.)

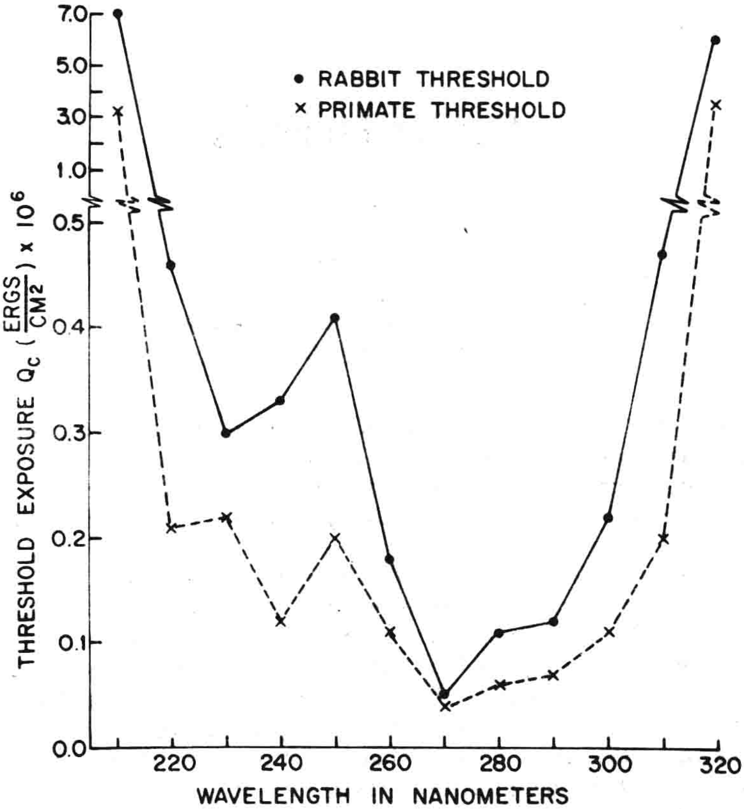

Fig. 1-2. A comparisón of thresholds (Q_c) for the production of photophthalmia in rabbits and primates, as a function of wavelength. (From Pitts, D. G., *et al.*, SAM-TR-70-28, USAF School of Aerospace Medicine, Brooks A. F. Base, Texas, in press.)

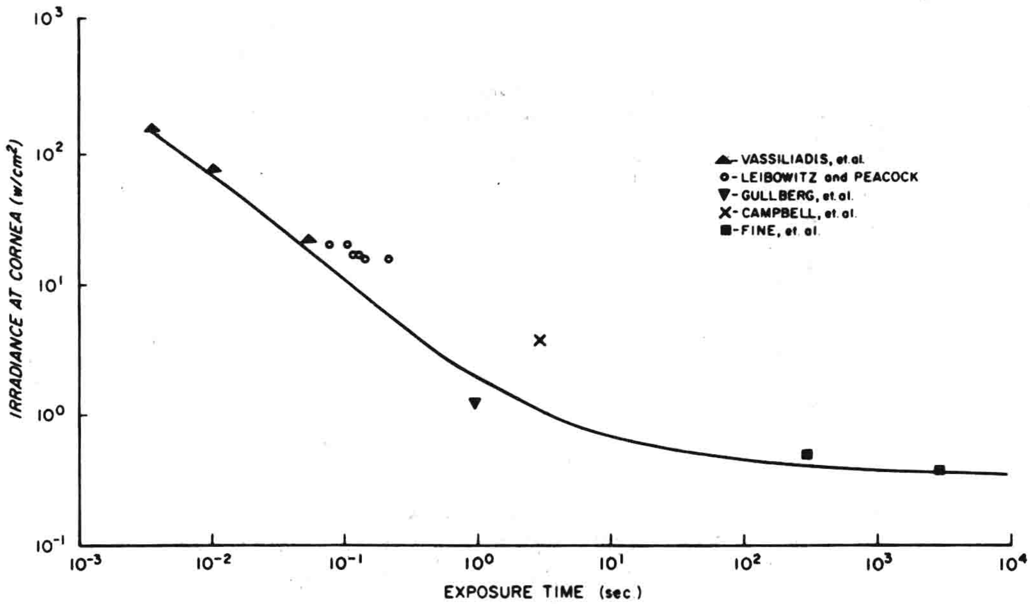

Fig. 1-3. Threshold CO_2 (10.6 μ) power levels for irreversible lesions on the cornea as a function of exposure time. Data taken from references 3 (Vassiliadis), 4 (Leibowitz), 5 (Gullberg), 6 (Campbell), and 7 (Fine).

The wavelength interval covering the visible and near visible region (400 nm to 1500 nm) must be considered in terms of the spectral characteristics of the eye. The transmission of the ocular media is illustrated in Figure 1-4, and the absorption of the retinal pigment epithelium (PE) and choroid, as measured by Geeraets and Berry,[8] is shown in Figure 1-5.

Some investigators[9] have considered laser devices operating in the 1.5–2.0 μ interval as "eye safe," a factor demonstrated by Lund and his associates[10] as possibly correct. However, until further work has been done on the vitreous and lens effects in this wavelength region, neither the middle infrared surface exposure levels nor the visible wavelength threshold levels should be exceeded for human occupational exposure.

Retinal damage has been observed in the visible and near visible wavelength interval by many observers. Figure 1-6 gives the Medical College of Virginia measured and calculated retinal irradiance for white light (Xenon arc) and ruby laser exposure necessary to cause an irreversible, minimal ophthalmoscopically visible lesion for an extended (10 μ to 800 μ diameter) image on the retina.[11,12] Table 1-1 gives the data for the minimum image size, barely ophthalmoscopically visible lesion production by several sources from the Stanford Research Institute.[3] The results are in reasonable agreement. Table 1-2 is a summary of the reported values of argon and helium–neon laser-produced power entering the eye to cause a threshold lesion for various exposure durations and image diameters.[13]

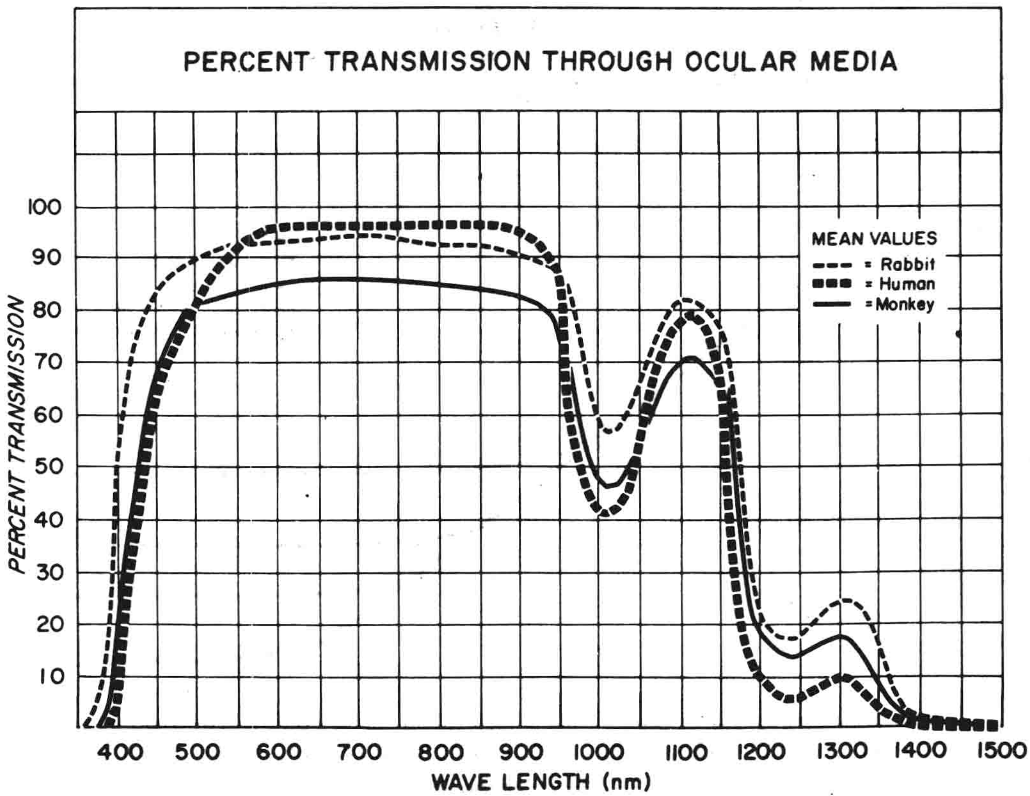

Fig. 1-4. Percent transmission for light of equal intensity through the ocular media of human, monkey (rhesus), and rabbit eyes. (From Geeraets, W. J. and Berry, E. R., *Amer. J. Ophthal.*, *66*, 15, 1968.)

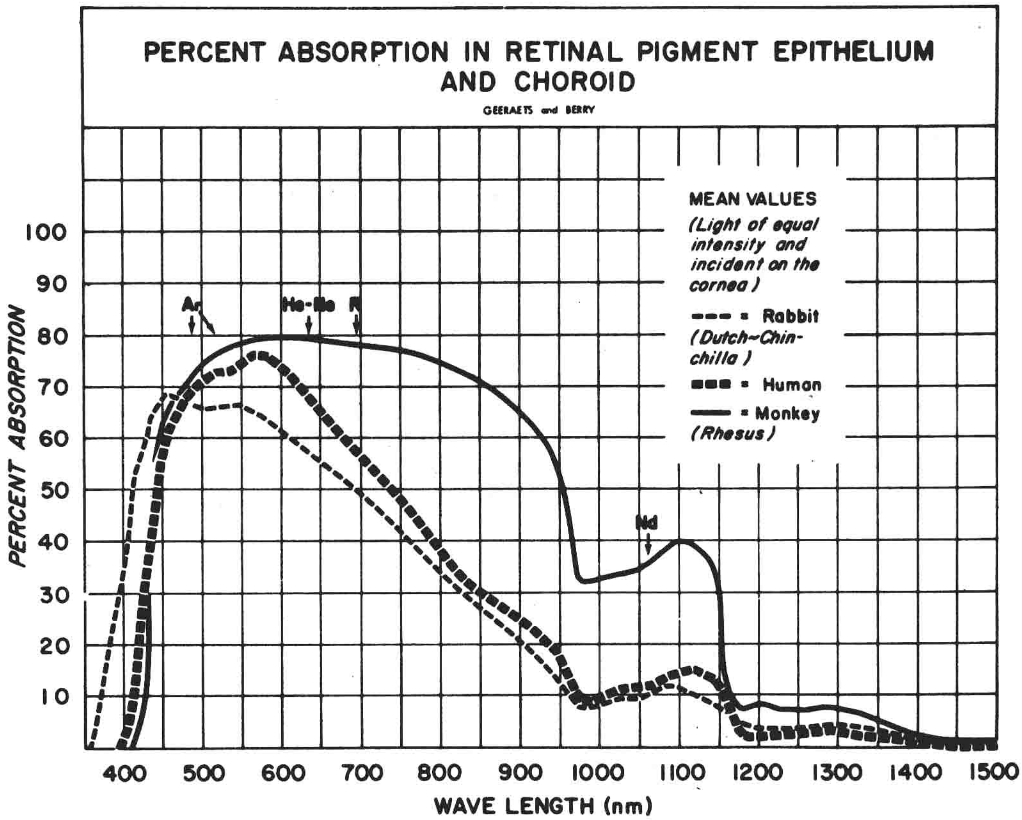

Fig. 1-5. Percent absorption of light of equal intensity at the cornea in the retinal pigment epithelium and choroid for rabbit, monkey, and man. (Redrawn to include correction for reflection from Figure 2 of Geeraets, W. J. and Berry, E. R., *Amer. J. Ophthal.*, *66*, 15, 1968.)

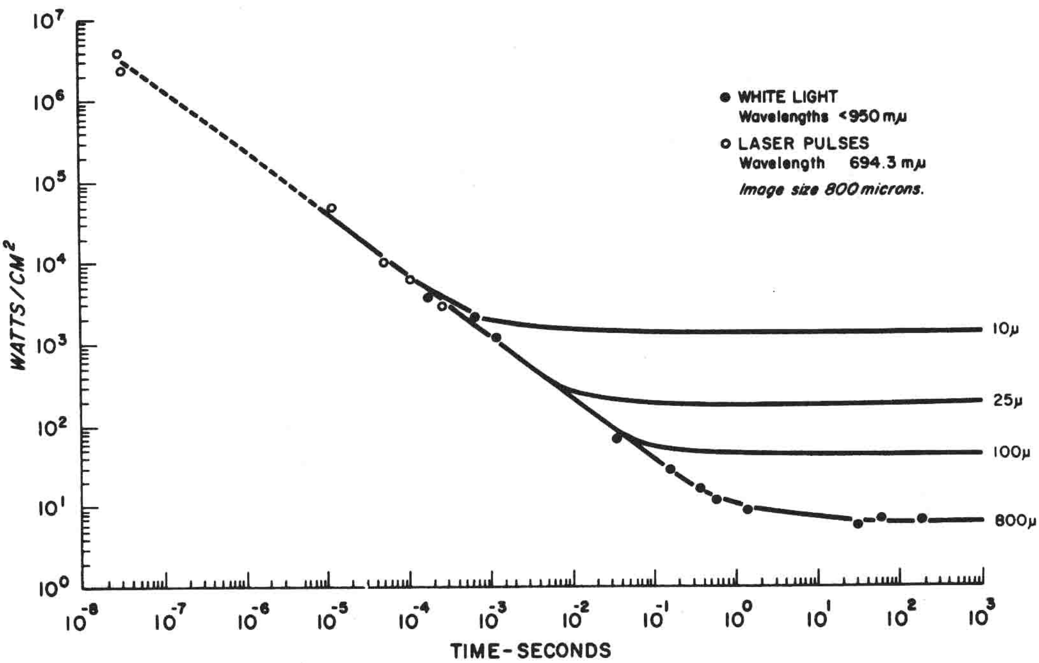

Fig. 1-6. Retinal power density necessary to cause minimal ophthalmoscopically observable lesions. (From Clarke, A. M., *et al.*, *Arch. Environ. Health*, *18*, 424, 1969.) Copyright 1969, American Medical Association.