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THE INHERENT DANGER IN LASER SAFETY EYEWEAR

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THE INHERENT DANGER IN LASER SAFETY EYEWEAR:
A Physical Optics Laboratory Experiment

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Abstract

I have designed an experiment which explained why the filter in a laser protective eyewear could crack under prolonged contact to a laser beam. My hypothesis stated that the nonlinearity of absorption of light played an important role in the failure of the filter. Using a xeon-arc lamp, a photoconductive cell, a multimeter and filters that consisted of 0 to 15 blue transparency(ies), I indirectly measured the amount of light that these filter absorbed. From the data I affirmed my hypothesis. If a laser beam hit an actual protective filter, because of the nonlinearity of absorption, the front surfaces of the filters would absorb much more laser light than the back surfaces, thus the front would heat up and expand more quickly than the back causing the filter to crack. Because future optometrists will need to learn the practical significance of the nonlinear process of absorption, I have also incorporated my experimental procedure into a physical optics experiment.

Introduction

Ever since T. H. Maiman in 1960 built and operated the first laser using ruby as an active medium[1], lasers have became a fascination to the public. Since 1960, different types of lasers have been invented. Various types of laser are defined by the medium that they propagate in. The medium can be a gas, a liquid, a semiconductor, Nd:YAG, Nd:glass or a ruby rod to just to name a few.[2] Furthermore, each kind of laser has its own distinctive wavelength.[3] For this thesis I will focus on lasers with wavelengths in the visible spectrum, such as the ruby laser. Visible lasers are double-edged swords. While these lasers, especially the ruby laser, can be quite attractive to the eye, one look into the laser can cause serious damage to the eyes, such as retinal hemorrhages and charring.[4] In fact, many laser accidents have occurred because of human errors.[5,6,7] One possible cause for laser accidents can be attributed to people's false sense of security on laser safety eyewear. While the safety eyewear is required when one operates high power lasers[8], accidental prolong look into a laser can crack the filter in the eyewear resulting in serious eye injury. What actually causes the filter to crack? The answer may lie not only in the construction of the filter, but also in the process of absorption. I have devised an optics experiment to investigate this process, a process that can raise much practical concern over laser safety.

Materials and Methods

A protective filter is made up of different layers, each with the same thickness and light absorbency. In order to construct filters with similar properties, I used slide holders made by Kodak to construct sixteen filters, each containing a various number of thin blue plastic films(transparencies) ranging from zero to fifteen, respectively. I chose the color blue because the photoconductive cell was most sensitive to blue. A photoconductive cell, usually made of cadmium sulfide, worked in such a way that as the illumination increased, its resistance decreased[9] (I bought it from Radio Shack, cat. no. 276-116A). I will discuss later on how light interacts with the filters. In order to measure absorption, on an optical bench I placed a xenon-arc lamp, a lamp best suited for optics experiments because it provided a point source, on the left-hand side of the bench three centimeters away from the filter holder and eight centimeters away from the photoresistor. Then I connected a multimeter, which was set to measure resistance in kilo-ohms, with the photoconductive cell. Refer to figures 1 & 2 below:

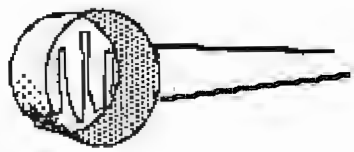


Figure 1. Cadmium Sulphide Photoresistor

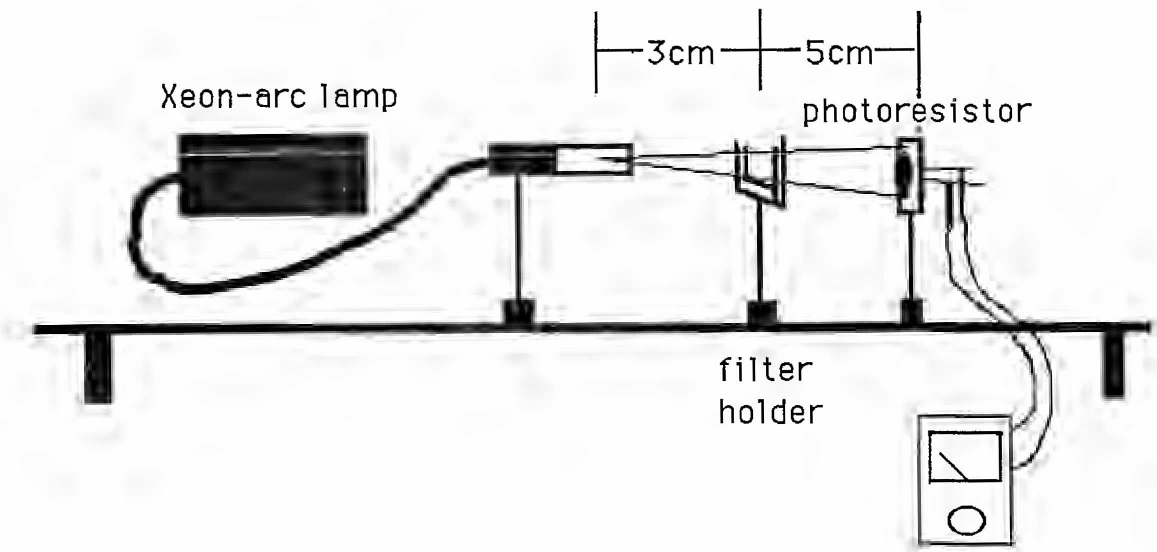


Figure 2. This diagram illustrates the experimental set-up.

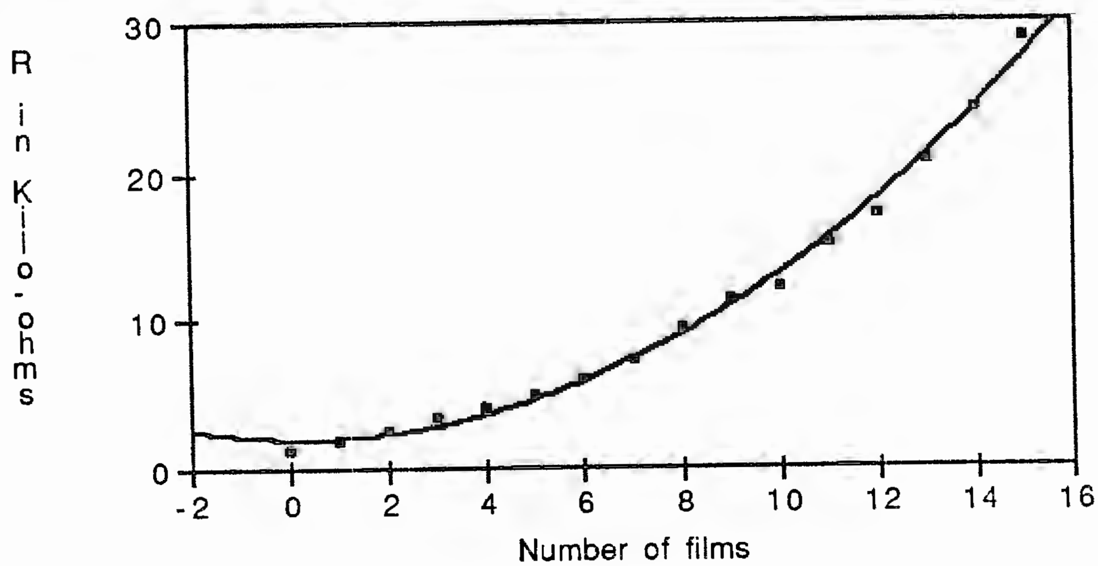
After I turned on the lamp, I equalized the height of the lamp, filter holder and the photoresistor. Then I placed the filters in the filter holder one by one, starting from the filter with no plastic film in it and continuing on to the filter with fifteen films in it. Resistance reading was noted for each filter. This experiment should be conducted in minimal room illumination so that the lamp's illuminance could have maximal effects on the photoresistor.

Results

The data clearly indicates the nonlinearity of the absorption process. Please refer to the table and graph. I extrapolated a best fit line from the data points, and it does increase exponentially. Furthermore, these data were repeatable.

Number of films	Resistance in kilo-ohms				D1 (cm)	D2 (cm)
	Trial 1	Trial 2	Trial 3	Mean	3	5
0	1.30	1.30	1.30	1.30		
1	1.88	1.83	1.86	1.86		
2	2.57	2.49	2.50	2.52		
3	3.35	3.25	3.40	3.33		
4	4.11	3.94	3.95	4.00		
5	5.07	4.78	4.80	4.88		
6	6.15	5.91	6.12	6.06		
7	7.53	7.15	7.20	7.29		
8	9.35	9.70	9.57	9.53		
9	11.0	11.3	11.3	11.3		
10	12.4	12.0	12.2	12.3		
11	14.8	15.3	15.5	15.2		
12	17.5	16.8	17.2	17.2		
13	21.0	20.5	20.7	20.8		
14	24.6	24.0	24.4	24.3		
15	29.2	28.6	29.0	28.9		

Table 1. Data from the absorption experiment



A graph of the data in table one (number of films vs. resistance)

Absorption

PURPOSE: Besides learning about transmittance, absorbance and absorptivity, you will investigate the *nonlinearity of absorption*. This nonlinearity is of great practical concern, especially for reasons of laser safety.

RECOMMANDED READING: Optics text, pages 484-486.

EQUIPMENT NEEDED: Optical bench, 3 carriers, 3 lens holders, light source(xeon-arc lamp), set of filters, centimeter rule, ohmmeter, photocell(the photocell we use is a photoconductive cell: its electric resistance decreases as the cell is exposed to light).

INTRODUCTION: When a colored sheet of plastic film absorbs 50% of the light incident on it, another identical sheet also absorbs 50%, but the two sheets together absorb less than twice the amount of light absorbed by one sheet. This principle is of practical significance. It shows that absorption is not a linear function of the thickness or density of a filter. If we assume that several of these thin sheets of plastic are fused into a single filter with a certain thickness, the first (front) layer of this filter will absorb considerably more energy than the later layers. Hence, with high powers of radiation incident on the filter, the part of the filter just below the front surface will expands more rapidly than the back part and may cause the entire filter to crack or shatter, posing a serious hazard to the eye. That must be avoided by the proper design of the filter (see later).

EXPERIMENTAL PROCEDURE:

[1] Use the filter marked (4). This filter contains four thin sheets of bluish plastic film in a single frame. Determine the transmittance, absorbance and absorptivity of this filter if this type filter allows 60% of incident light to go through it. Use these formulas and be familiar with them:

1) Transmittance(T) = 0' / 0o

0o = incident radiant power

0' = transmitted radiant power

For example, if 85% of the light is going through the filter, the transmittance is :

T = 85/100 = 0.85

2) Absorbance(A) = log (1/T); absorbance is the logarithm to the base 10 of the inverse of the transmittance. For the same example as before the absorbance is:

A = log (1/0.85) = 0.07

3) Absorptivity(a) = 2.3 A/x

where for one sheet of plastic film per frame we set x = 1, for two sheets x = 2, and so on. In our example,

a = (2.3) (0.07) / (4) = 0.04

[2] Your filters contain up to 15 individual sheets per frame. They are labeled (1), (2), (3) and so on, depending on the number of sheets contained within. Determine the transmittance of each of these filters, from (1) through (15). Set the filter holder 3 cm from the light source (not from the front of the glass bulb) and set the photoconductive cell 5 cm from the filter holder. Keep stray light to a minimum.

[3] Carefully plot the result, showing the number of sheets per frame on the x axis and the transmittance on the y axis. The plot should show that the transmittance varies as a <u>nonlinear function</u>.

The <u>loss of light</u> is presumably directly proportional to the heating, and therefore, to the thermal expansion of the filter.

Question: Indication on your plot where the filter will probably expand most and therefore, if it were made out of a solid piece of material, where it will begin to crack.

Discussion

The optimal safety control against laser hazard is complete enclosure of the laser or laser system.[10] However, since this would not be practical, the best alternative is laser eye protection. Yet, the nonlinearity of absorption can make laser safety eyewear obsolete. The reason lies in the construction of the protective eyewear. Although the eyewear appears to be made up of one solid piece of filter, the filter can be assumed to be composed of many individual filter plates stacked up against each other. Even though each of these filter plate absorbs an identical amount of laser light i.e. 50%, if two of these filter plates are stacked together, they will absorb less than twice the amount of laser light absorbed by one filter plate. Thus, the front filter plates absorb the most light while the later filter plates absorbs less and less light. The amount of laser light absorb decreases exponentially(Figure 3). The front filter plates would then expand more rapidly than the later filter plates, and the entire filter would shatter(figure 4).[11] Moreover, the lost of light would probably be directly proportional to the heating, and therefore, to the thermal expansion of the filter.

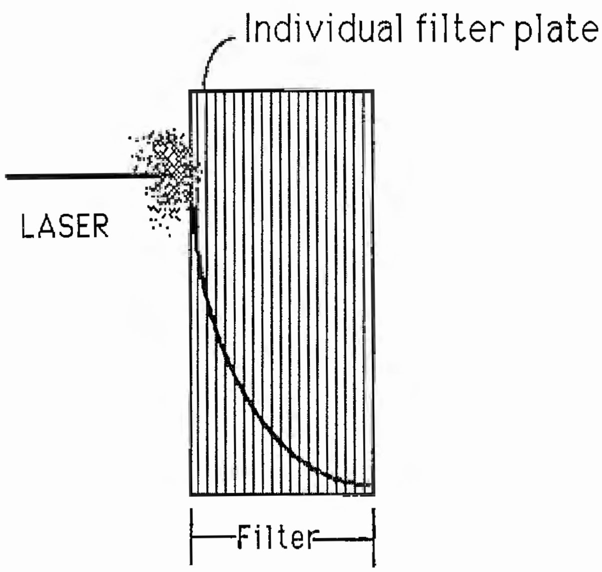


Figure 3. This illustrates the non-linearity of the absorption process. Notice the exponential decrease in absorption.

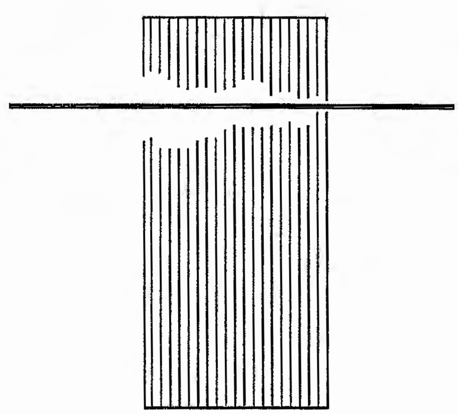


Figure 4. The front filter plates eventually over-heat and crack, causing the entire filter to shatter.

Because various types of laser safety eyewear have been designed to selectively attenuate at specific laser wavelengths, one needs to wear the appropriate type of eyewear. Besides the wavelengths, there are other factors to consider when selecting protective eyewear, such as the laser beam intensity and the laser filter radiation damage threshold. If in doubt one should contact the manufacturer for determination of the failure point of the eyewear.[12] Otherwise, any power laser will shatter an inappropriate protective eyewear in a relatively short time. Therefore, besides looking at comfort and fit of the protective eyewear, one should realize that when the laser beam hits the filter, the laser beam is absorbed nonlinearly and that if one overexposes his/her eyewear to the laser beam, the filter may melt or shatter.

Conclusion

Through the absorption experiment I have confirmed the hypothesis that absorption is a nonlinear process. I have also discussed some of the practical significance this process have in terms of how it affects the safety of laser protective eyewear. In order to enhance the reliability of the eyewear, one option is to apply reflective coating(s) on its front surface.[13] However, one should apply the correct type, or combination of types of reflective coating(s) because the eye can easily fatique if too much of the visible light is reflected along with the laser radiation.[14]
If used appropriately, the reflective coating can selectively reflect the wavelength of the laser while transmitting most of the visible light.
With the reflective coating on the filter the nonlinear absorptive process will not pose such a significant danger to the eyes.

Footnotes

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