

# Training modules for an advanced interactive course on optical design

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**Abstract.** There is already a plethora of Internet optical teaching materials, including Java and Flash applets which demonstrate the basics of refraction, reflections, thin lens theory, diffraction, interference etc. However, most of these are designed for school or undergraduate use, and there is very little at postgraduate level. Furthermore, there is a potential shortage of optical design skills in the future. AMO is committed to developing multi-media multi-lingual courses in optical design, making use of the best available technologies, for worldwide use. One example is a training aid to demonstrate the effect upon spherical aberration and coma of bending a single element lens. This shows the advantages of the Internet over ordinary print. Another example is an online presentation illustrating the processes involved in the manufacture and assembly of lenses by traditional methods.

## 1. Introduction

This is an update on the preliminary ideas presented at Photon02 on the subject of remote teaching of optical design. Since then a great deal of tutorial material has been prepared for conventional training methods, some of which is now available online.

## 2. The learning process

First, it is worth looking at what a professional psychologist has to say about the learning process. Howard Gardner [1] assures us that we learn 10% of what we read, 20% of what we hear, 30% of what we see, 50% of what we see and hear, 70% of what we say and 90% of what we do. This underscores the importance of interactivity in the online learning process.

Of course, nothing can supersede the quality of a first-rate educator with a stick of chalk and a blackboard. Anyone who heard H. H. Hopkins lecture would agree that he was unsurpassed as an educator in this field. It is interesting that John Macdonald, who continues his tradition of teaching optical design at Reading University (where the first three authors of this paper also studied), has recently given a valuable conference paper on the subject of remote learning [2].



## 3. Comparison of traditional teaching and internet methods

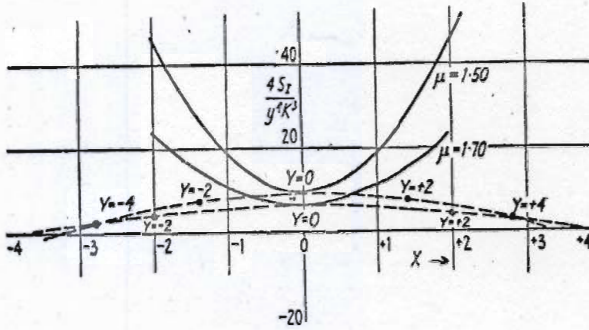
### 3.1. Traditional material from a text book

Consider first some of the equations on Seidel aberration theory which H. H. Hopkins published in his textbook [3]. The intention is to see how these equations and the diagram

which illustrates them can be made more comprehensible, using the benefits which only the internet can provide.

The equation for the primary spherical aberration of a thin single element is:

$$\frac{4}{y^4 K^3} S_1 = \frac{\mu + 2}{\mu(\mu - 1)^2} X^2 - \frac{4(\mu + 1)}{\mu(\mu - 1)} XY + \frac{\mu^2}{(\mu - 1)^2} + \frac{3\mu + 2}{\mu} Y^2$$



**Figure 1** The primary spherical aberration of a thin single element as a function of bending factor  $X=(c_1+c_2)/(c_1-c_2)$  and magnification factor  $Y=(u_2'+u_1)/(u_2'-u_1)$ , taken from reference [3].

The corresponding equation for the central coma (that is, primary coma when the lens is located at the stop) of a thin single element, is linear in both X and Y.

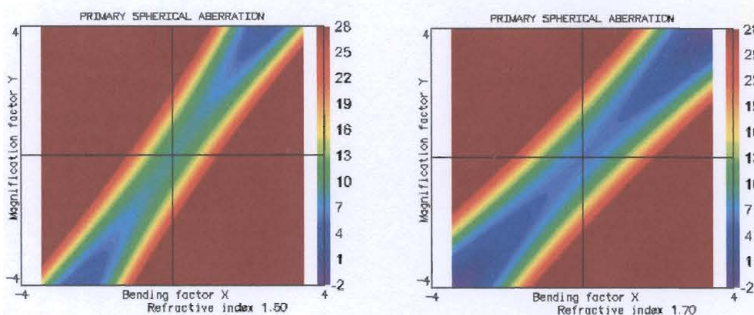
$$S_2 = \frac{1}{2} Hy^2 K^2 \left( \frac{\mu + 1}{\mu(\mu - 1)} X - \frac{2\mu + 1}{\mu} Y \right)$$

### 3.2. The internet version of the same material

Material presented on the internet has advantages of the possibility of the use of unlimited colour at no extra cost. It gives the opportunity for the user to flick through images sufficiently fast to give the impression of motion, thereby in effect adding the fourth dimension, time, as an extra parameter in the information presented to the user.

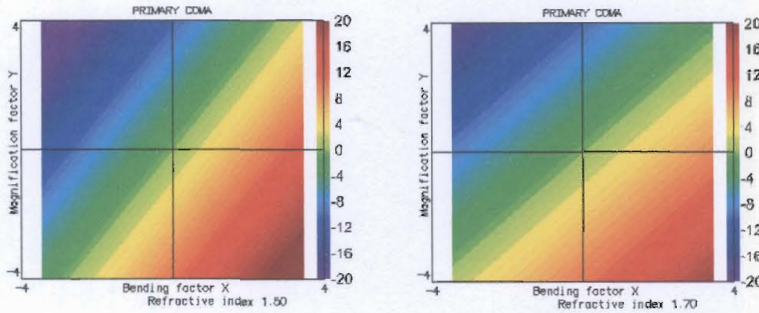
In the first example presented here, the vertical axis (spherical aberration) is replaced with a colour-coded contouring, and this releases the second dimension to be used for the magnification factor. A sequence of images was produced with great ease using the OSLO<sup>®</sup> program simply as a compiler platform for the C-like macro language CCL. This was undertaken by placing the Hopkins formulae into the kernel of the sample code in the command `fill_contour_sample`, provided with the program in a file named `public/graph_plot_ex.ccl`. The results for the case of primary spherical aberration are shown in figure 2.

Note that the only areas where the spherical aberration falls to zero are in the upper right and lower left corners of the graph. These correspond to the two classical "aplanats," with one surface at which the incident and refracted marginal ray angles are proportional to the refractive indices, and with the other at which the marginal ray is incident normally.



**Figure 2** The primary spherical aberration of a thin single element as a function of bending factor (X) and magnification factor (Y), for refractive indices 1.5 and 1.7.

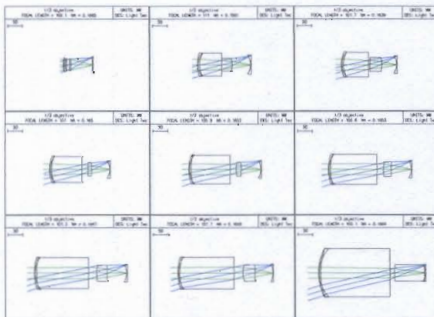
In a similar manner the graphs for the central coma (that is, the coma where the stop is at the lens) can be plotted as a function of X and Y. Two of the frames of the sequence corresponding to different refractive indices are shown in figure 3. The light green colour corresponds to the line of zero coma.



**Figure 3 The primary coma of a thin single element, also for refractive indices 1.5 and 1.7.**

#### 4. The use of the time dimension to illustrate the optimisation process

The paper presented by one of the authors at the SPIE conference on Optical Design and Engineering held last year in Jena [4], addressed the issue of making the process of optical design accessible to a wider audience. The central feature was a demonstration of the use of numerical optimisation in lens design, using OSLO to find a path through parameter space to locate the global minimum of a well known optical design problem. This is the “Monochromatic Quartet” [5]. The two sequences of illustrations presented here show at intervals of 24 cycles in the optimisation process, the changes in the shape of the lens itself, and the corresponding aberration curves.



**Figure 4 Some of the frames from the video showing the progress of a solution to the problem of the “Monochromatic Quartet”, from a remote starting point to a final design, near the global minimum.**

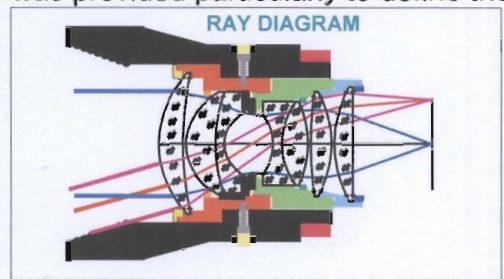


**Figure 5 Corresponding frames from the video which shows the aberration curves for each of the lenses, in which the aberration which has the largest contribution to the figure of merit is in each case marked with the red dot.**

## 5. The current state of play

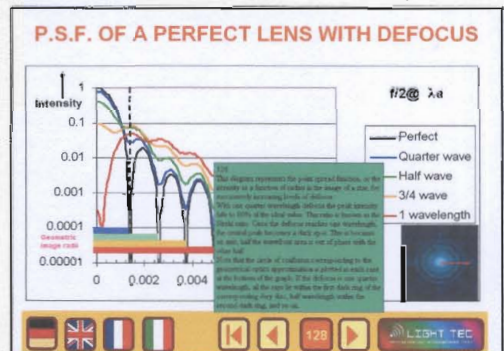
### 5.1. Lens Manufacturing and Assembly

The presentation on lens manufacturing and assembly was provided particularly to define the terms used in English for the manufacture of lenses by traditional methods. It uses as a case study the example of a hypothetical double Gauss objective to demonstrate the manufacturing processes of one of the positive lenses, as well as the assembly procedures for the entire objective. It also illustrates a number of alternative assembly methods. It is available on the Ancient and Modern Optics web site on [www.amoptics.com](http://www.amoptics.com) in the section on resources.



### 5.2. Fundamental Optical Design

The course on the fundamental optical design consists of 217 interactive frames, and is available online exclusively to participants in the OSLO training courses provided by Light Tec. Since most of these courses take place on the continent of Europe, it is necessary for this material to be given in other languages, and at present French, German and Italian are available. For ten days preceding each course, this material is available to introduce the basic concepts of optical design, such as the nature of light, definitions of stops and pupils, and the Seidel aberrations. It has already played a valuable role in bringing less experienced participants in the OSLO courses up to a level where they find the intensive four-day training less intimidating.



## 6. Acknowledgements

Valuable contributions were made to this presentation by Gerry Dale, Sam Dale, Jean Marc Dennerly, Alan Reddish, Isaac Seymour, Tony Seymour, Andrew Westlake and Paula Williams. The authors are also grateful to Christine Hopkins for providing the photographs of Harold. OSLO is a registered trade mark of Lambda Research Corporation, Littleton, Mass., USA, and the authors are grateful for the encouragement that they receive from them, and from all those at Light Tec at Hyères in France.

## References

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