Journey through time: Optics of Yesterday and Today through Charles Féry's Spectrophotometer

L. Dordor.[a], L. Froehly[b], M. Jacquot[b], and J. M. Dudley[b]

[a]Lycée Victor Berard, 35 Quai Lamy, BP 70087, 39403 Morez, France
[b]Institut FEMTO-ST, Université de Franche-Comté CNRS UMR 6174, 25000 Besançon, France

ABSTRACT

In 2015, we launched a program with the aim of preserving the scientific heritage of our laboratory, which entails conserving and showcasing historical documents and objects. Within this program, we offer internships that integrate history and science. One such internship focuses on utilizing modern optical design software to comprehend historical optical devices such as Charles Féry's spectrophotometer from the 1910s. This approach illustrates how contemporary tools can illuminate the origins of scientific knowledge.

Keywords: History of science, Education , Heritage preservation, Computational modeling of ancient instruments

1. INTRODUCTION

"We do not fully understand a science until we know its history". This quotation by the famous 19th century philosopher and sociologist Auguste Comte was repeated by P. M. Duffieux (1891-1976), a pioneer of Fourier optics, in a correspondence with one his early mentors Charles Fabry (1867-1945) in 1931. This quotation underscores the importance of the history of a science in understanding its depth. Optics, as a scientific field, is no exception. Delving into its past greatly enriches the teaching of optics, enabling students to trace the evolution of scientific thought, and draw inspiration from the challenges faced by eminent scientists. Despite its potential richness, the local history of smaller universities and their notable figures is often overlooked. Since 2015, in collaboration with our institution, we have been implementing a program aimed at preserving the scientific heritage of our laboratory. This involves the conservation, contextualization, and exhibition of scientific documents and objects, some of which date back to the 19th century, and whose operation and alignnment sometime remains mysterious due to a lack of documentation. Within this framework, we offer students internships that combine history and science[1,2] . This presentation will specifically highlight the use of the optical design software ZEMAX OpticStudio@ANSYS (ZOS) to understand and model an optical device from the 1910s: Charles Féry's spectrophotometer. It is fascinating to observe how a modern tool like Optics Studio can illuminate the roots of our science by exploring historical instruments.

2. OUR INSTRUMENT COLLECTION

The University of Franche-Comté celebrated its 600th anniversary in 2023, prompting a comprehensive reflection on its scientific heritage. Efforts were directed towards preserving its contributions to physics, particularly in optics. A primary objective was to compile records of Physics Chairs since 1845, shedding light on individuals who shaped academic discourse and advanced scientific knowledge. However, a concerning realization emerged – many colleagues were unaware of this rich history, hindering its transmission to students. Visibility was a challenge for our smaller university, which often struggled to compete with larger institutes. Highlighting our scientific heritage became imperative for enhancing visibility and attracting students from beyond our region. Plans were made to showcase artifacts and documents in a local museum, prioritizing minimal restoration to maintain authenticity. Oral histories from retired staff members were recorded to capture the intangible aspects

Further author information: (Send correspondence to L. Froehly)
L. Froehly: E-mail: luc.froehly@univ-fcomte.fr, Telephone:00 33 3 81 66 20 97

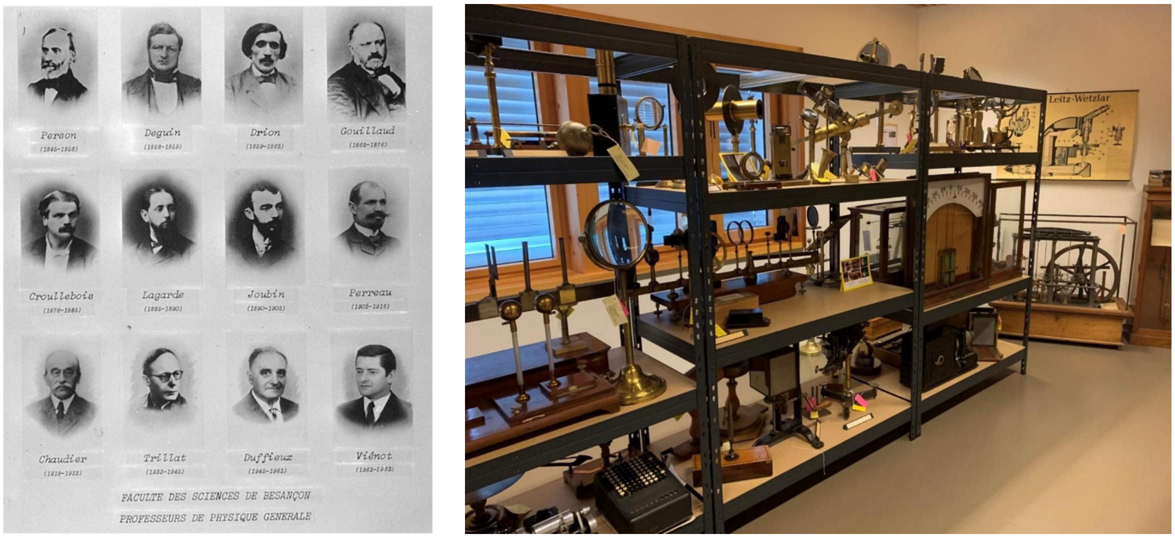

Figure 1. Left image : complete record of all appointed Chairs of Physics at the university of Franche-Comté since the establishment of the science faculty in 1845 ; right image : part of our older instrument collection dating back to the 19th century

of our scientific journey, providing firsthand accounts of the laboratory's evolution and contributions to optics. To encourage our students' interest in the rich local scientific heritage, we have set up a number of internships at different levels. One of the proposals we have made is to deepen our understanding of the functioning and use of certain instruments for which we have little information. This involves not only bibliographical research, but also modelling the equipment and comparing it with experiments carried out with it when it is still operational. The work which we describe here was the result of a 6 week internship for a student in their first year of the French national diploma BTS (Brevet de technicien supérieur) in Photonic Systems, a coordinated programme of theoretical and hands-on training that prepares students for technical employment in industry.

3. FÉRY SPECTROPHOTOMETER

Charles Féry was a French physicist who was born in Paris in 1865 and died there on 23 February 1935. He worked on the development of numerous measuring instruments including refractometers, pyrometers, spectrographs and spectrophotometers. In our collection, we are lucky enough to have a specimen of his spectrophotometer, invented in 1910[3] , and shown in Fig. 2.

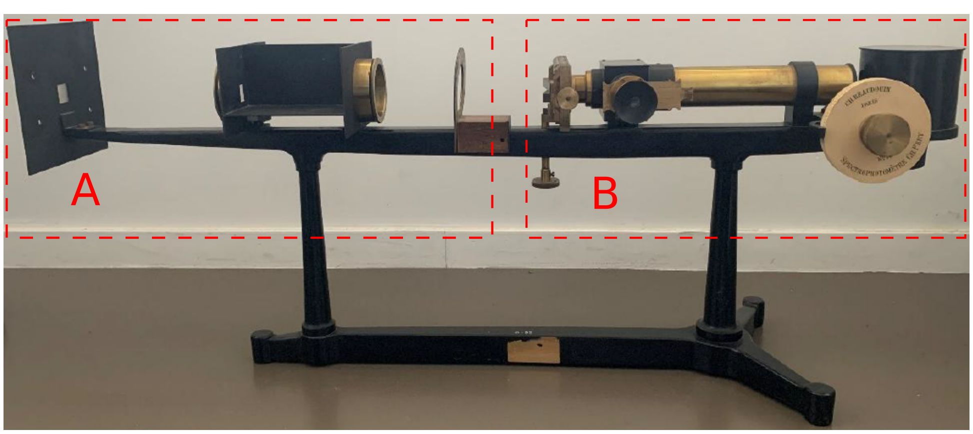

Figure 2. The Féry spectrophotometer. A) illumination path B) analysis path

Féry's spectrophotometer is an absorption system. At that time, it differed from other systems based on Malus's law and polarisation in general, or on complex pupil systems[3] . The general principle of the system is to compare the spectrum transmitted after passing through a solution to a reference spectrum and then determine the absorption coefficient depending on the wavelength of the solution or its concentration, knowing "a priori" its absorption coefficient.

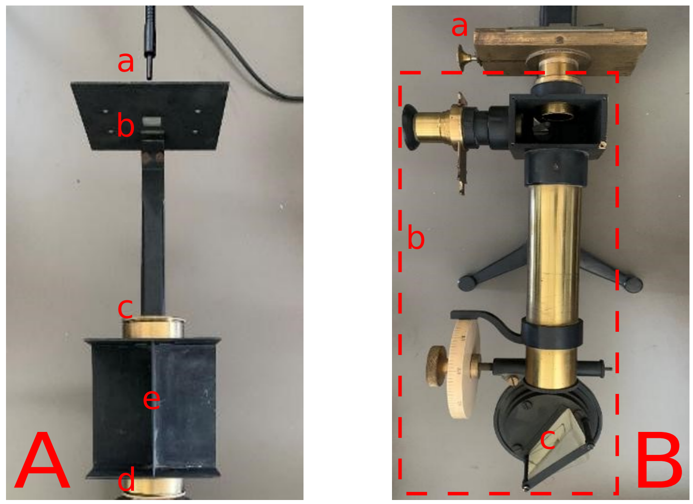

Figure 3. Top-view of the Féry spectrophotometer. A) illumination path: a-light source, b-scattering plate,c and d-lenses, e-sample holder. B) analysis path: a-double absorption prisms, b-prism spectrometer, c-reflective prism

4. THE ABSORPTION PRISMS

The main innovation proposed by Féry is the addition of the double prism absorber system B-a in Fig.3. Let's imagine that two smoked glass prisms are placed in front of the slit of a spectroscope, their edges facing each other. The angles of the prisms are calculated to compensate for the deviation induced by the 2f illumination system consituted by lenses c and d of Fig.3A. The rays incident on the prisms will be deflected differently depending on whether they are incident on the upper prism or the lower prism. some of the rays are redirected and pass towards the spectrometer's entrance slit, while the other part is deflected more strongly and is blocked by the outer part of the slit (Fig.4). The two prisms can be moved relative to each other, allowing the thickness of the glass through which the rays pass to be adjusted, and therefore the absorption according to the Beer-Lambert law.

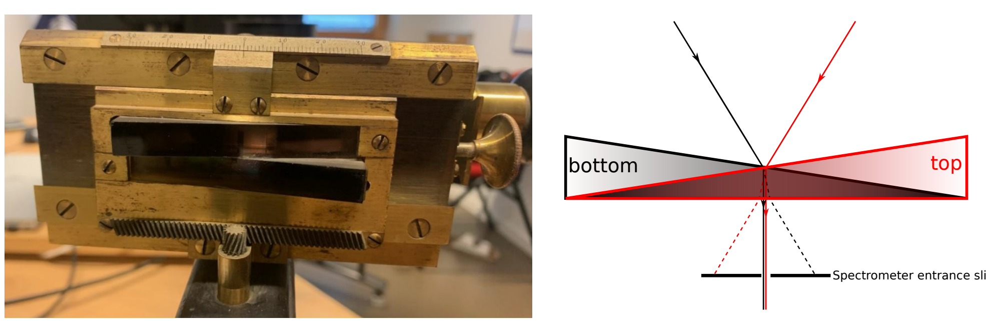

Figure 4. The double prism system. Left:the image of the system ; Right:schematic of the principle. The dotted rays are those that are blocked by the spectrometer's entrance slit because they have been over-deflected by the prism, which does not compensate for the incident angle of deflection.

5. MODEL WITH ZOS

Our understanding of the complete system has been greatly enhanced by reverse-engineering the system, which we have done with great care to avoid damaging it but also by modeling the complete system thanks to ZOS used in non-sequential mode. We needed to design some absorbing prisms and, to do this, we used the 'Polygon Object' type in the non-sequential editor. We defined the co-ordinates of each vertex and linked the different points to generate the double prism. The model of the system is shown in Fig. 5.

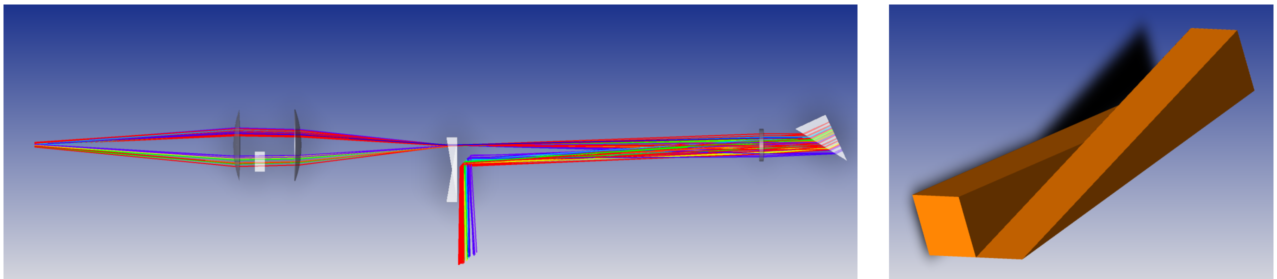

Figure 5. The complete model of the system developed under ZOS. On the left is the global system including a tank of eosine solution and on the right a focus on the double prism design

An initial qualitative validation of our model was done by comparing what we see directly through the pupil of the system with what we see in the pupil simulated by ZOS when no solution is added in the tank. The result is shown in Fig. 6 . We then simulated a real case where an eosin solution is present in the tank, leading to an absorption maximum around 500 nm. We simulated the spectrum without compensation and then calculated the offset we need to apply to the prisms to compensate for the absorption at 500 nm. We obtained an offset that should be 2.6 cm. The results are as shown in Fig.7.

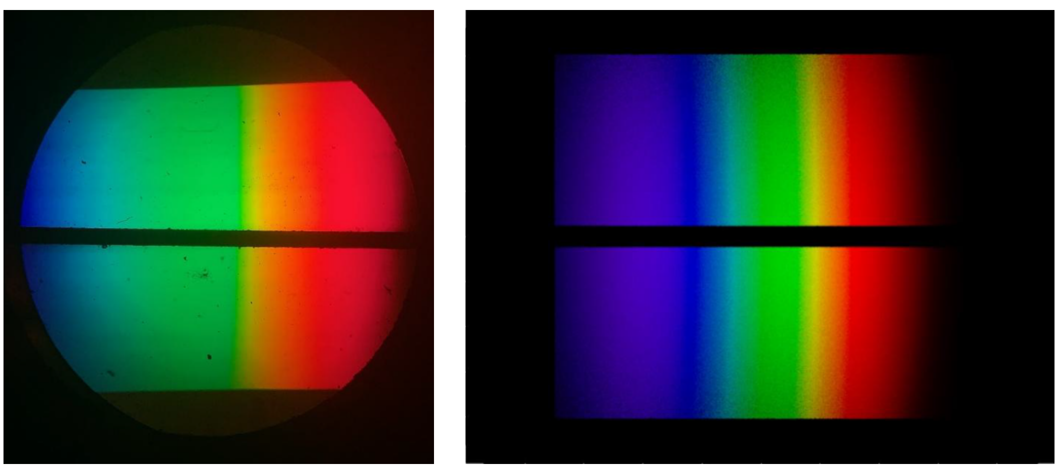

Figure 6. Experimental spectrum obtained (left) compared to simulated one with ZOS (right)

6. CONCLUSION

When we began our mission to preserve the history of optics at the Université de Franche-Comté, we did not fully appreciate the potential impact our collection could have on education. However, during this internship at the BTS level, it became clear how we could effectively integrate modern optical design software into teaching in an engaging and practical manner, whilst simultaneous adding to our knowledge of local scienctific heritage. The hologram and instrument collections, which currently occupy approximately 100 square meters of floor space, have the potential to serve as a valuable educational resource. They offer concrete applications and entertaining methods for learning, and play a pivotal role in visits to our institute by dignitaries and external visitors, providing significant added value. Furthermore, they inspire both students and faculty to leverage our historical foundation to spearhead innovative advancements in optics and photonic science.

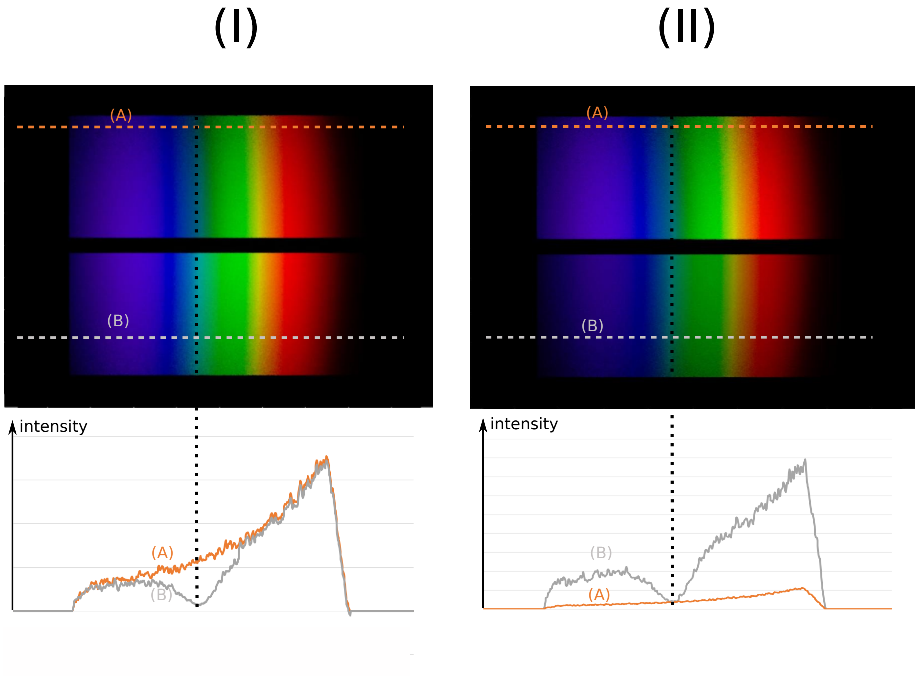

Figure 7. Simulated experiment with an eosin solution in the tank. The eosin spectra are at the top of the spectrum figures. The graphs below the spectra are cross-sections of (A) and (B). (I) spectrum without compensation; (II) spectrum with a 2.6cm translation of the prisms. It can be seen that the absorption has been compensated at 500 nm which is in agreement with the theory.

7. ACKNOWLEDGEMENTS

This work was supported by the Agence Nationale de la Recherche (projects OPTIMAL ANR-20-CE30- 0004 and HOLO-CONTROL ANR-21-CE42-0009) and by the French Investissements d'Avenir program, through the cross-disciplinary research (EIPHI) Graduate School (ANR-17-EURE-0002).

REFERENCES

[1] Magnin, J., Querenet, J., Froehly, L., Salvi, J., Jacquot, M., Levenson, A., and Dudley, J. M., "Teaching through history: the preservation of modern french scientific heritage in optics," in [*Education and Training in Optics and Photonics*], 127230F, Optica Publishing Group (2023).

[2] Dudley, J. M., Magnin, J., Froehly, L., Salvi, J., Verschueren, P., and Jacquot, M., "Research and teaching in physics at the university of franche-comt\'e 1845-1970," *arXiv preprint arXiv:2403.09271* (2024).

[3] Féry, C., "Spectrophotomètre à absorption," *Journal de Physique Théorique et Appliquée* **9**(1), 819–822 (1910).