Palacký University
Olomouc

Droplet Microscope
IYPT 2024

Tomáš Opatrný

Department of Optics
Faculty of Science
Palacký University Olomouc

Prague, October 21, 2023

The Task

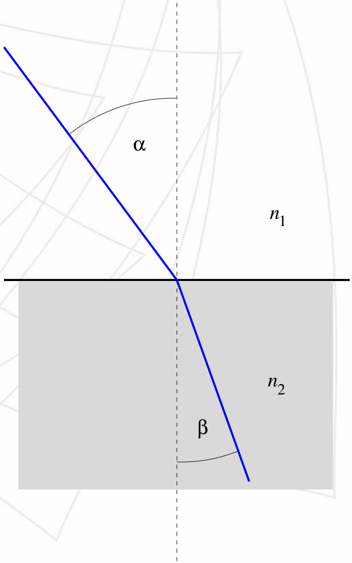
By looking through a single water droplet placed on a glass surface, one can observe that the droplet acts as an imaging system. Investigate the magnification and resolution of such a lens.

Outline

- Basic laws of optics
- Imaging, magnification, resolution
- Optical aberration
- Lab and SW possibilities at the Optics Department
- Some useful published work
- Some hints to explore
- Some hints to win the tournament
- Summary

Snell's law

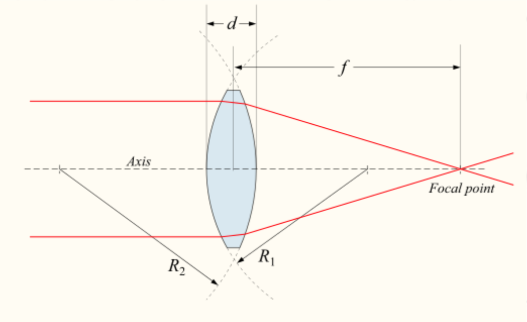
$$n_1 \sin \alpha = n_2 \sin \beta$$



- $n_{1,2} \ldots$ index of refraction
- α, β measured from the normal to the interface
- for air $n_1 \approx 1.00$
- for water $n_2 \approx 1.33 \approx 4/3$

Lensmaker's equation

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right]$$



Positive (converging) lens

https://en.wikipedia.org/wiki/Lens

Lensmaker's equation

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right]$$

If $R_2 = \infty$ then

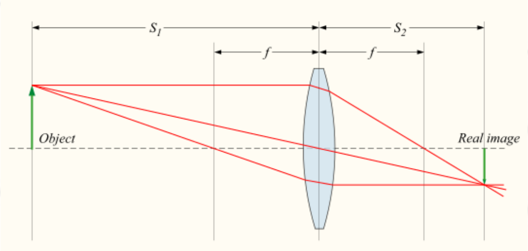
$$f = \frac{R}{n-1}$$

for water $n - 1 \approx 1/3$, therefore

$$f \approx 3R \qquad (1)$$

Thin Lens Formula

$$\frac{1}{f} = \frac{1}{S_1} + \frac{1}{S_2}$$

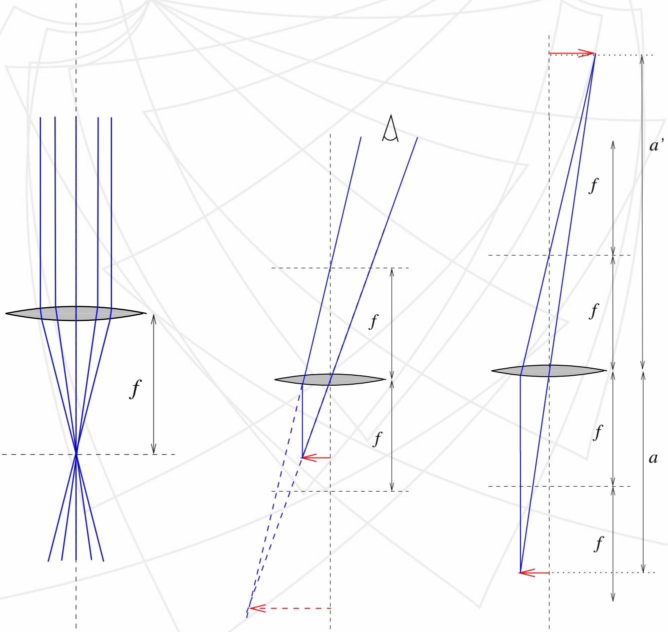


Magnification:

$$M = -\frac{S_2}{S_1} = \frac{f}{f - S_1}$$

https://en.wikipedia.org/wiki/Lens

Lens Imaging



Lens Imaging

When the object is placed at the focal point, the magnification goes to infinity!

Can the magnification be arbitrarily large???

When the object is placed at the focal point, the magnification goes to infinity!

Can the magnification be arbitrarily large???

In principle, yes, but it does not make sense to magnify beyond the resolution.

The smallest resolvable detail should be inside the area of view.

Lens Imaging

When the object is placed at the focal point, the magnification goes to infinity!

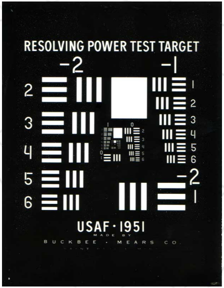
Can the magnification be arbitrarily large???

In principle, yes, but it does not make sense to magnify beyond the resolution.

The smallest resolvable detail should be inside the area of view.

So, what influences the resolution?

1951 USAF resolution test chart



- 9 groups, each consisting of 6 elements, i.e., 54 target elements
- Each element - three bars which form a minimal Ronchi ruling
- logarithmic steps in spatial frequency from 0.250 to 912.3 line pairs per mm

https://en.wikipedia.org/wiki/1951_USAF_resolution_test_chart#

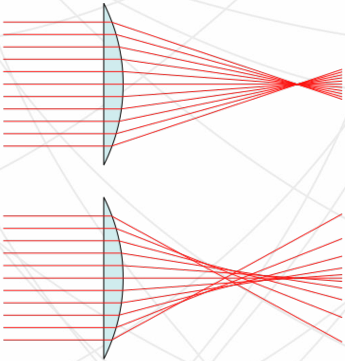
Optical Aberrations

The assumption that a point of an object is projected to a point of the image is just an **approximation**.
In reality, various aberrations play a role:

- Spherical aberration
- Coma
- Astigmatism
- Field curvature
- Image distortion
- Chromatic aberration

Moreover, there is also the **diffraction limit** due to the wave nature of the light.

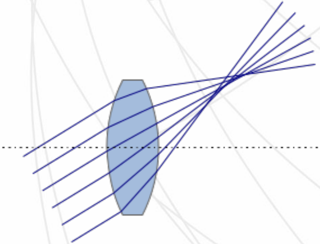
Spherical aberration

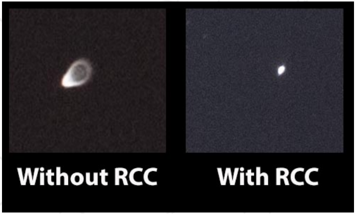


Light rays that strike a spherical surface off-centre are refracted or reflected more or less than those that strike close to the centre.

https://en.wikipedia.org/wiki/Spherical_aberration

Coma



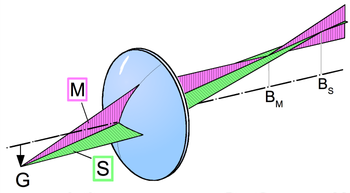


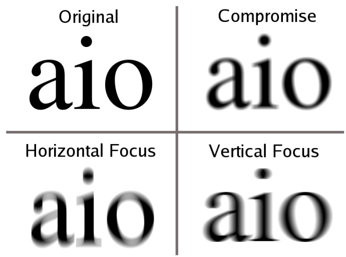
Off-axis point sources are distorted, appearing to have a tail (coma) like a comet.

https://en.wikipedia.org/wiki/Coma_(optics)

Optical Aberrations

Astigmatism

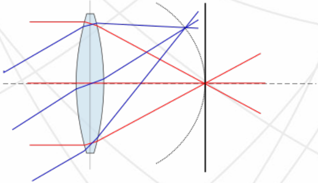




Rays that propagate in two perpendicular planes have different foci.

https://en.wikipedia.org/wiki/Astigmatism_(optical_systems)

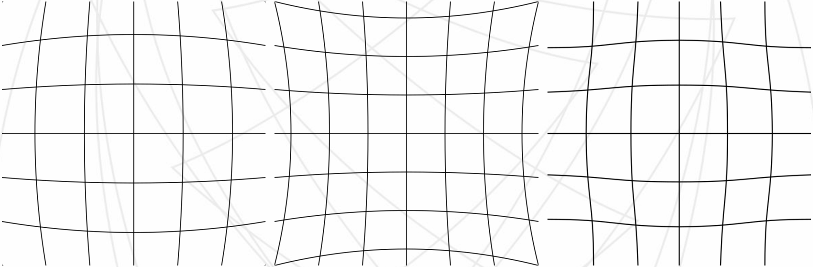
Field Curvature



Flat object normal to the optical axis cannot be brought into focus on a flat image plane.

https://en.wikipedia.org/wiki/Petzval_field_curvature

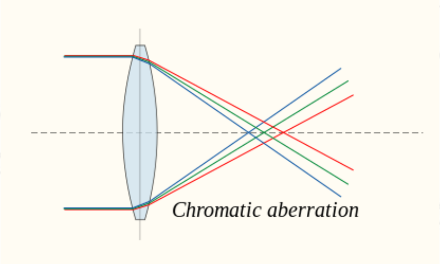
Image distortion



Magnification depends on the distance from the opticsl axis.
(here: "barrel", "pincushion", "mustache")

https://en.wikipedia.org/wiki/Distortion_(optics)

Chromatic aberration



Index of refraction depends on the wavelength.

https://en.wikipedia.org/wiki/Chromatic_aberration

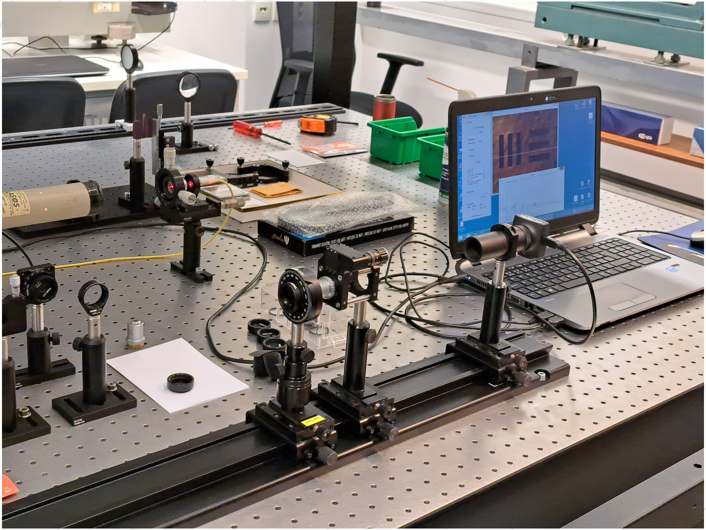
Diffraction limit, Airy disc

The resolution is limited by the wavelength:

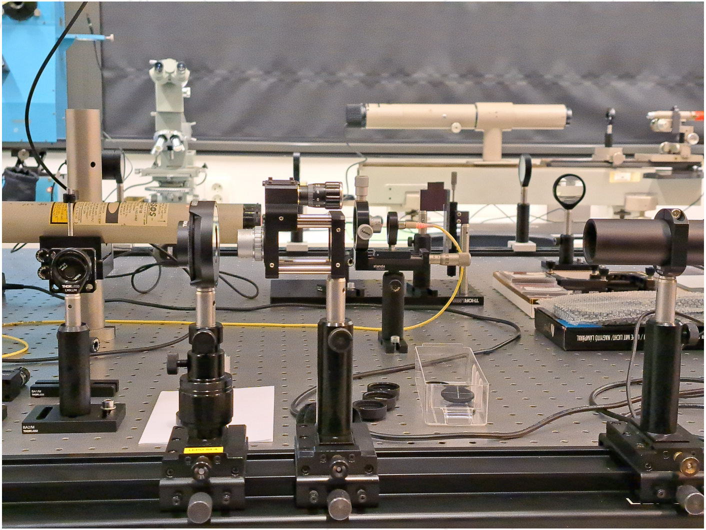
$$d = \frac{\lambda}{2n \sin\theta} = \frac{\lambda}{2\ \mathrm{NA}}$$

`https://en.wikipedia.org/wiki/Airy_disk`

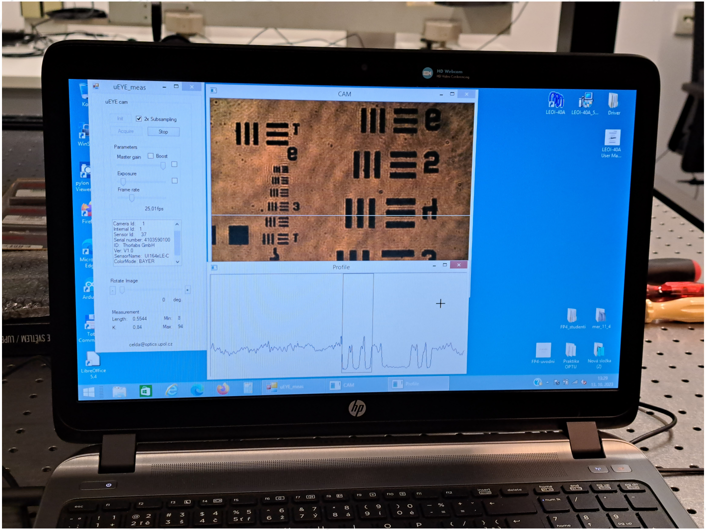
Lab Testing



Lab Testing



Lab Testing


uEYE_meas
uEYE cam
Init
2x Subsampling
Acquire
Stop
Parameters
Master gain
Boost
Exposure
Frame rate
25.01fps
Camera Id: 1
Internal Id: 1
Sensor Id: 37
Serial number: 4103590100
ID: Thorlabs GmbH
Ver: V1.0
SensorName: UI164xLE-C
ColorMode: BAYER
Rotate Image
0 deg
Measurement
Length: 0.5544
Min: 8
K: 0.84
Max: 94
celda@optics.upol.cz
CAM
Profile
LEOI-40A
Driver
LibreOffice 5.4
hp

Software tools

Available at the Optics Department

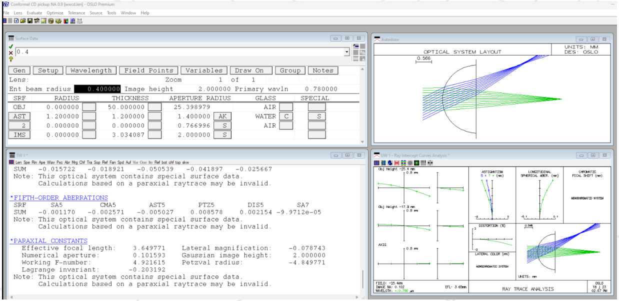
- OSLO (Optical Software for Layout and Optimization)
- VirtualLab

Available at the Optics Department

OSLO

Optics Software for Layout and Optimization meets today's lens design and optical engineering requirements.

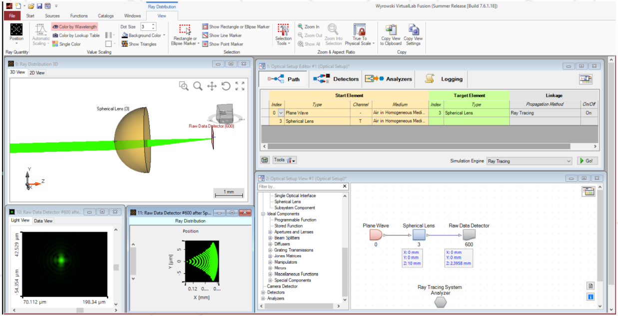
- ray-tracing of the system
- computing optical parameters of the system
- analysis of imaging power and optimization



Available at the Optics Department

WYROWSKI VirtualLab FUSION

- simulation of wave and vector characteristics of the optical field
- physical simulations
- ray-tracing of the system



Published work

SPECIAL FEATURE: PRACTICAL PHYSICS

www.iop.org/Journals/pe

Water droplet lens microscope and microphotographs

H H Myint[1], A M Marpaung[2], H Kurniawan[2], H Hattori[3] and K Kagawa[3]

[1] No 2 Basic Education High School, Dagon Township, Yangon, Myanmar

[2] Applied Spectroscopy Laboratory, Graduate Program in Opto Electrotechniques and Laser Applications, Faculty of Engineering, The University of Indonesia, 4 Salemba Raya, Jakarta 10430, Indonesia

[3] Department of Physics, Faculty of Education and Regional Studies, The University of Fukui, Fukui 910, Japan

E-mail: kagawa@edu00.f-edu.fukui-u.ac.jp

H. H. Myint et al., Phys. Educ. 36, 2, 97-101 (2001)

Published work

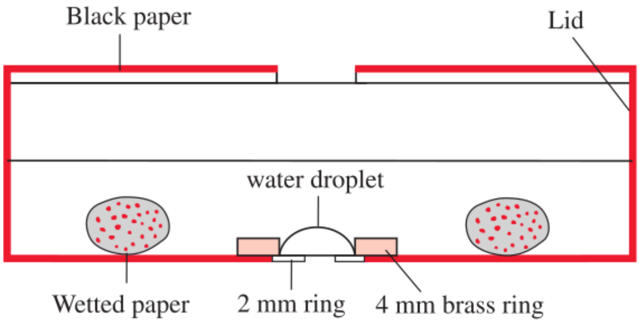


Figure 1. Cross-sectional view of the water droplet lens contained in a plastic vessel.

H. H. Myint et al., Phys. Educ. 36, 2, 97-101 (2001)

Published work

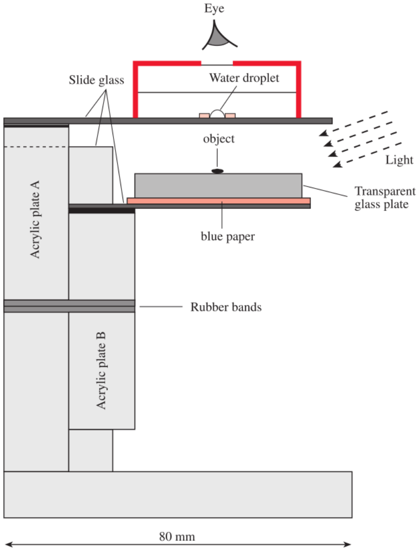


Figure 2. Side view of the water droplet lens microscope.

H. H. Myint et al., Phys. Educ. 36, 2, 97-101 (2001)

Published work

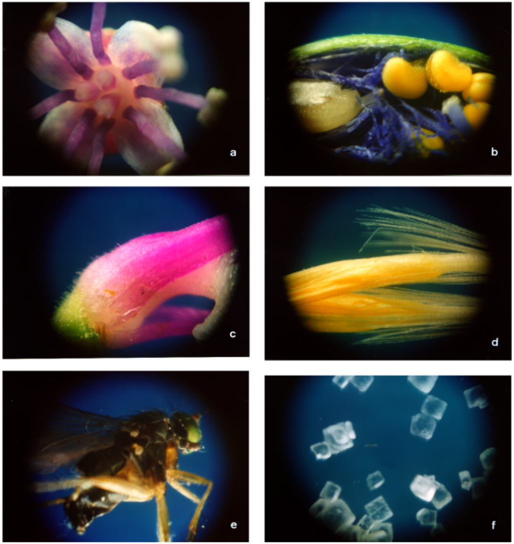
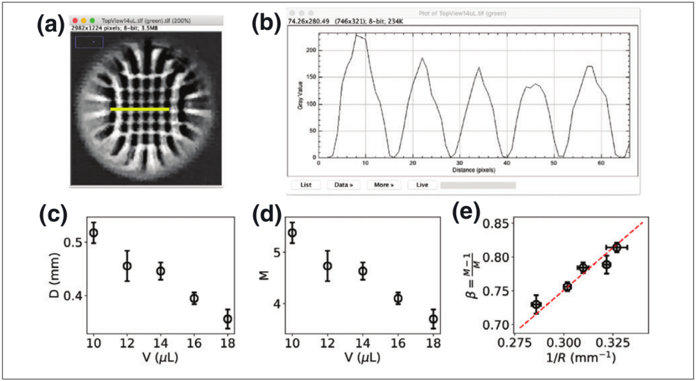


Figure 3. Microphotographs taken by a compact camera using the water droplet lens microscope: (a) pistil and stamen of a Hydrangea flower; (b) inside of a bud of a Tradescantia reflexa flower; (c) corona of a Spiranthes sinensis flower; (d) ligulate petal and corona hair of Taraxacum officinale; (e) a fly; (f) NaCl crystal powder. The distance between the object and the lens is 21.5 mm for (a)–(e) and 15 mm for (f).

H. H. Myint et al., Phys. Educ. 36, 2, 97-101 (2001)

Learning the lens equation using water and smartphones/tablets



J. Freeland et al., The Physics Teacher **58,** 360, May 2020

Other useful resources

- Preparation to the Young Physicists' Tournaments' 2024 Ilya Martchenko, Foundation for Youth Tournaments
- G. Planinsic. Water-drop projector. Phys. Teach. 39, 18-21 (2001), https://users.fmf.uni-lj.si/planinsic/articles/planin2.pdf
- J. Walker. A drop of water becomes a gateway into the world of catastrophe optics. Sci. Am. 261, 120D-123 (1989)
- N. A. Szydlowski, H. Jing, M. Alqashmi, and Y. S. Hu. Cell phone digital microscopy using an oil droplet. Biomed. Optics Expr. 11, 5, 2328-2338 (2020)
- One drop of water turns an iPhone into a Microscope - Day of Curiosity 17 (youtube, Jeremy Pedersen, 30.03.2022), https://youtu.be/aYQsxB2p4KI
- Make a FREE Microscope! (DIY With a Water Drop Lens) (youtube, Squint Science, 28.07.2020), https://youtu.be/cnKCbW75dIk

Possible further ideas

What can one explore?

- Find the shape of the drop and verify the lens equation. What is the best way to determine the dimensions and shape of the drop?
- Find the ways to control the size and shape of the drop. Precise pipette? Controlling the surface tension? Could anything be changed by letting the drop "hang from the ceiling" rather than "sit on the bottom"?
- Does the asymmetry of the lens play a role? Is it better to place the object to the flat or convex side of the lens?
- Can one manipulate the index of refraction? Can that improve the performance of your microscope?
- Which aberration limits the resolution dominantly? Can one find a way to mitigate it?

Some hints to win

- Do a neat experiment, have all relevant parameters under control, collect data and process them correctly. Estimate the precision of your results.
- Check how the measured results agree with the theory, explain any deviations.
- Try to reproduce previously published results, comment on any differences.
- Be creative and come with new ideas that were not published previously (it's hard, but try).
- Try to collaborate with institutions with good optics labs. How do your home-made measuremens relate to those done with professional equipment?
- Bring your device to the tournament and show it to the jury. (I typically give an additional point to those who bring a real stuff.)
- Make nice photographs of some interesting objects.
- Cite properly used sources.

Summary

- Basic laws of optics (Snell, Lensmaker's Equation, Lens Equation)
- Imaging, magnification, resolution
- Optical aberration
- Lab and SW possibilities at the Optics Department
- Some useful published work
- Some hints to explore
- Some hints to win the tournament

Motto:

"Kein Versuch ist so dumm, dass man ihn nicht probieren sollte."
(No experiment is so dumb, that it should not be tried.)

(I. Estermann [Am. J. Phys. 43, 661 (1975)] qoting W. Gerlach 1920, quoting E. Meyer)

THANK YOU!