Meniscus optics

Vitaliy Matiunin
Aleksandr Severinov
Vladislav Tumanov

Russia
IYPT

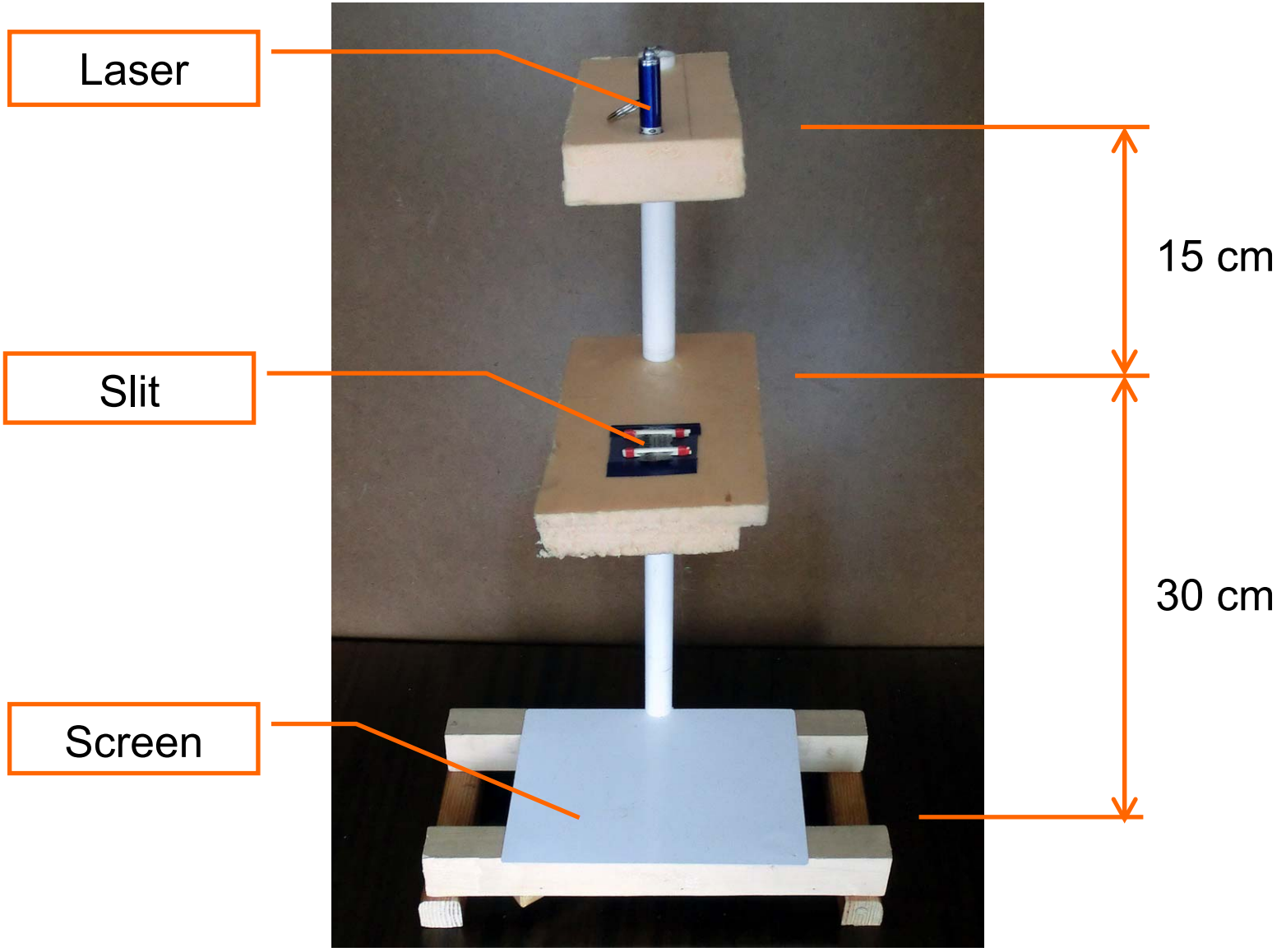
The problem

Cut a narrow slit in a thin sheet of opaque material. Immerse the sheet in a liquid such as water. After removing the sheet from the liquid, you will see a liquid film in the slit. Illuminate the slit and study the resulting pattern.

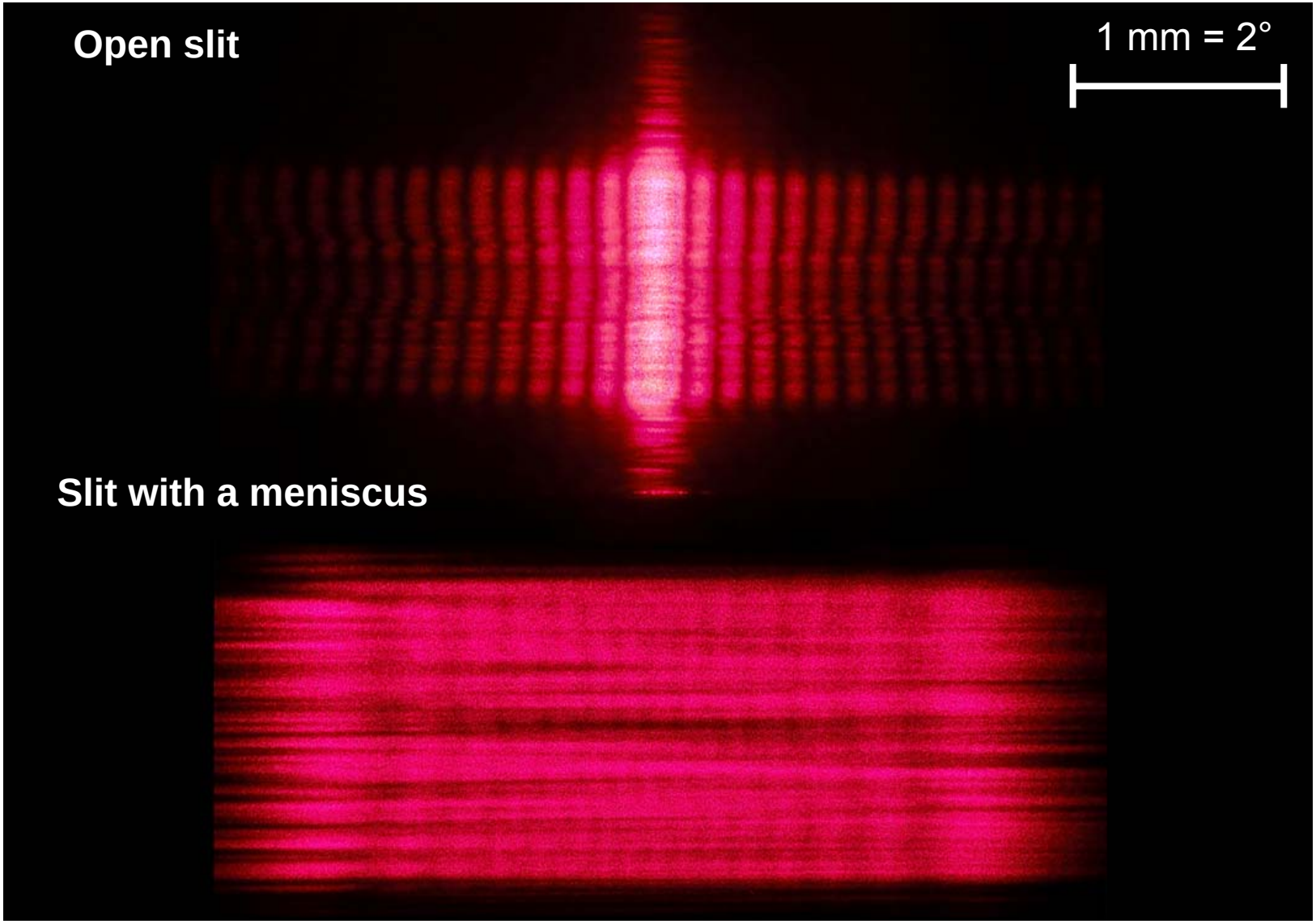
Experiment

Slit

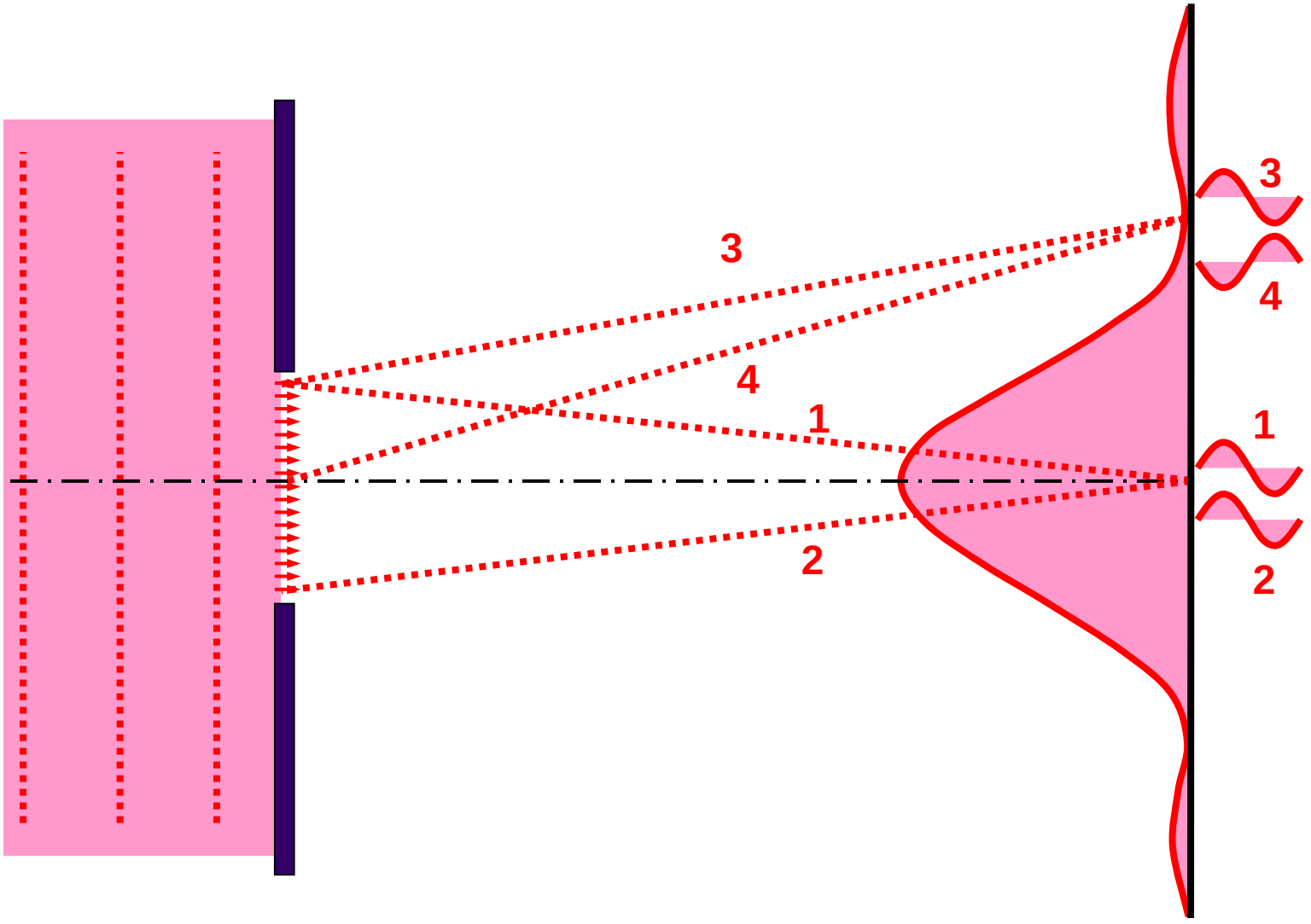
Experimental setup



Slit width 0.15 mm

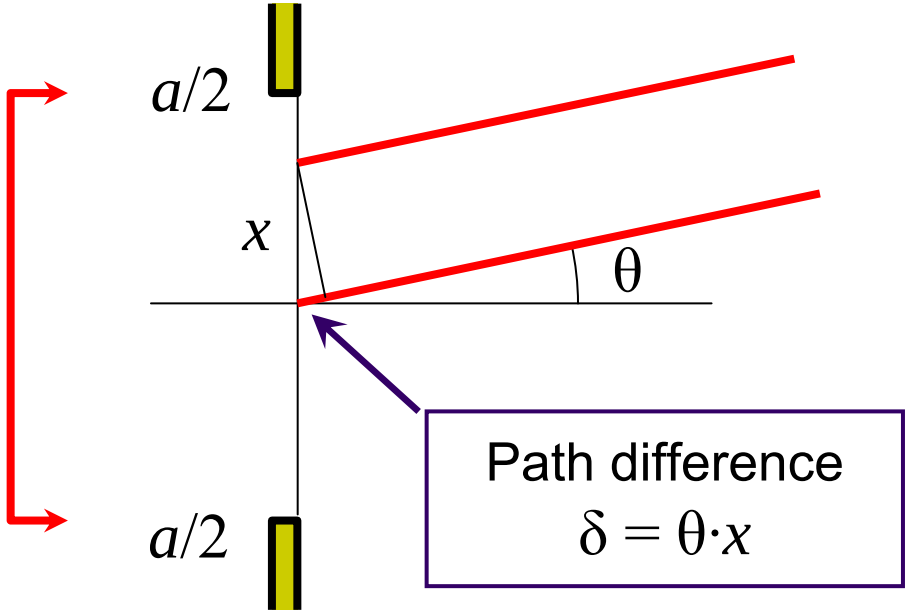


How does diffraction occur?



Fraunhofer diffraction by a slit

Calculation of the integral amplitude

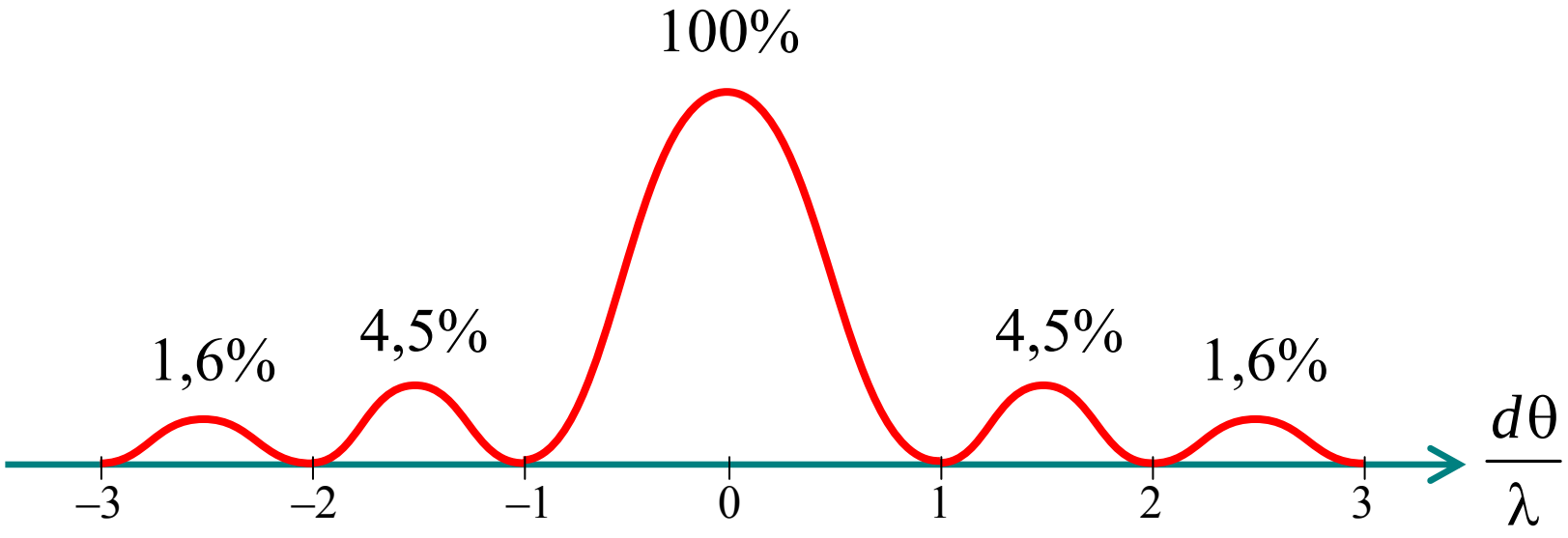


Integral amplitude in direction θ:

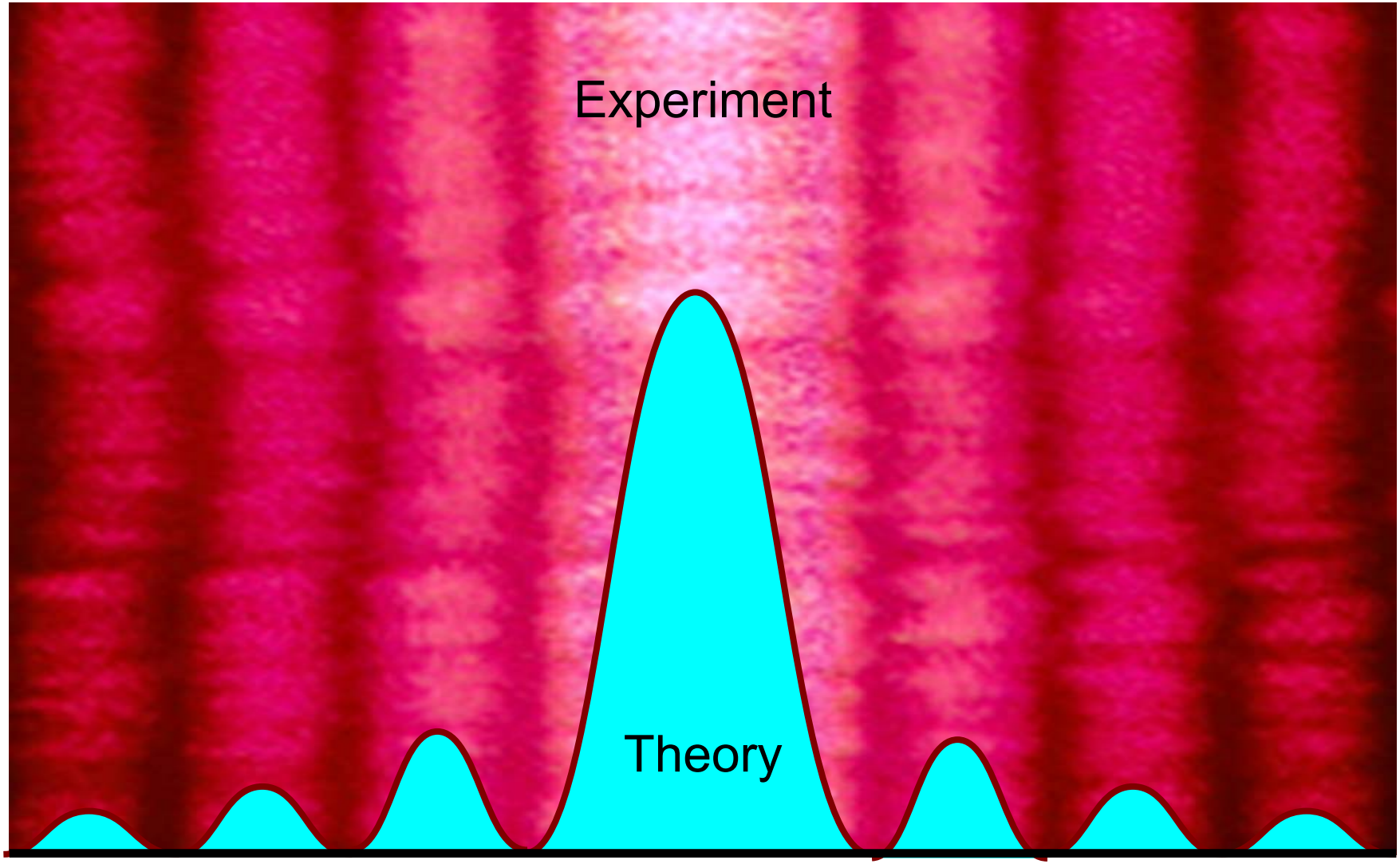
$$A(\theta) = A_0 \int_{-a/2}^{a/2} \cos\left(\frac{2\pi\theta}{\lambda} x\right) \cdot \frac{dx}{a}$$

Screen illumination

$$I(\theta) = A^2(\theta) = I_0 \left\{ \frac{\sin\left(\frac{\pi a \theta}{\lambda}\right)}{\left(\frac{\pi a \theta}{\lambda}\right)} \right\}^2$$

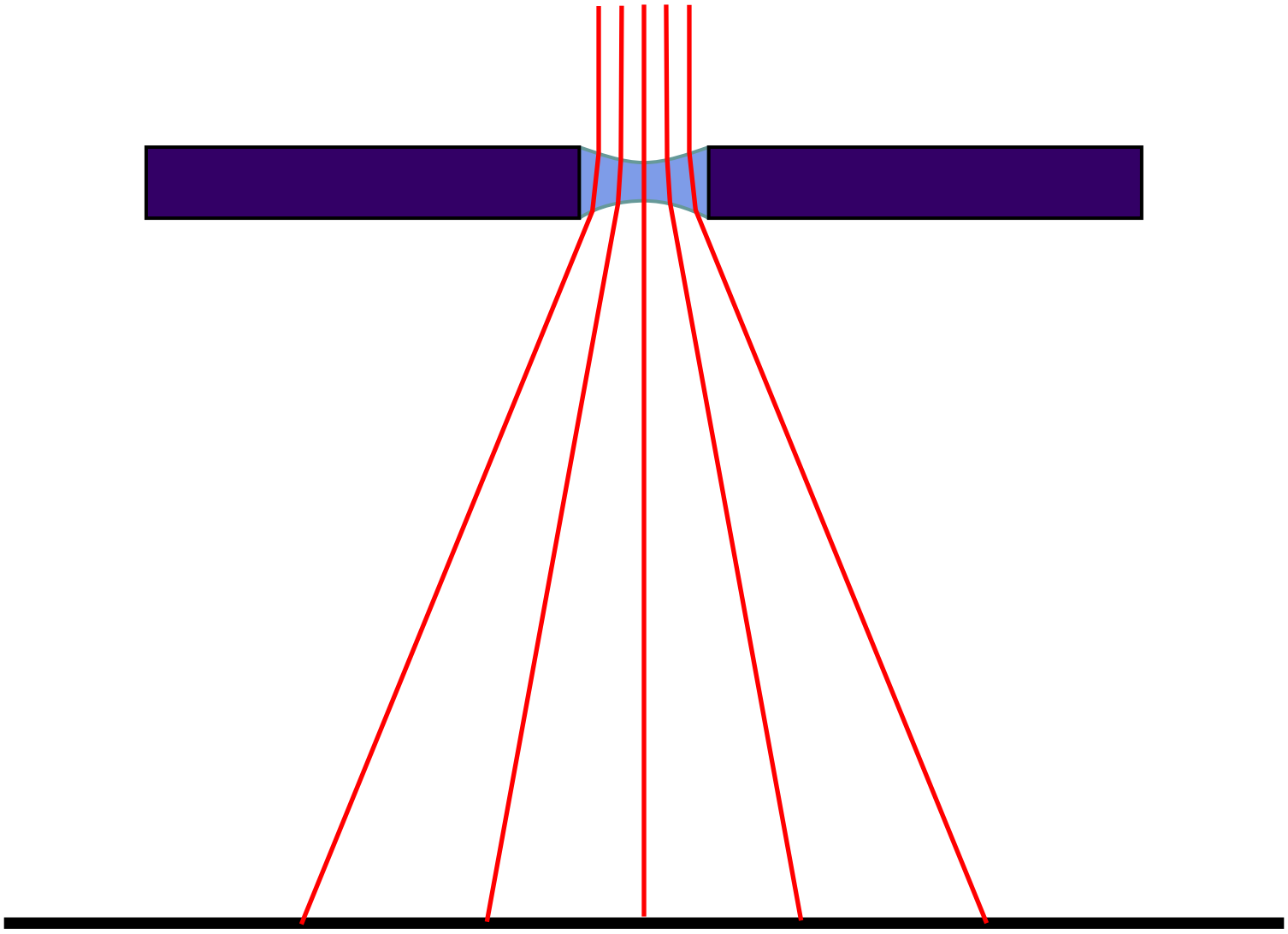


Fraunhofer diffraction pattern

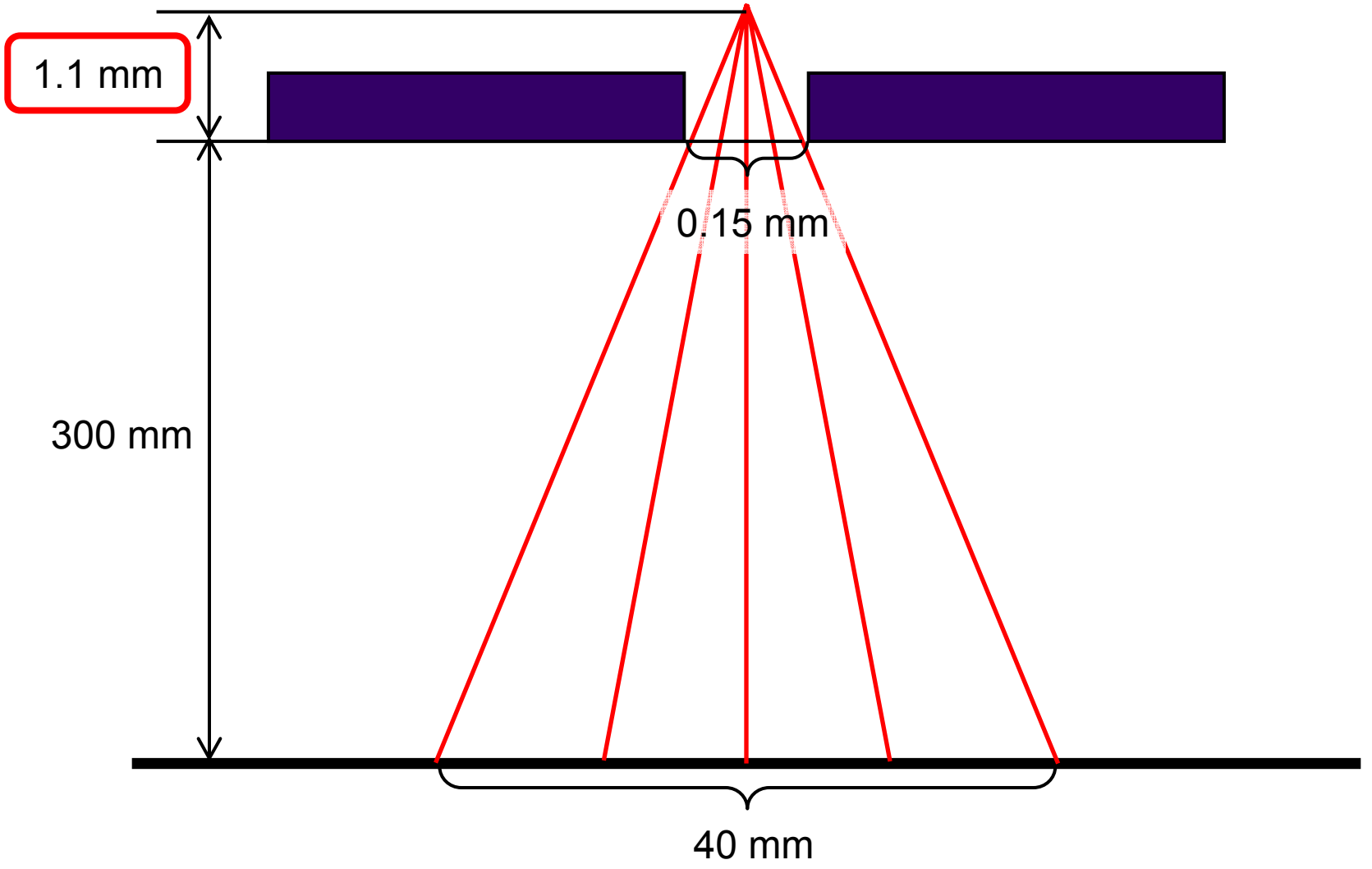


Meniscus in geometrical optics

Water meniscus as a biconcave lens

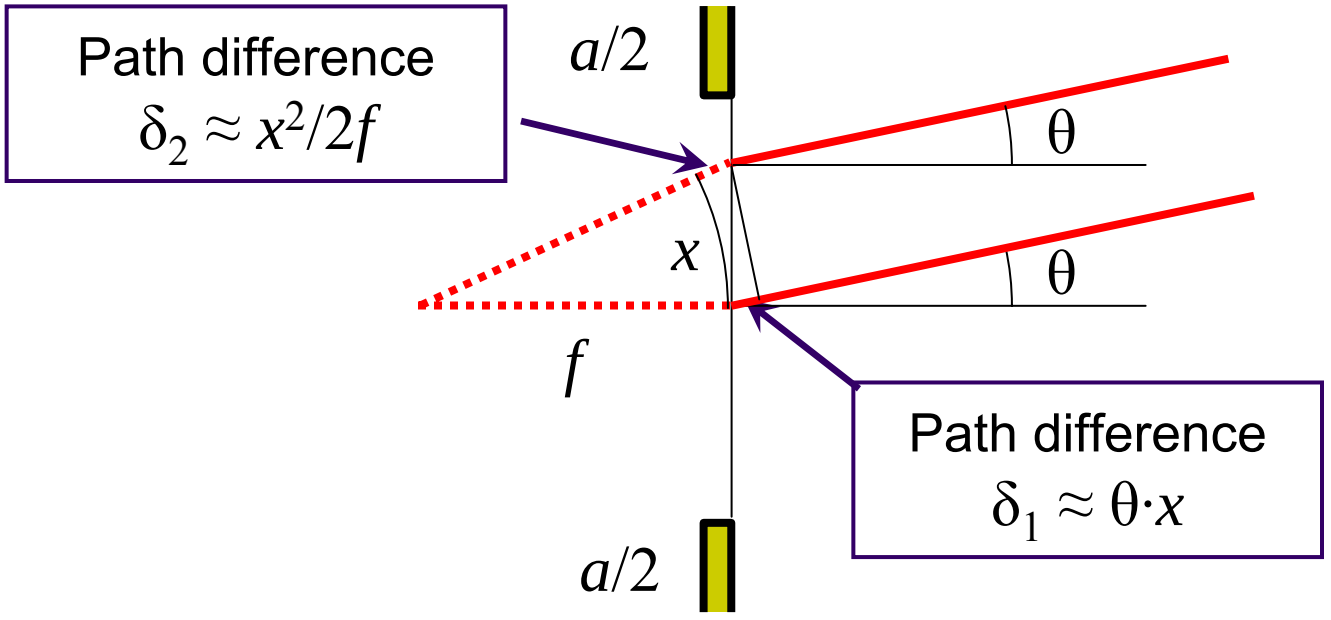


Equivalent scheme



Fresnel diffraction by a slit with the meniscus

Calculation of the path difference



$$\delta = \delta_1 - \delta_2 = \theta x - \frac{x^2}{2f}$$

Screen illumination

$$I(\theta) = \frac{I_0}{2}\left(\left\{ \int_{-a/2}^{a/2} \cos\left(\frac{2\pi\theta x}{\lambda}\right) \cos\left(\frac{\pi x^2}{\lambda f}\right) \frac{dx}{a} \right\}^2 + \left\{ \int_{-a/2}^{a/2} \cos\left(\frac{2\pi\theta x}{\lambda}\right) \sin\left(\frac{\pi x^2}{\lambda f}\right) \frac{dx}{a} \right\}^2 \right)$$

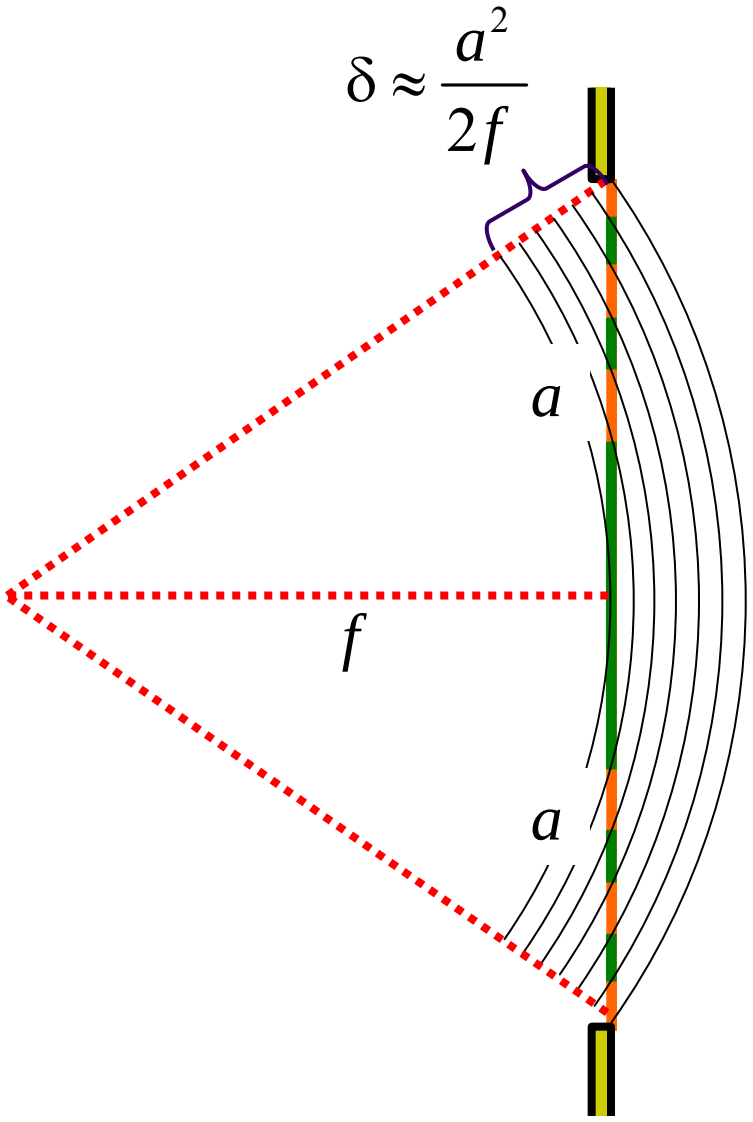
In Fraunhofer case

$f = \infty$

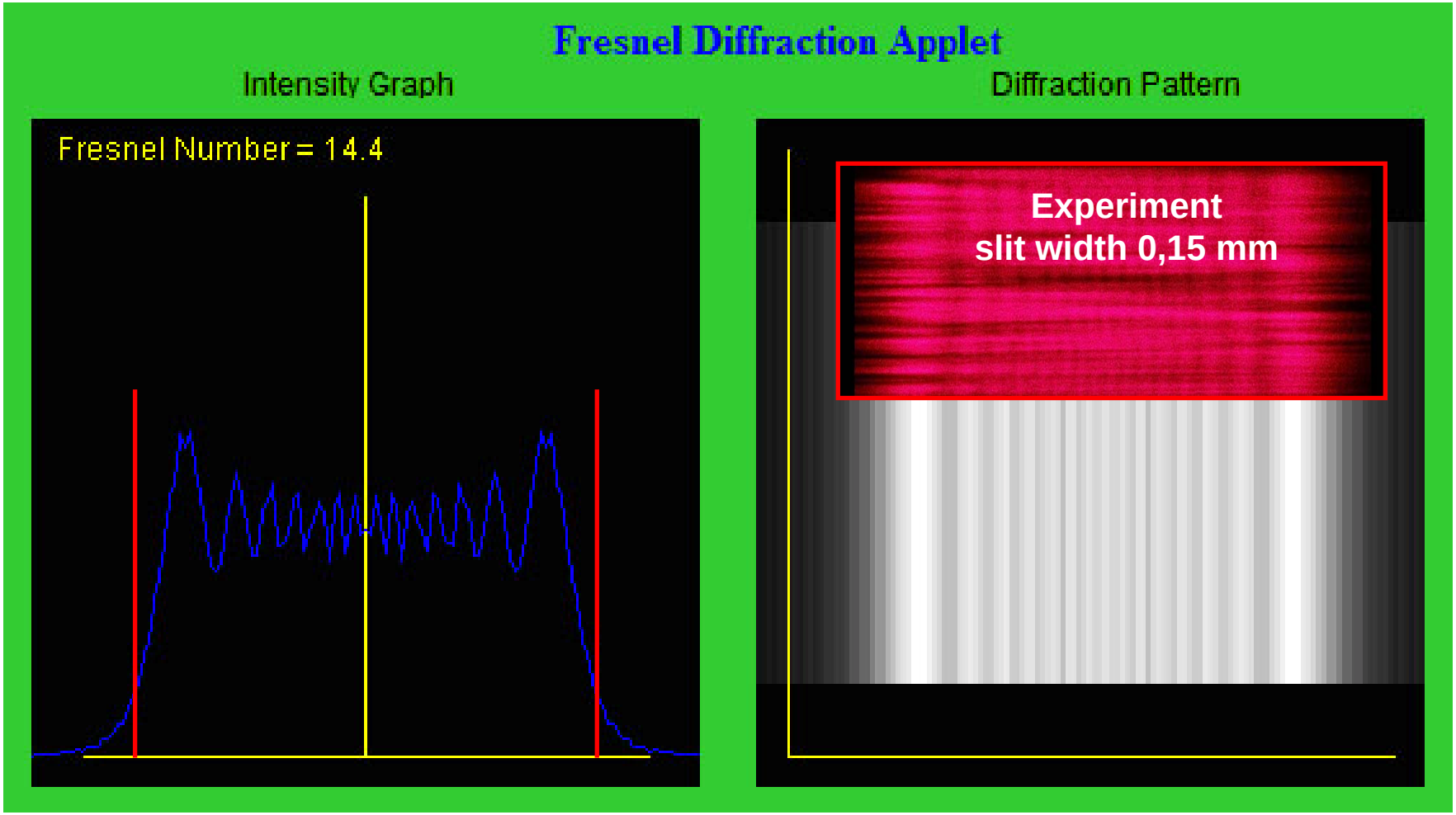
Fresnel number

The number of bright fringes on the screen ≈ the Fresnel number

$$F = \frac{\delta}{\frac{1}{2}\lambda} = \frac{a^2}{\lambda f}$$



Fresnel number = 14,4

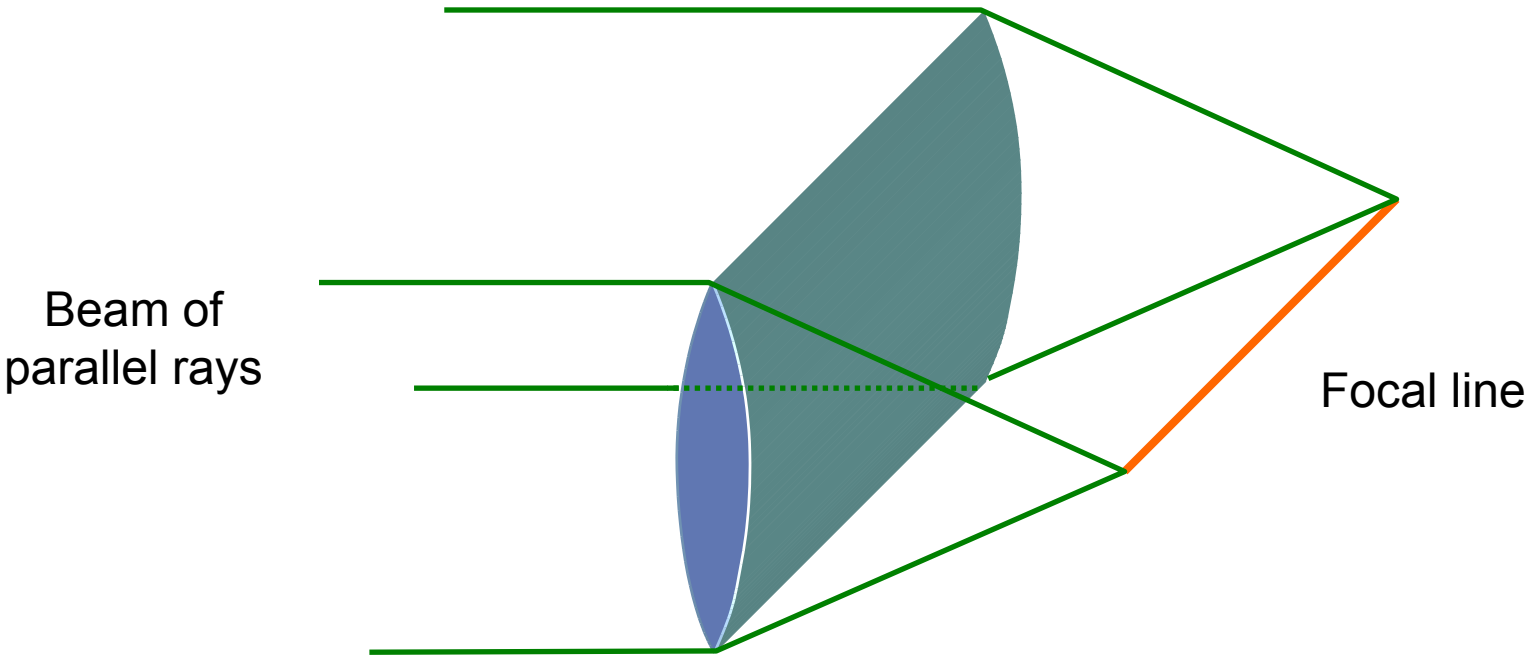


More accurate focal length of meniscus

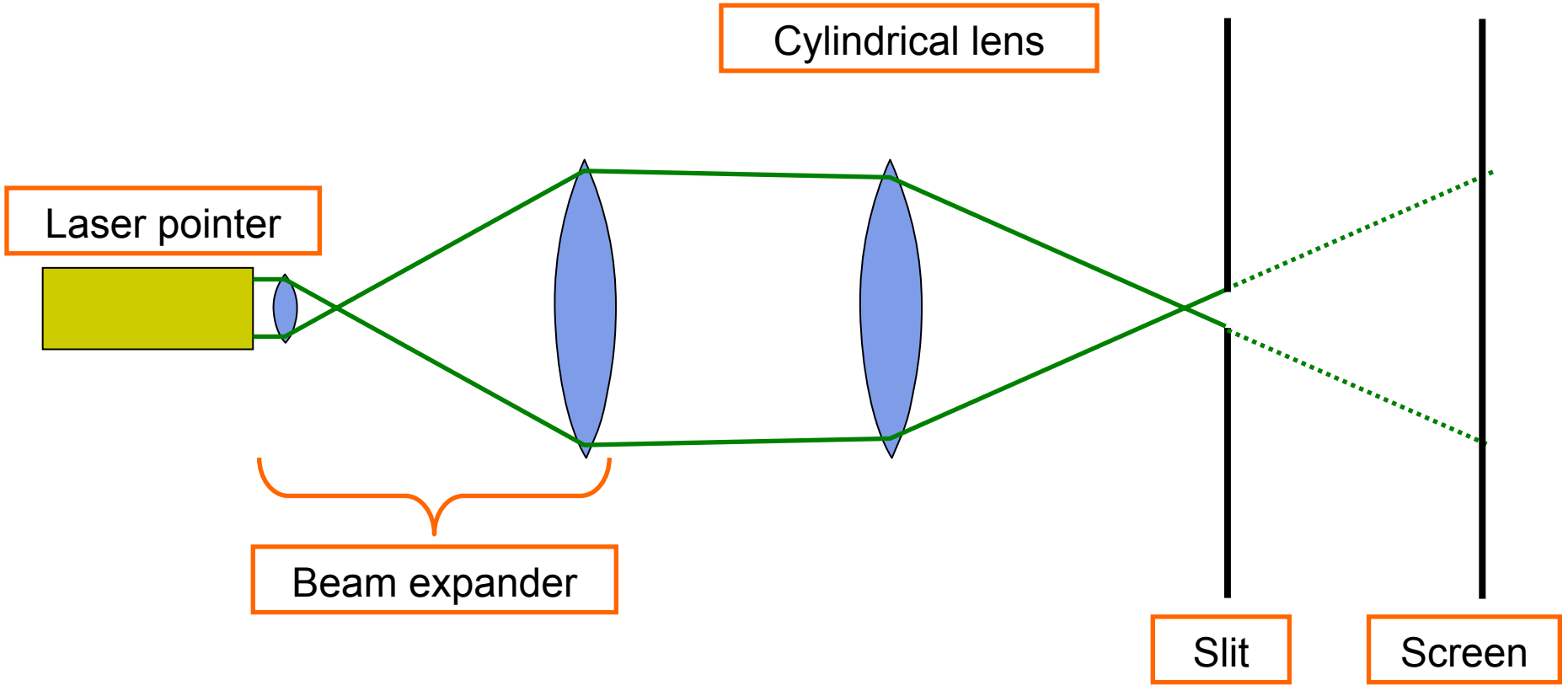
$$f = \frac{a^2}{4F\lambda} = 0.67 \text{ mm}$$

Experiment with a cylindrical lens

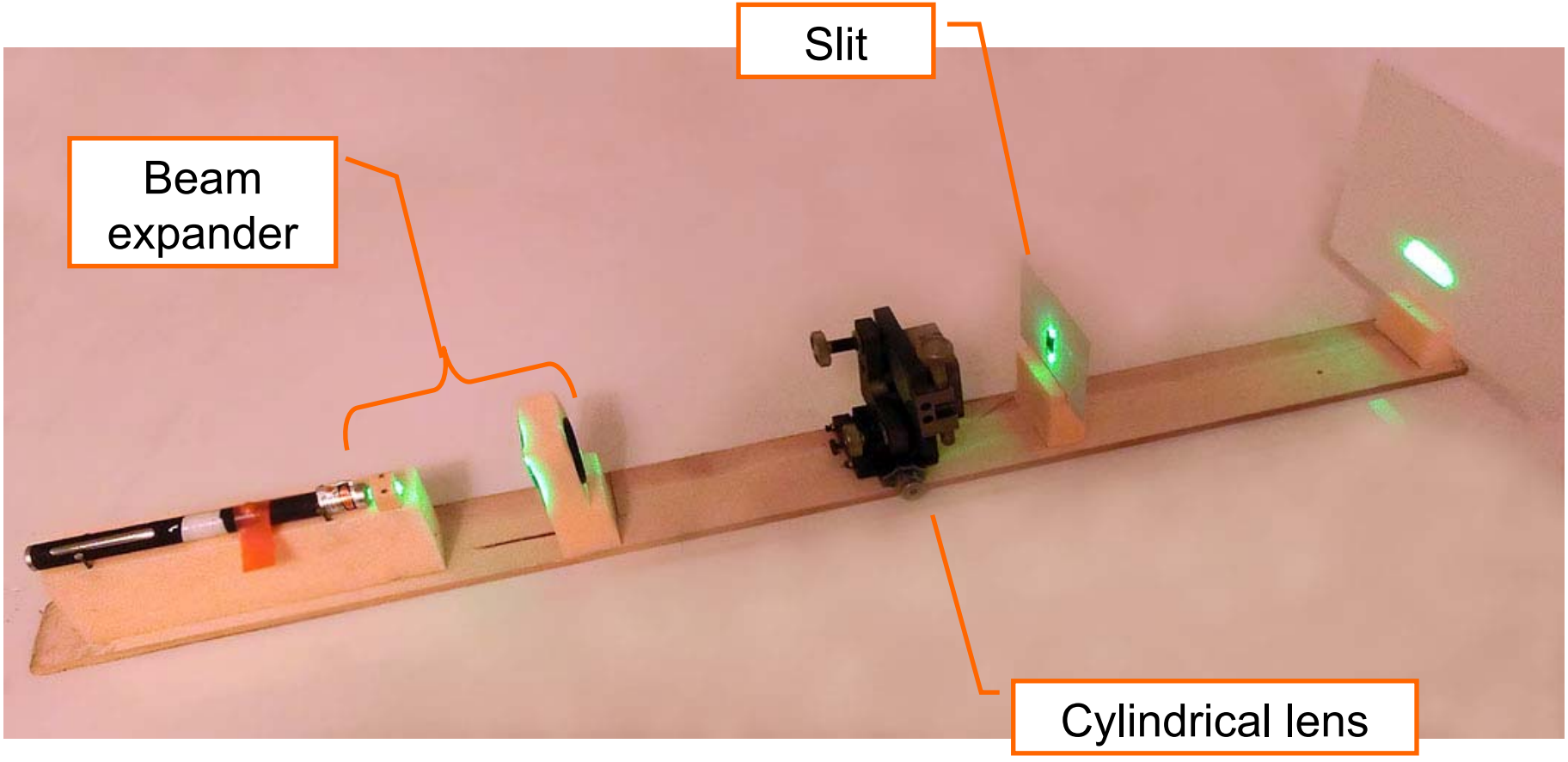
Cylindrical lens



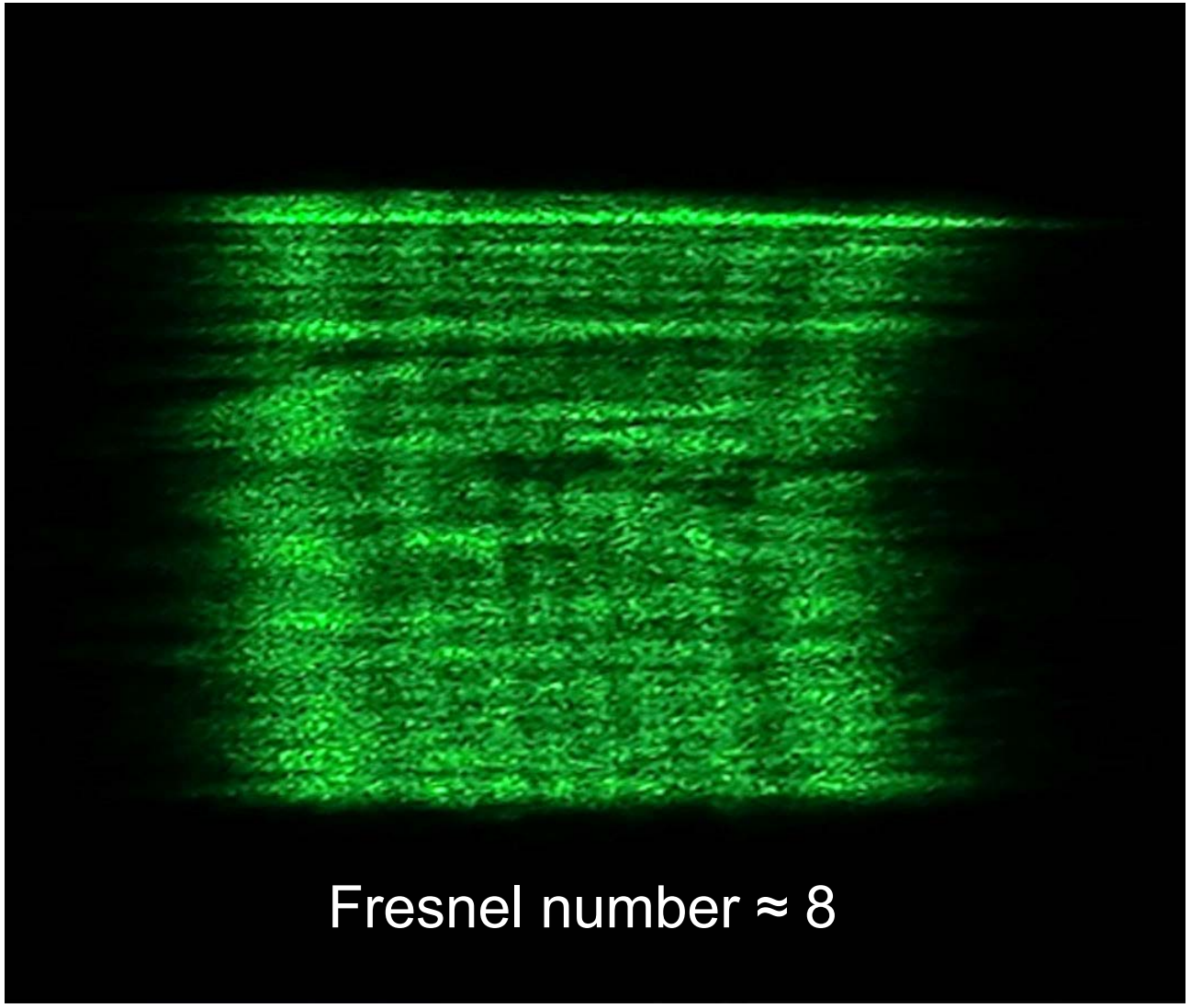
Scheme of experimental setup



Experimental setup

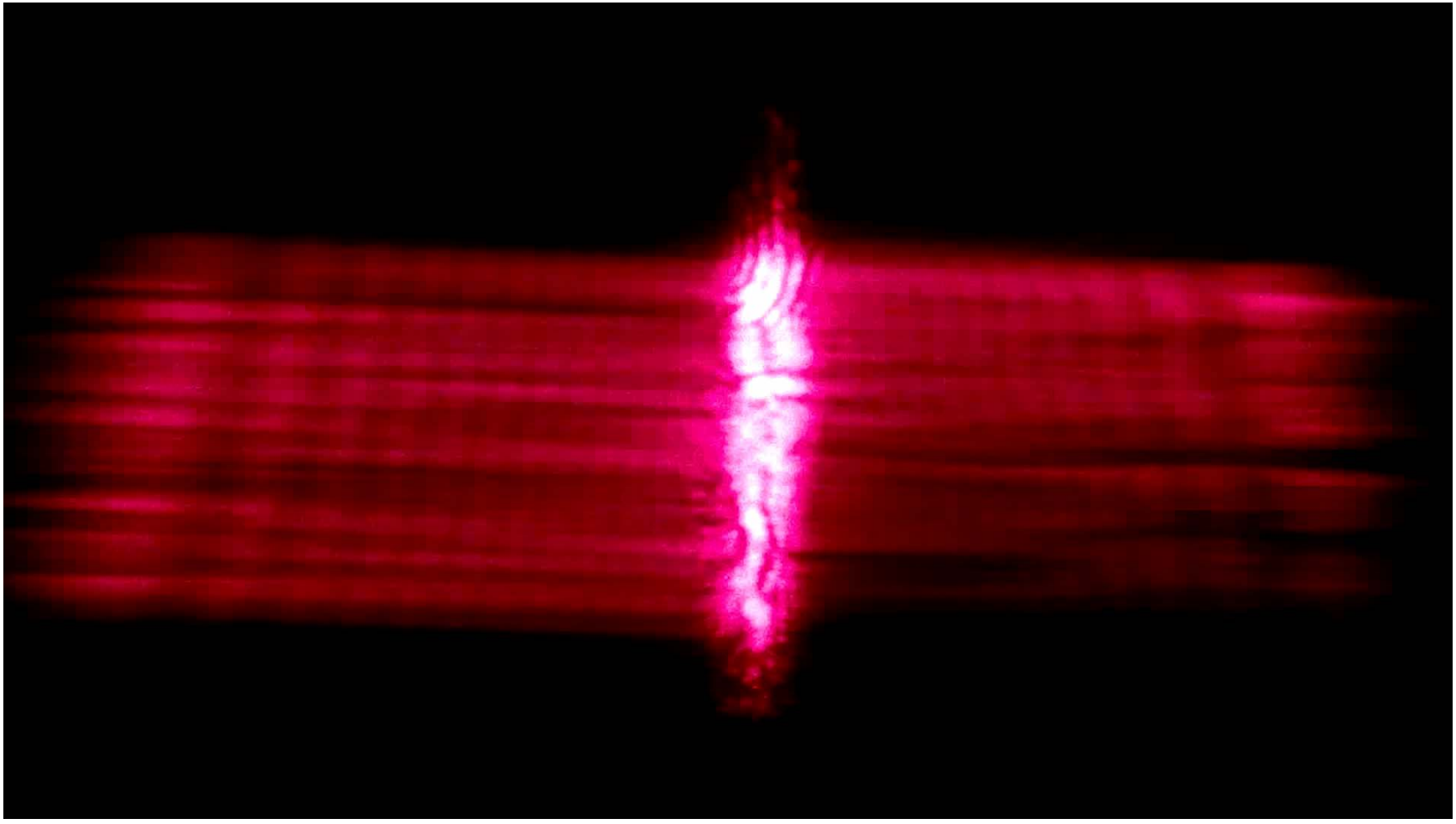


Diffraction pattern on the screen

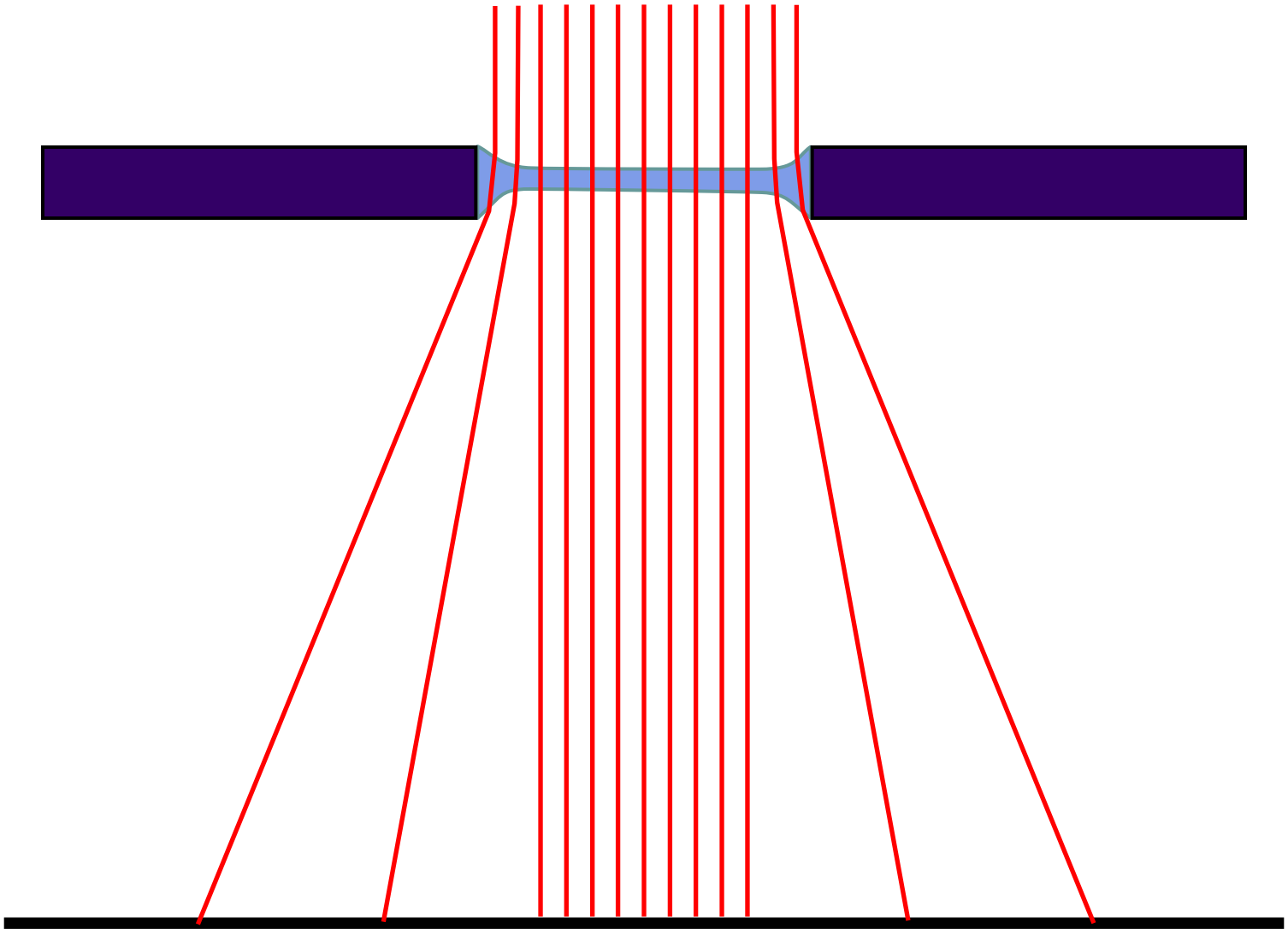


Experiment with a wide slit

Slit width 0.45 mm (video)

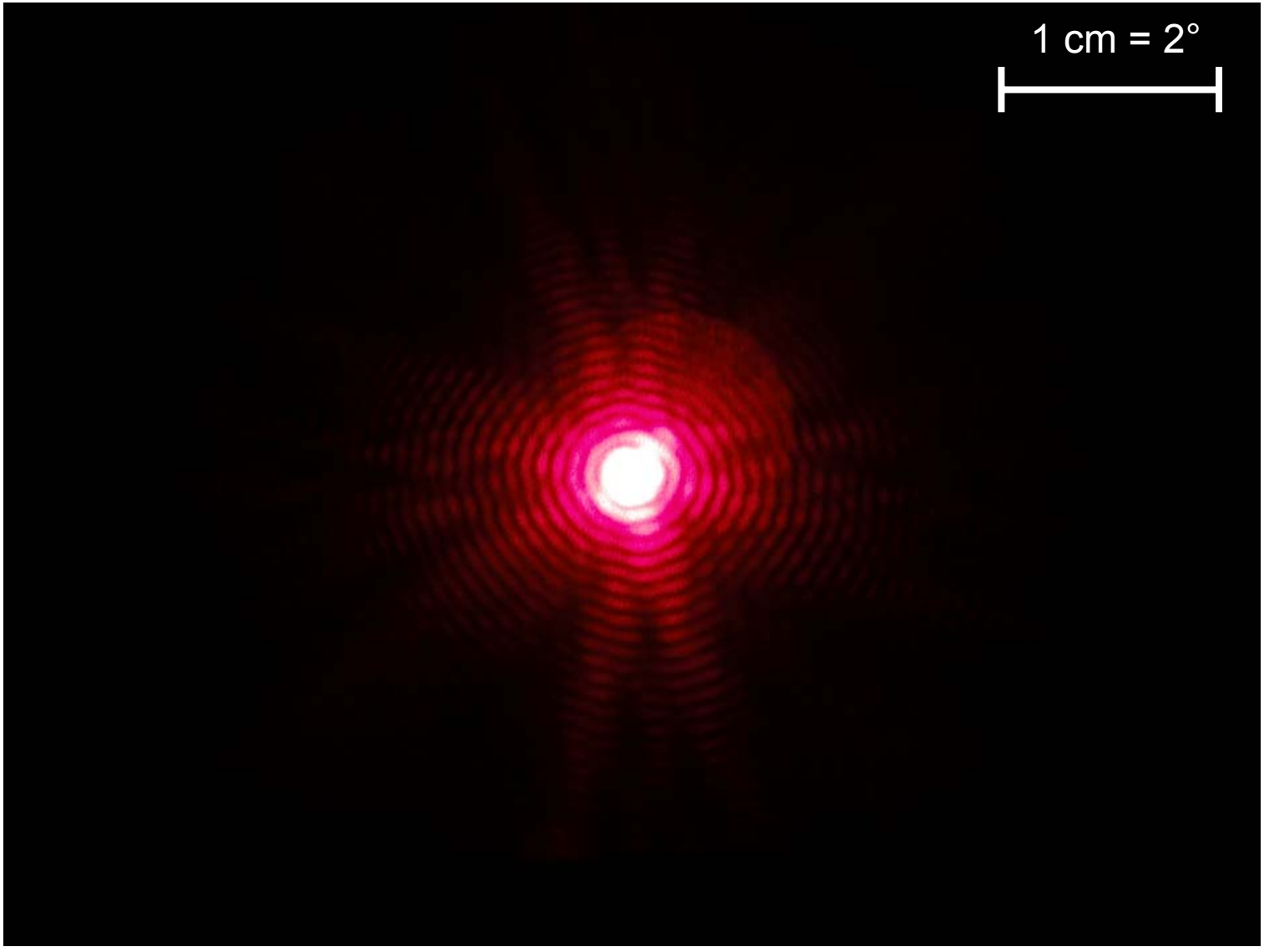


Rays in geometrical optics

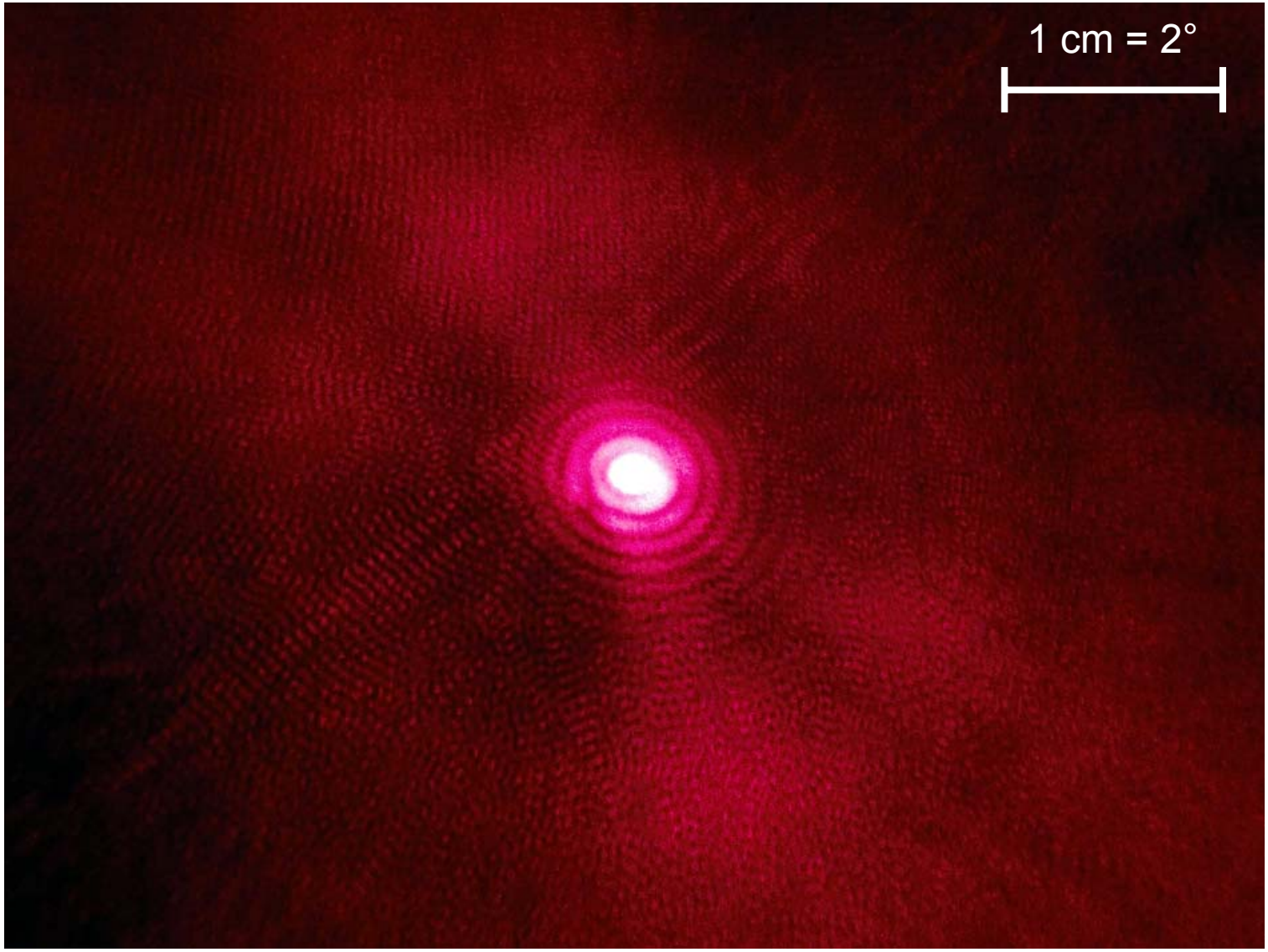


Experiment with a circular aperture

Aperture 0.25 mm without water



Aperture 1 mm with water



Summary

Conclusions

- A narrow slit with a water meniscus behave as a cylindrical biconcave lens.
- Diffraction by a slit with a meniscus is usual Fresnel diffraction.
- The same diffraction pattern can be obtained experimentally with a slit without meniscus, placing a linear light source at a short distance from the slit.

References

- Hecht E. (2002) *Optics.*
- Sharma K.K. (2006) *Optics principles and applications.*

Thank you for your attention!