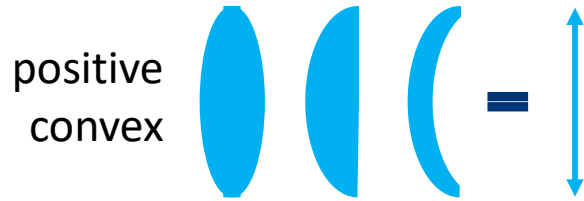




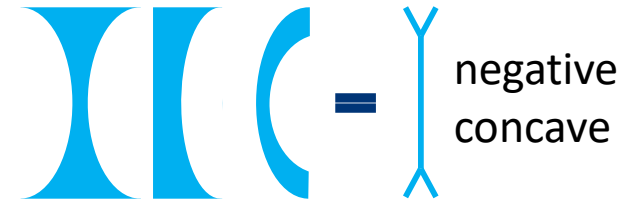
# Lenses

## Converging lenses



Thicker in the center than on the edge

## Diverging lenses



Thicker on the edge than in the center

Ray optics describes light in terms of rays – light rays are lines showing the direction of passing light.

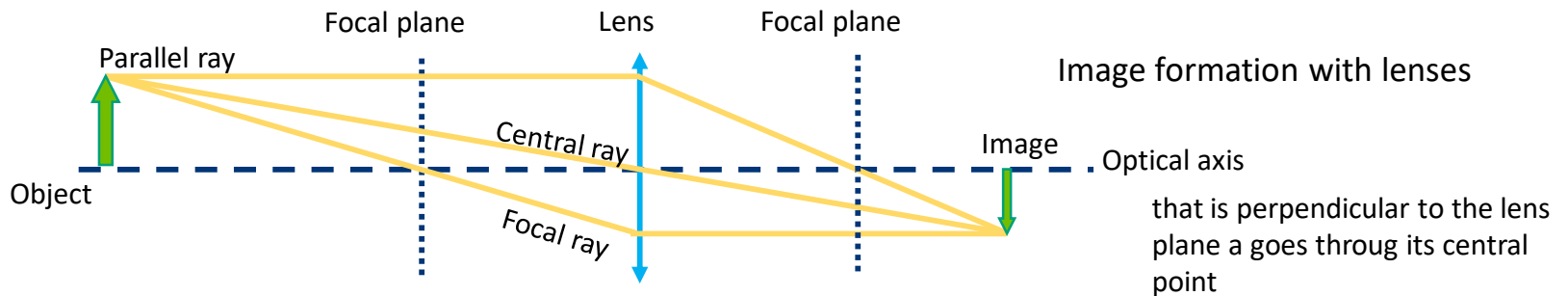
Light ray

Lenses refract the light rays.

Parallel rays passing through a positive lens converge to a focal point behind the lens.

Parallel rays passing through a negative lens diverge as if they were coming from a virtual focal point in front of it.

**Parallel rays:** all rays that are parallel to the optical axis will converge to a point behind the lens



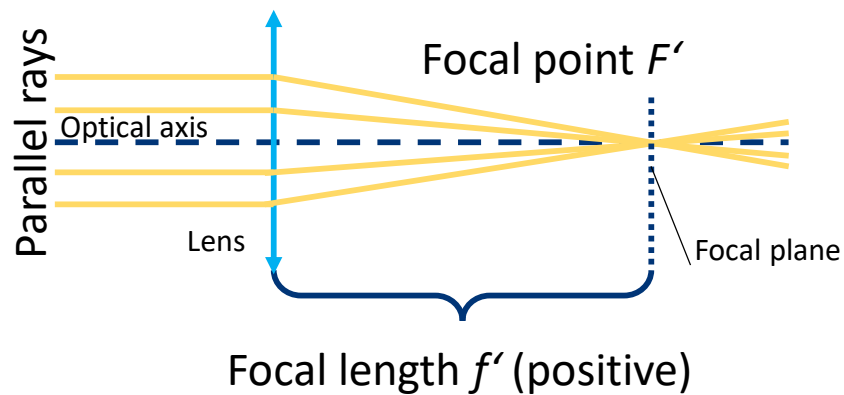
**Focal rays:** all rays that pass through the focal point will be parallel to the optical axis after passing through the lens a

**Central rays:** in an approximation, the central rays will pass the lens without being refracted





# Positive Lenses



Positive lenses refract all rays that are parallel to the optical axis to a single point, which is called focal point.

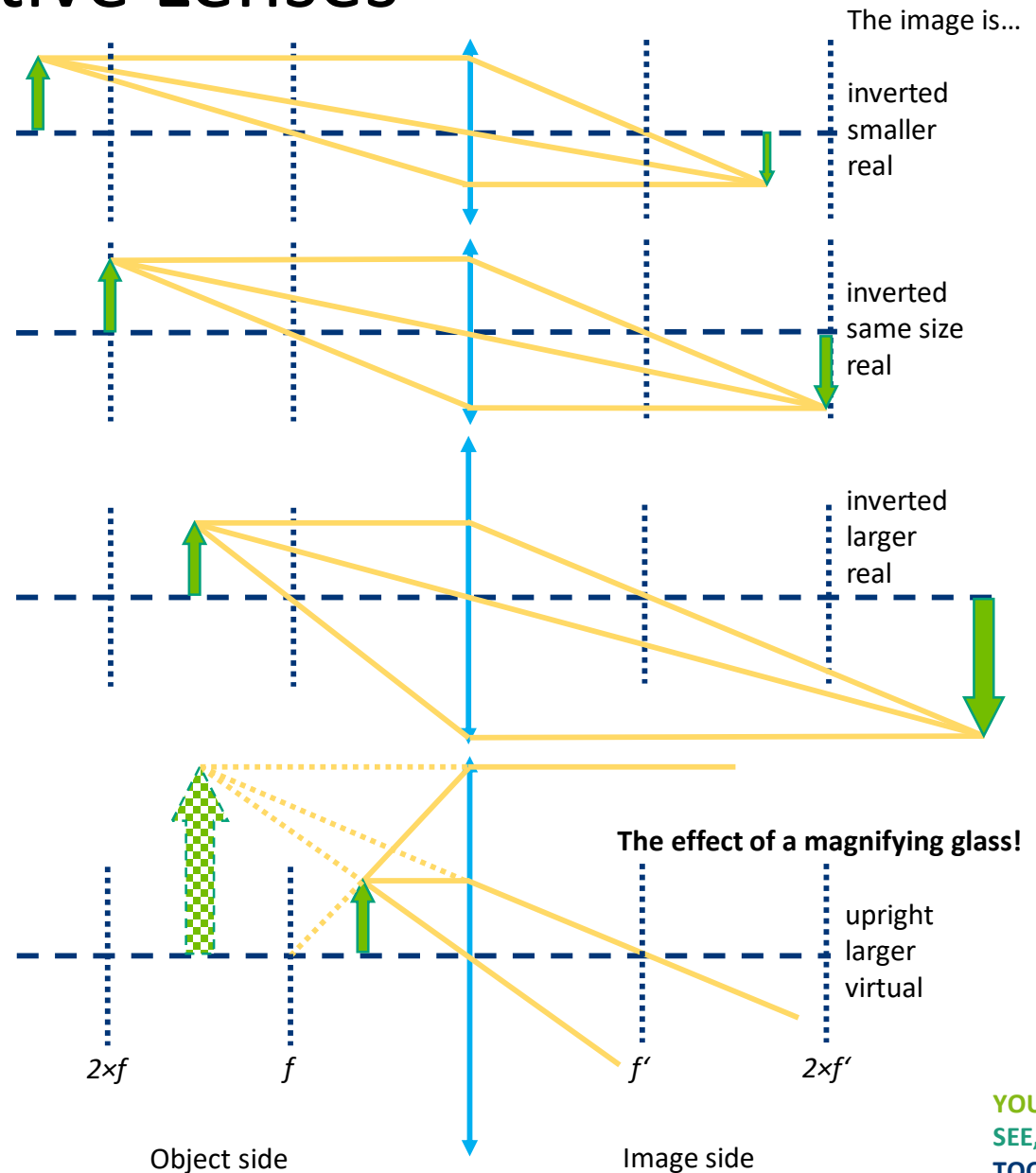
The magnifying glass, ...

Magnification of the magnifying glass

$$m = \frac{250 \text{ mm}}{f'}$$

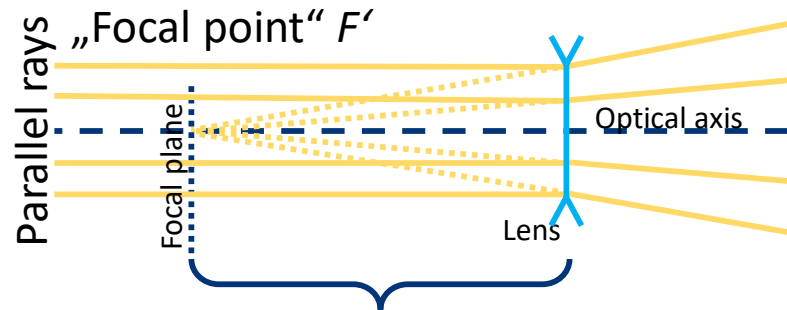


Try the lenses!



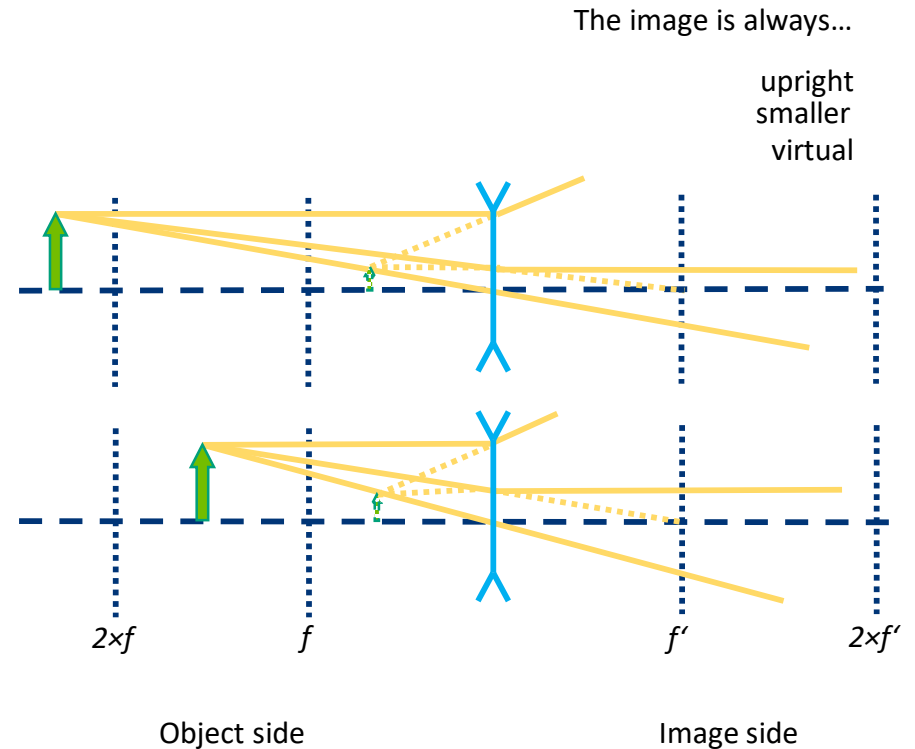


# Negative Lenses



Focal length  $f'$  (negative)

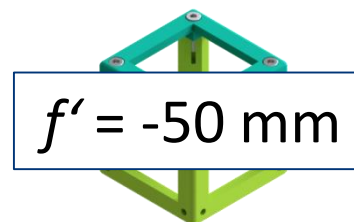
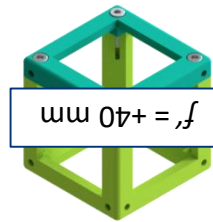
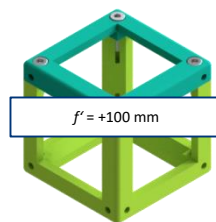
The negative lenses refract all rays of light parallel to the optical axis in such a way that it seems like they are coming from a single point in front of the lens.



Try the lenses!



How does the image look like through different lenses?



The correct text size

With the right lens held in the right distance, the text looks like it has the same size and orientation.

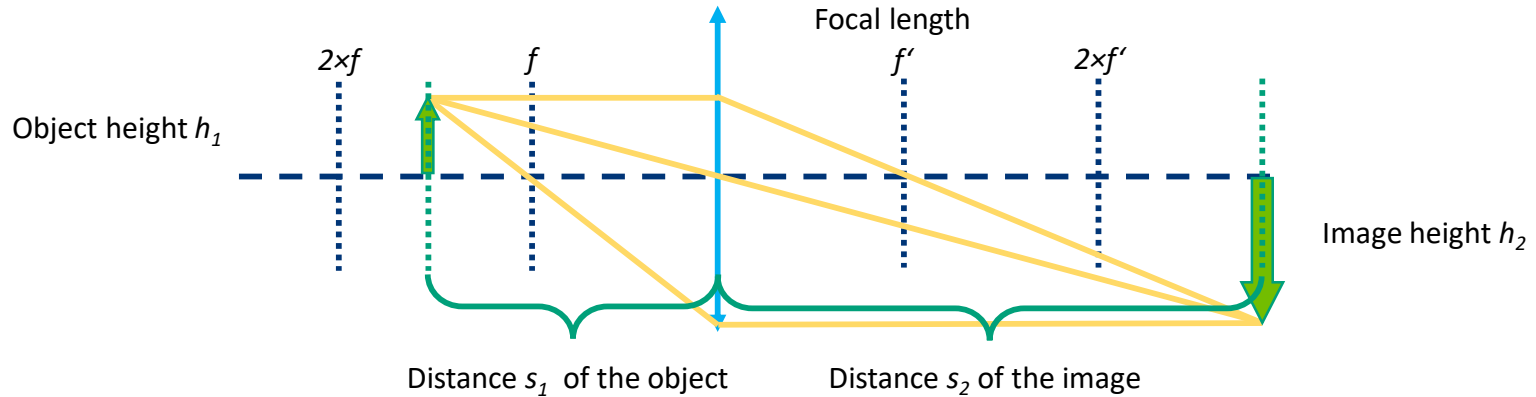


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TOO



# Projector



Lens Equation

$$\frac{1}{f'} = \frac{1}{s_1} + \frac{1}{s_2}$$

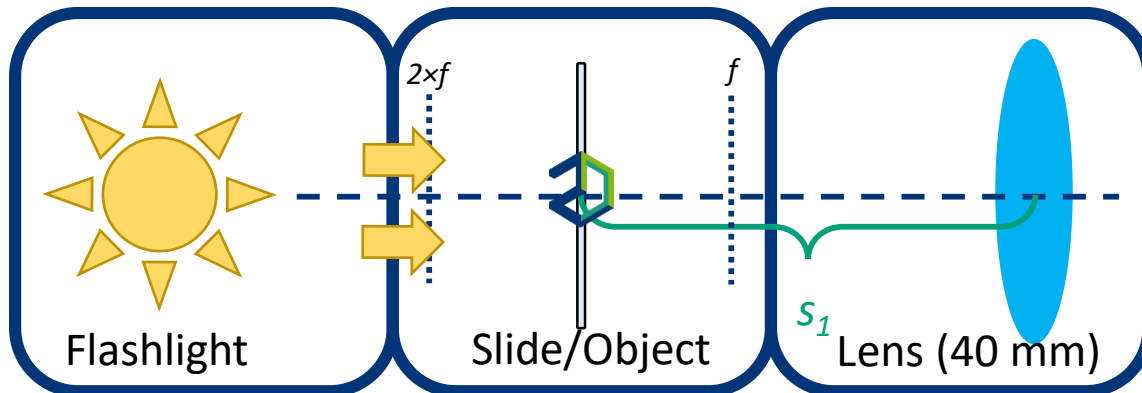
The image is not anywhere!

When imaging an object through a positive lens, the position and size of the image depend on the distance  $s_1$  of the object from the lens and its focal length  $f'$ .

Magnification of the lens

$$m = \frac{s_2}{s_1} = \frac{h_2}{h_1}$$

The image is not arbitrarily large!



Where is the image?  
What is the magnification?

- Change the distance of the lens
- Exchange the lens



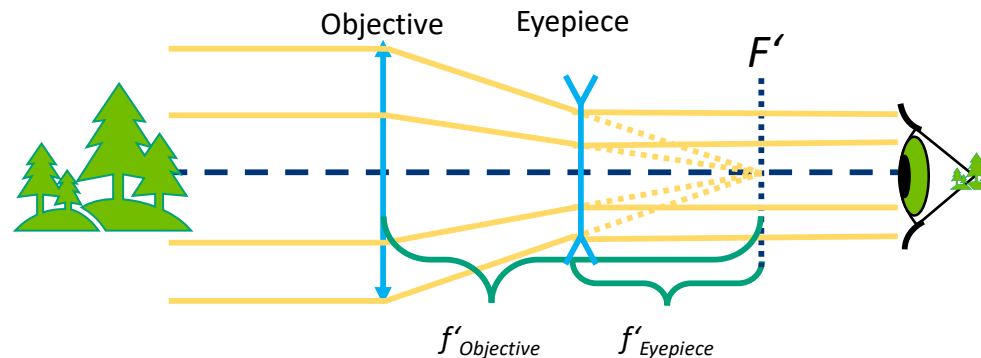


# Galileian Telescope



Magnification

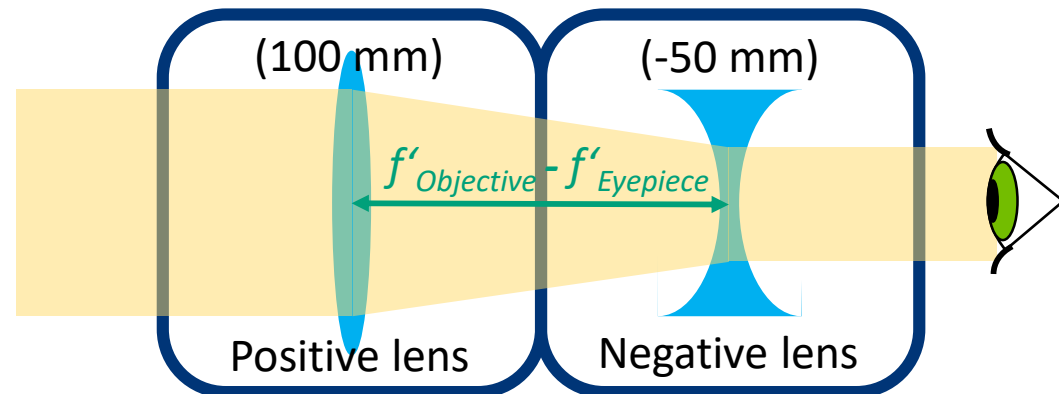
$$m = \frac{f'_{\text{Objective}}}{f'_{\text{Eyepiece}}}$$



The image is  
virtual  
and upright

The field of view (FOV) is  
small

The telescope is an optical  
instrument that magnifies  
objects, which are far away.



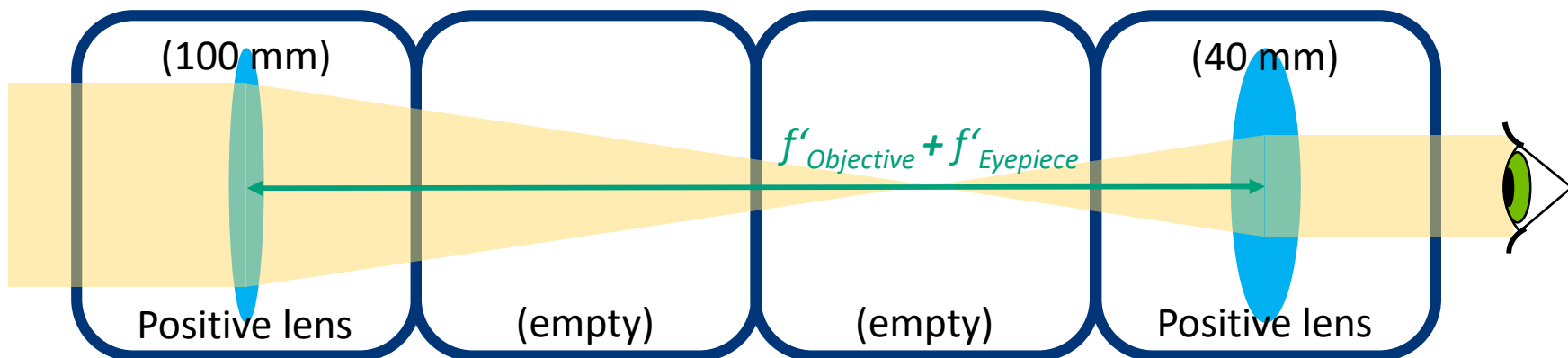
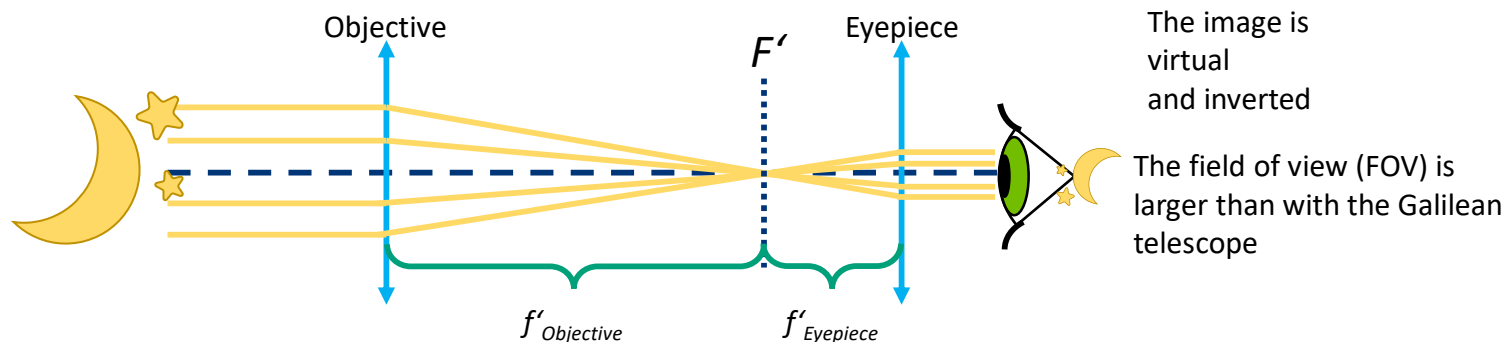


# Keplerian Telescope



Magnification

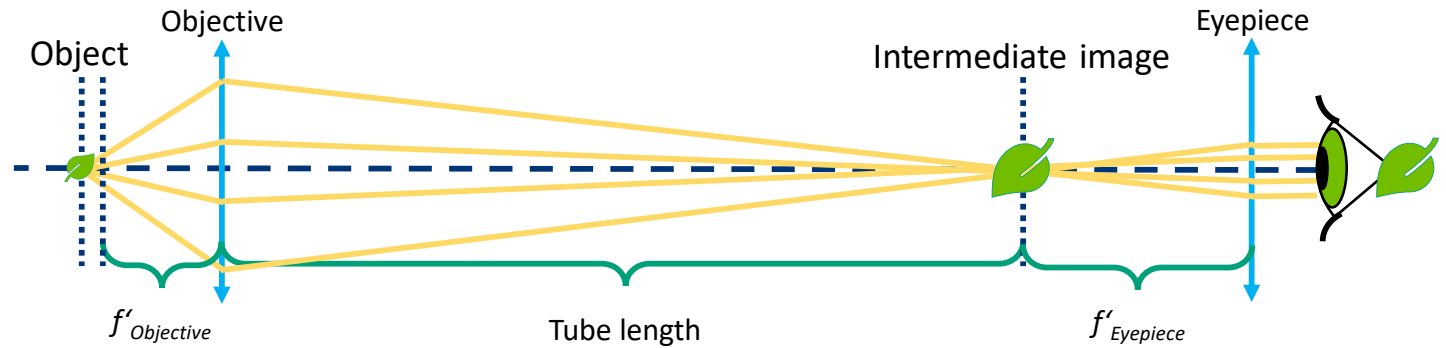
$$m = \frac{f'_{\text{Objective}}}{f'_{\text{Eyepiece}}}$$





The microscope is an optical instrument that makes it possible to see magnified images of objects that are too small to be seen by the naked eye.

# Light microscope



Old or simple microscopes use objectives that are designed for a defined tube length and they form a real intermediate image in a given distance from the objective. The intermediate image is further magnified by the eyepiece. These microscopes are „finite“ optical systems.

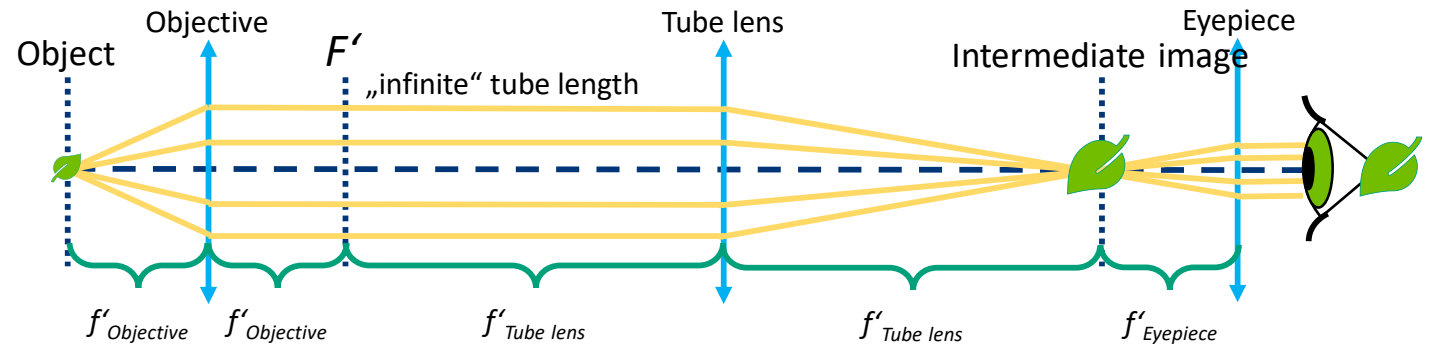
The image is...

in the intermediate image plane

inverted  
larger  
real

through the eyepiece

inverted  
larger  
virtual



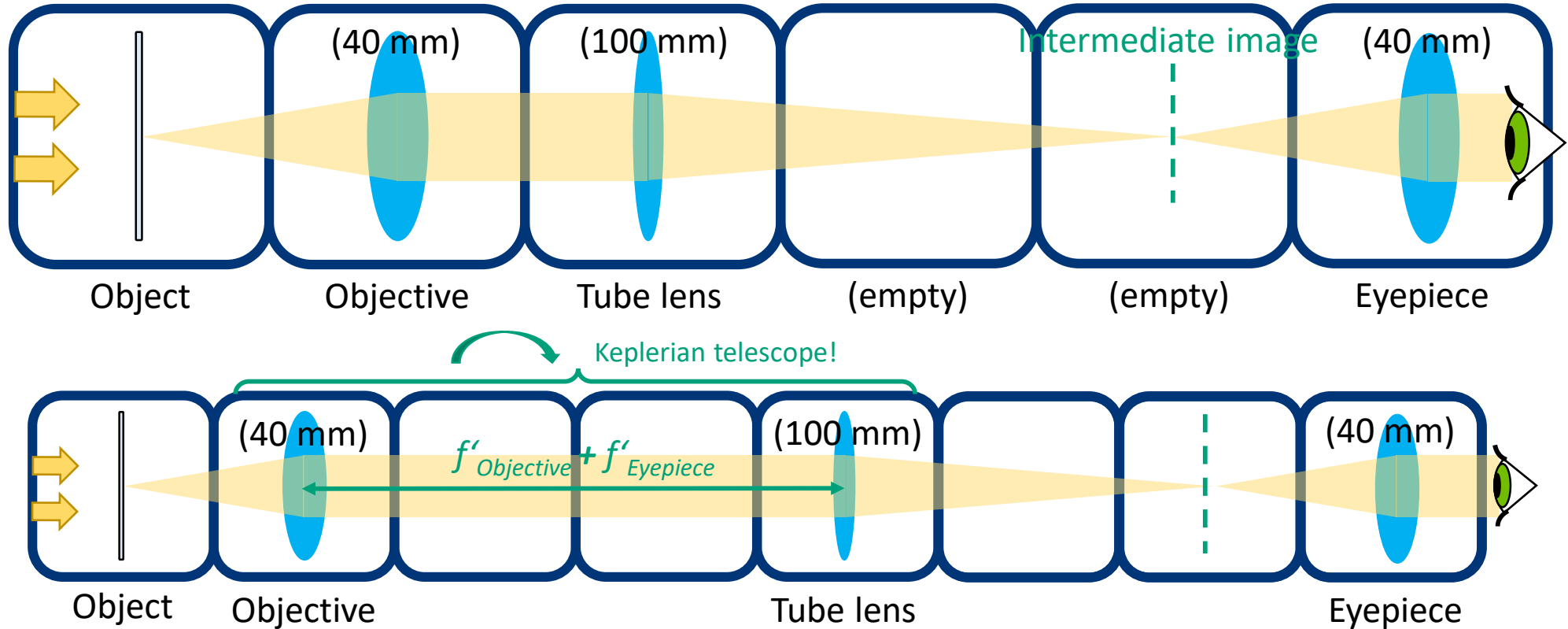
Newer microscopes use so-called „infinity“ optics. In this case, the objective doesn't form any real intermediate image. The light rays are parallel after passing through the objective. At the end of the tube, which can be arbitrarily long, is a tube lens that forms the intermediate image, which is then again further magnified by the eyepiece.





# Light microscope

„Infinity-corrected“ microscope



Magnification of the intermediate image

$$m = \frac{f'_{\text{Tube lens}}}{f'_{\text{Objective}}}$$

Total magnification

$$m = \frac{f'_{\text{Tube lens}}}{f'_{\text{Objective}}} \times \frac{250 \text{ mm}}{f'_{\text{Eyepiece}}}$$







# Smartphone Microscope

