Lenses and optical instruments

Laboratory course for students of the TUHH

Wladimir Banda-Barragán

Introduction

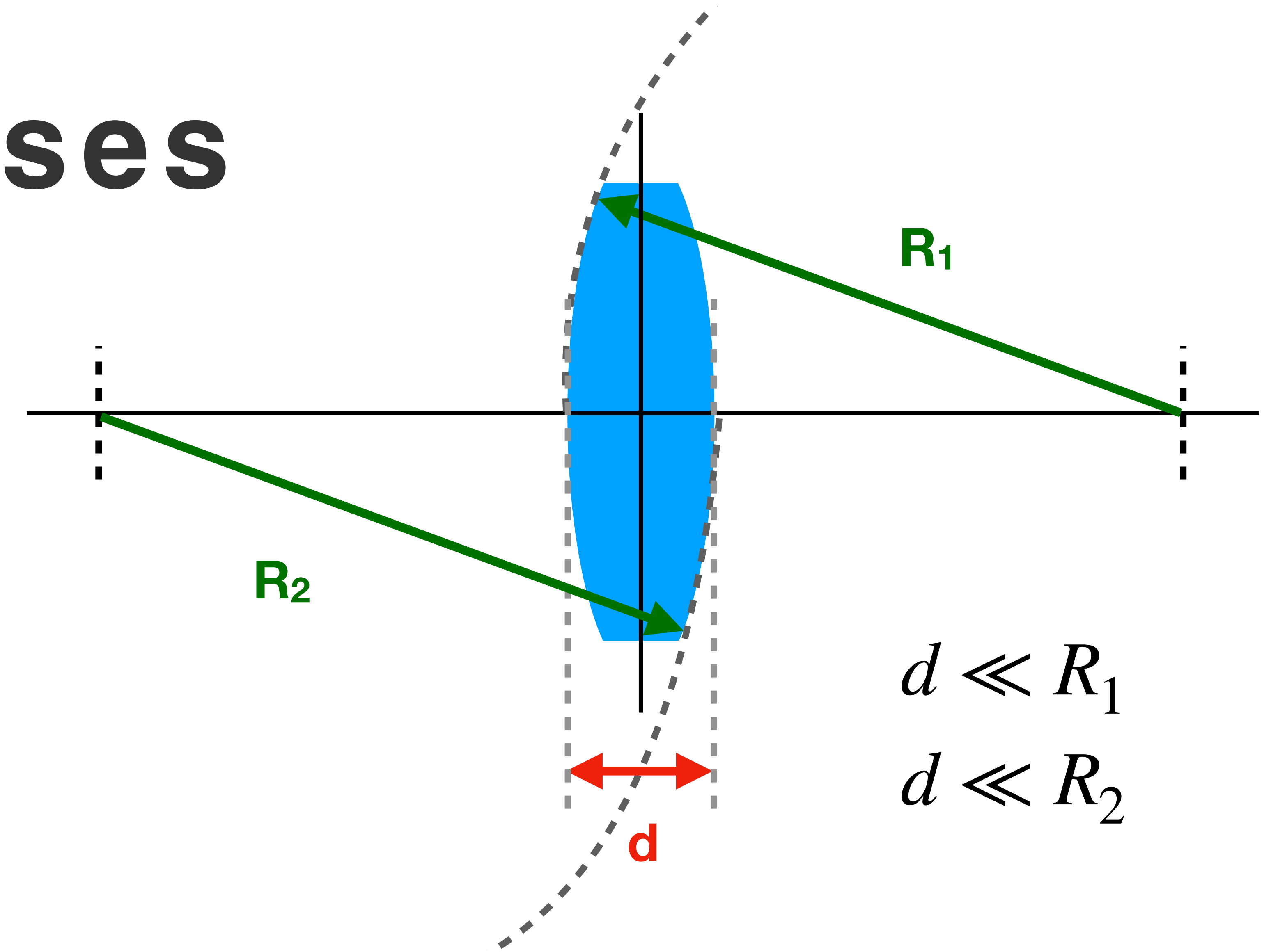
My name is Wladimir Banda-Barragán.

I will be your tutor for this laboratory session.

The class will be organised as follows:

1. Lecture with step-by-step examples (1 hour).
2. Exercises in the protocol (2.5 hours)
3. Questions and wrap-up (0.5 hours)

Thin lenses



$$d \ll R_1$$

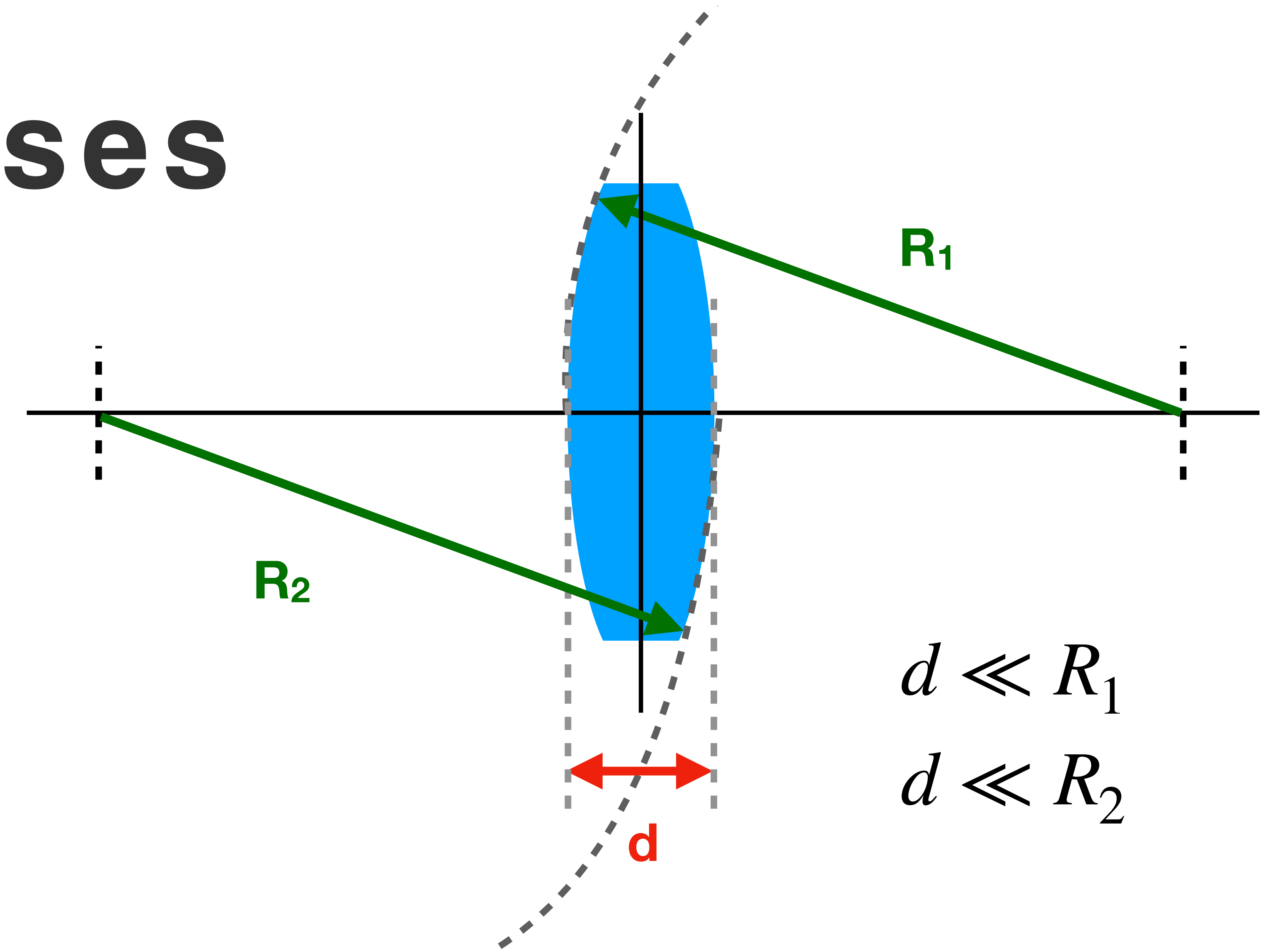
$$d \ll R_2$$

Lenses are transparent objects with aligned refracting surfaces.

Thin lenses are those with a thickness, d, that is negligible compared to the radii of curvature, $R_{1,2}$, of the lens surfaces.

Source: Wikipedia

Thin lenses



$$d \ll R_1$$

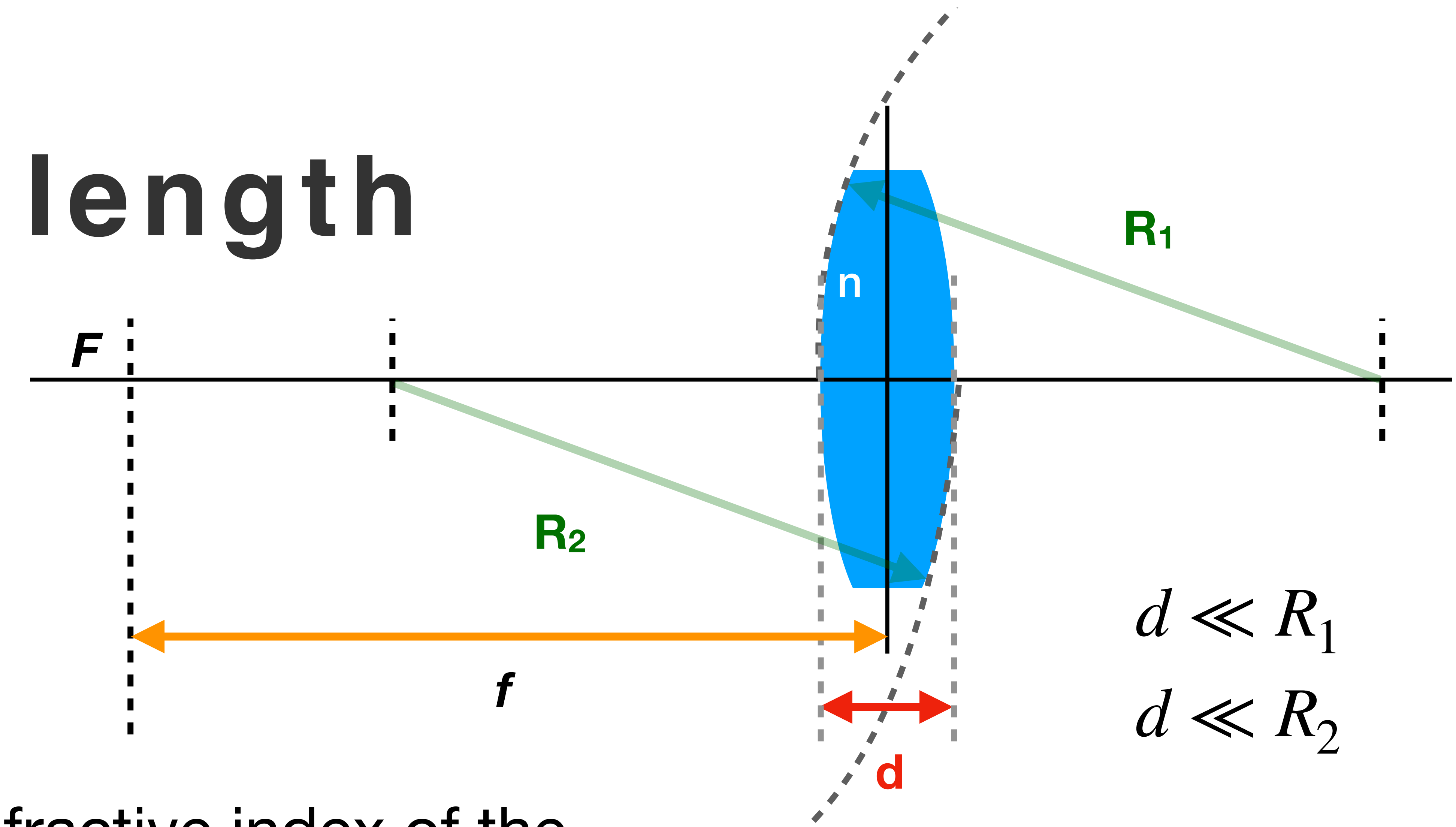
$$d \ll R_2$$

The **thin lens approximation** ignores optical effects due to the thickness of lenses and simplifies ray tracing calculations.

Lenses whose thickness is not negligible are sometimes called thick lenses.

Source: Wikipedia

Focal length



$$d \ll R_1$$
$$d \ll R_2$$

Depends on the refractive index of the lens material, n:

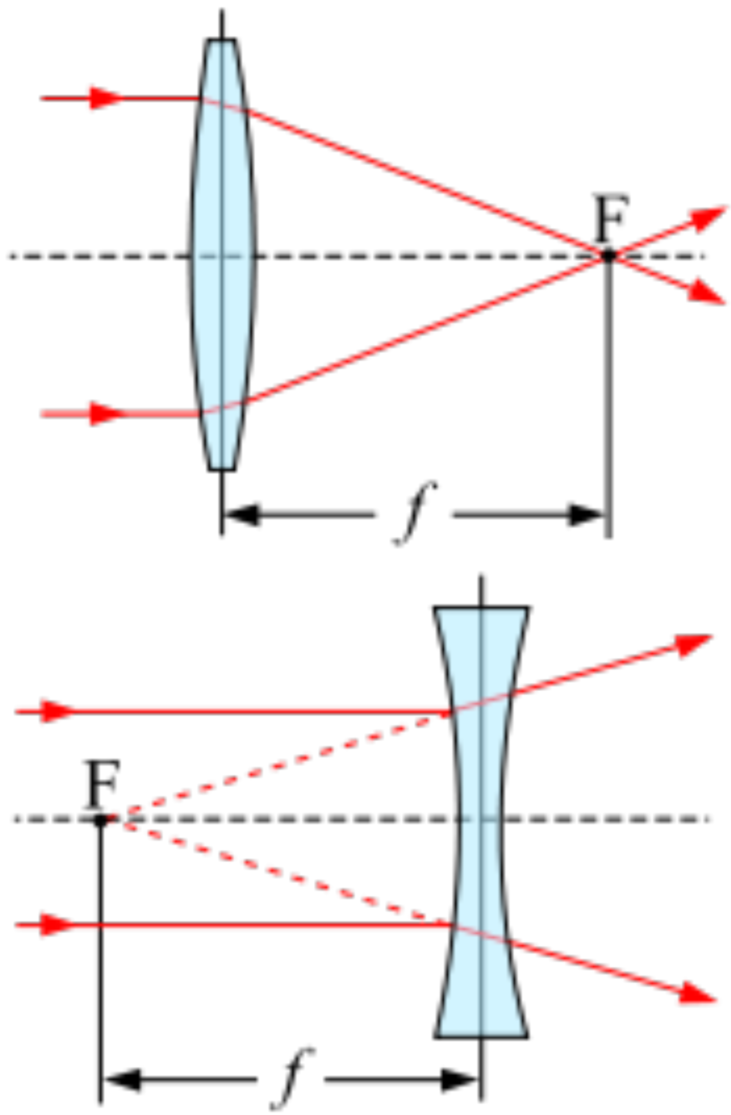
$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right]$$

In the thin lens approximation:

$$\frac{1}{f} \approx (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

Source: Wikipedia

Lenses types



For thin lenses, the focal length is the distance from the centre to the focal point.

Converging lenses (e.g. convex lenses) have positive focal lengths.

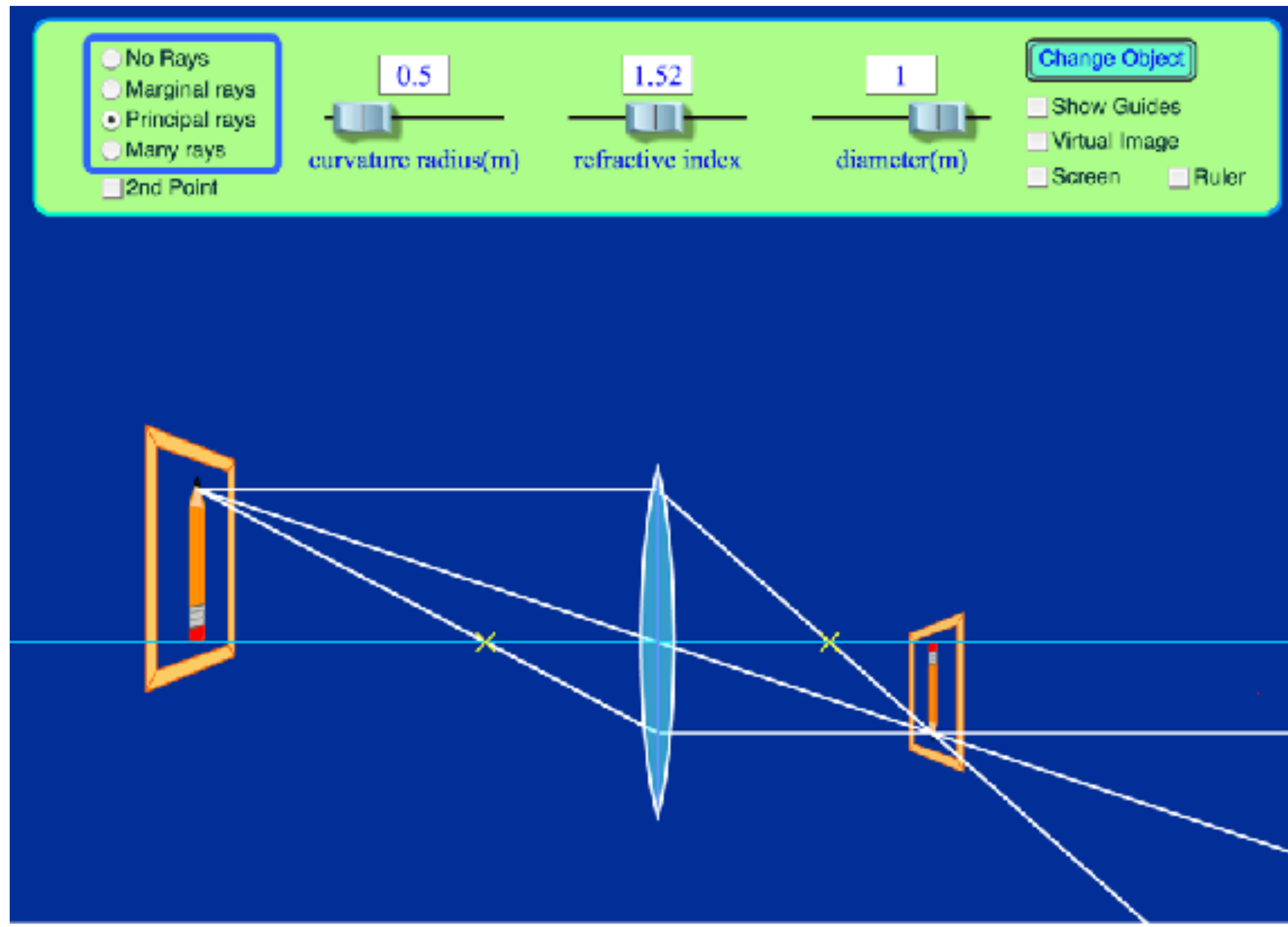
Diverging lenses (e.g. a concave lenses) have negative focal lengths.

Source: Wikipedia

Focal length: example

Let us see how "*f*" changes with "*n*"

$$\frac{1}{f} \approx (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

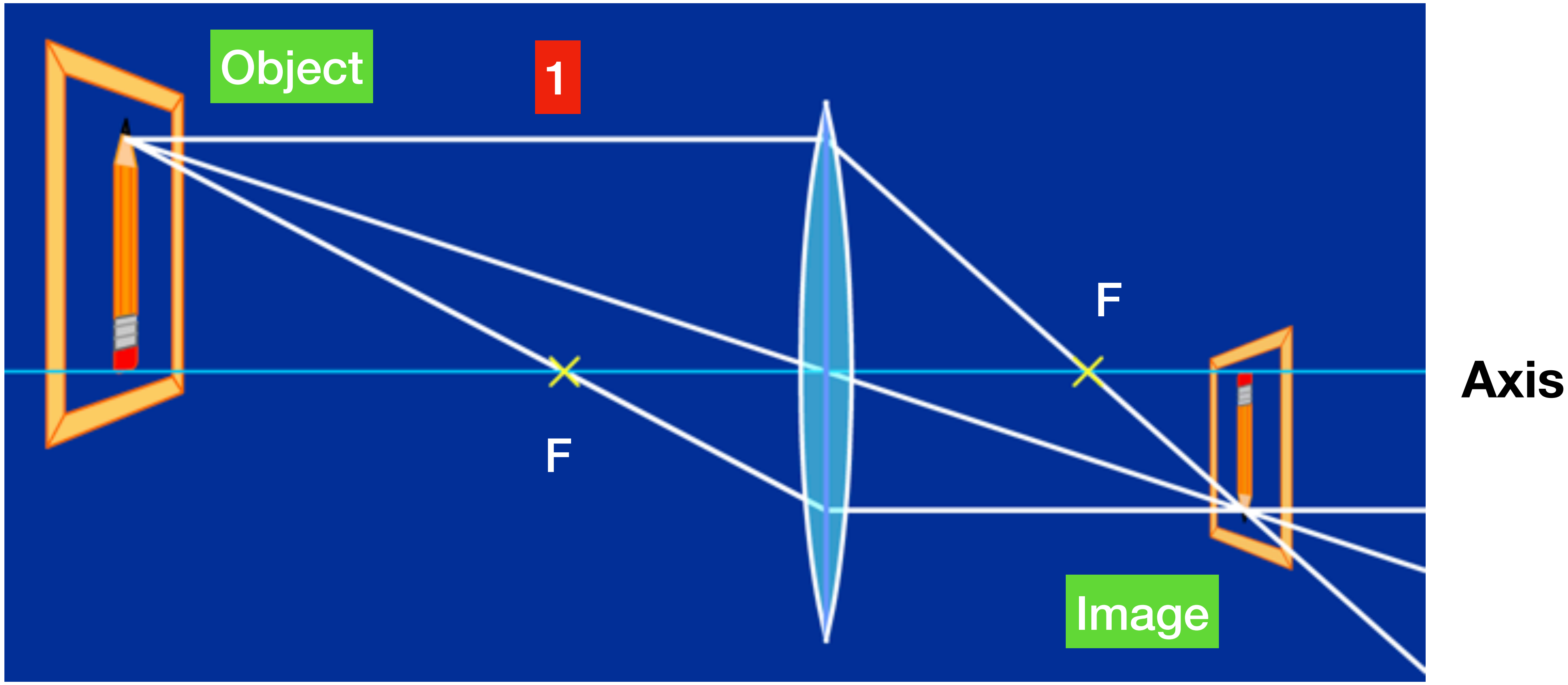


https://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html

Geometric optics

We can use the so-called principal rays:

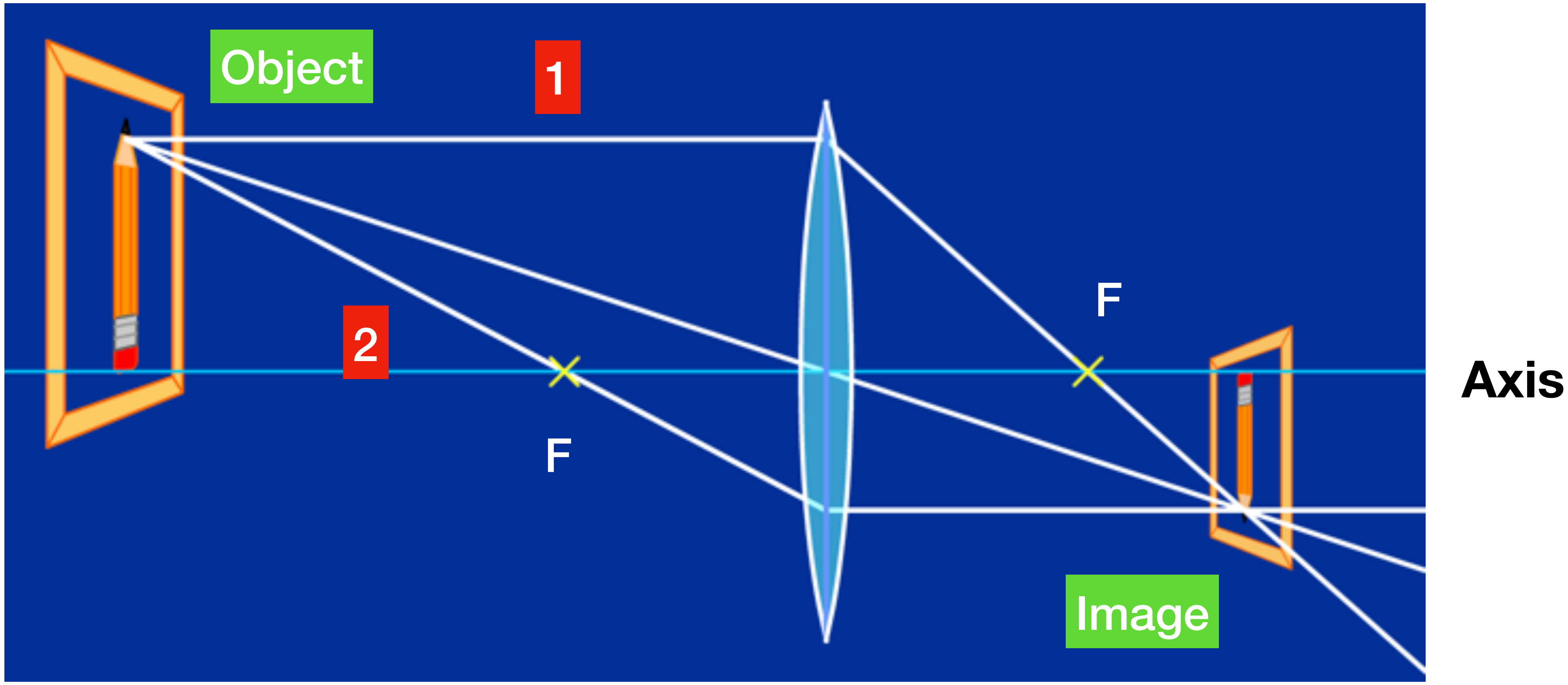
1. Any ray that enters parallel to the axis on one side of the lens proceeds towards the focal point F on the other side.



Sources: Wikipedia & https://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html

Geometric optics

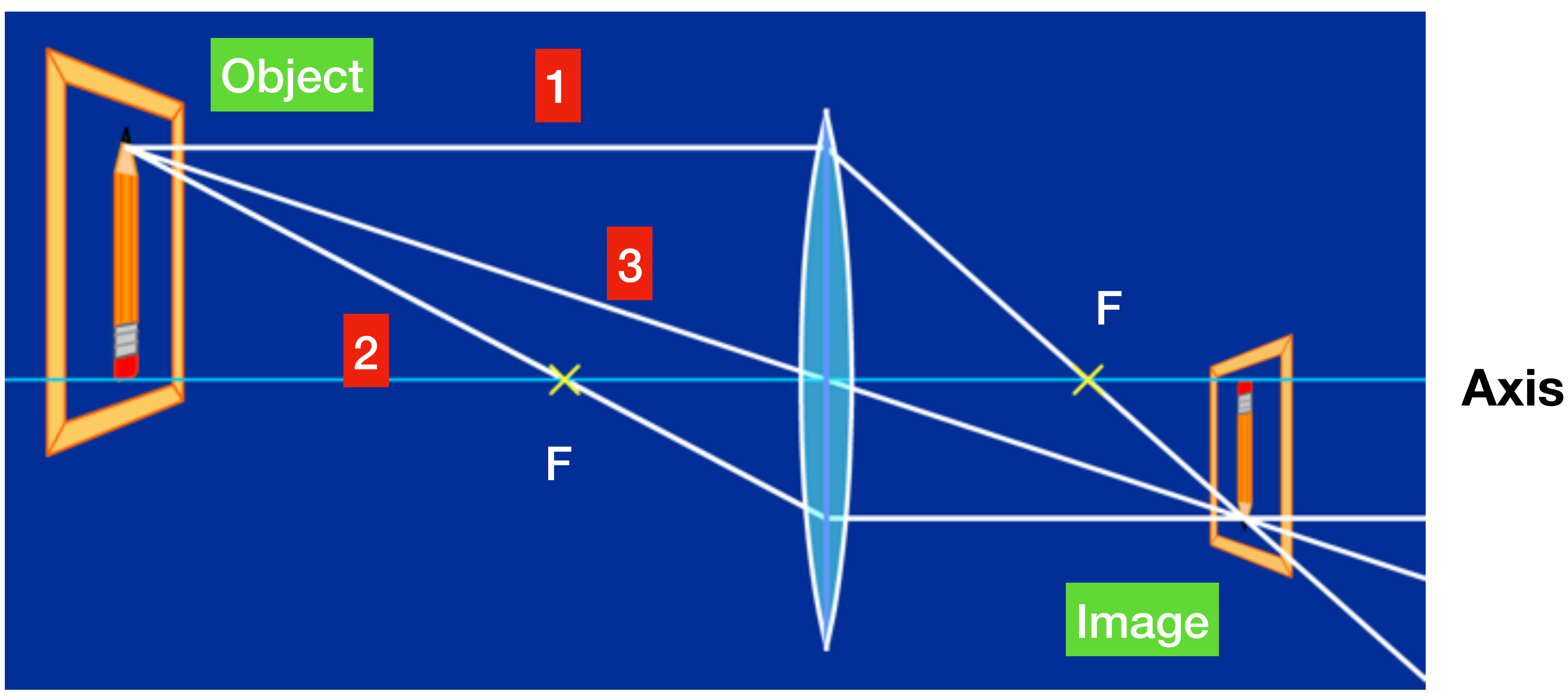
2. Any ray that arrives at the lens after passing through the focal point on the front side, comes out parallel to the axis on the other side.



Sources: Wikipedia & https://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html

Geometric optics

3. Any ray that passes through the centre of the lens will not change its direction.

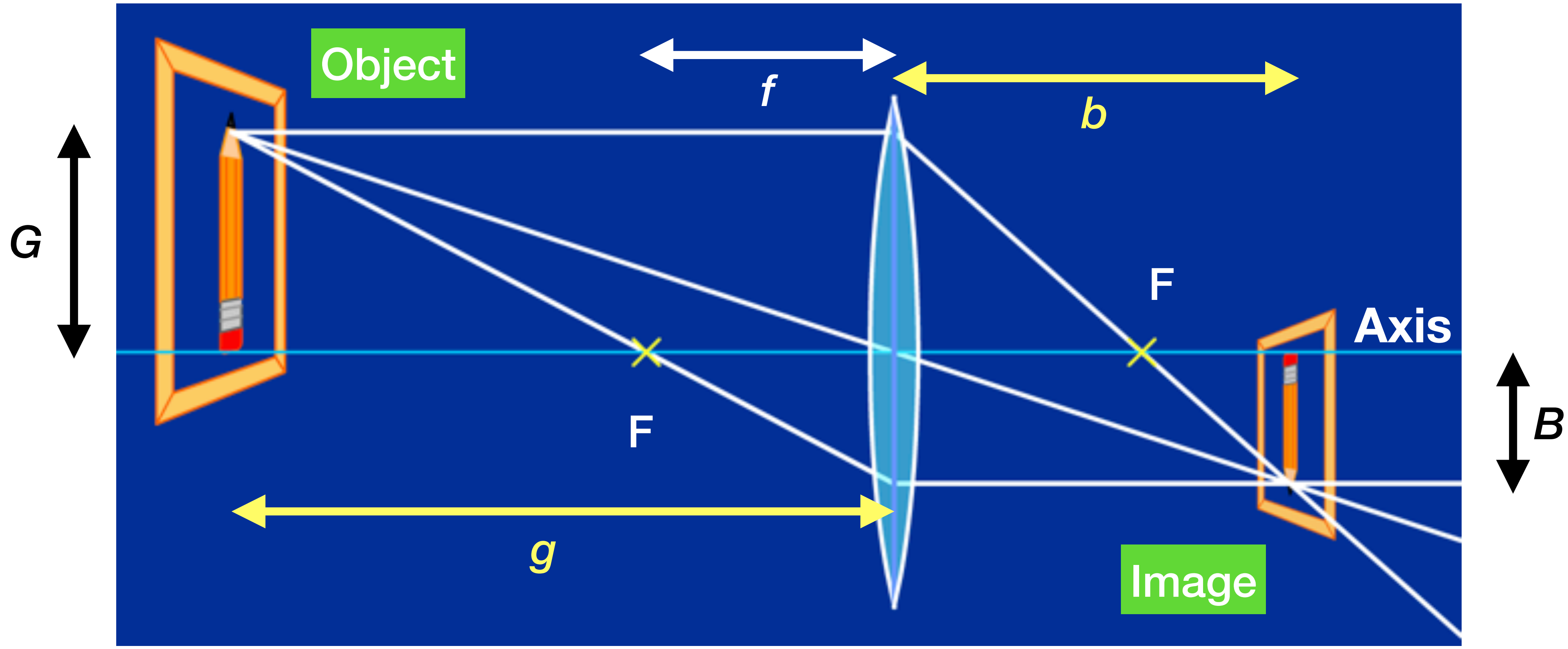


Sources: Wikipedia & https://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html

Lens laws

We can trace these rays 1, 2, and 3.

The focal length *f*, the object distance *g,* and the image distance *b* determine the ratio of the image height B to the object height G.



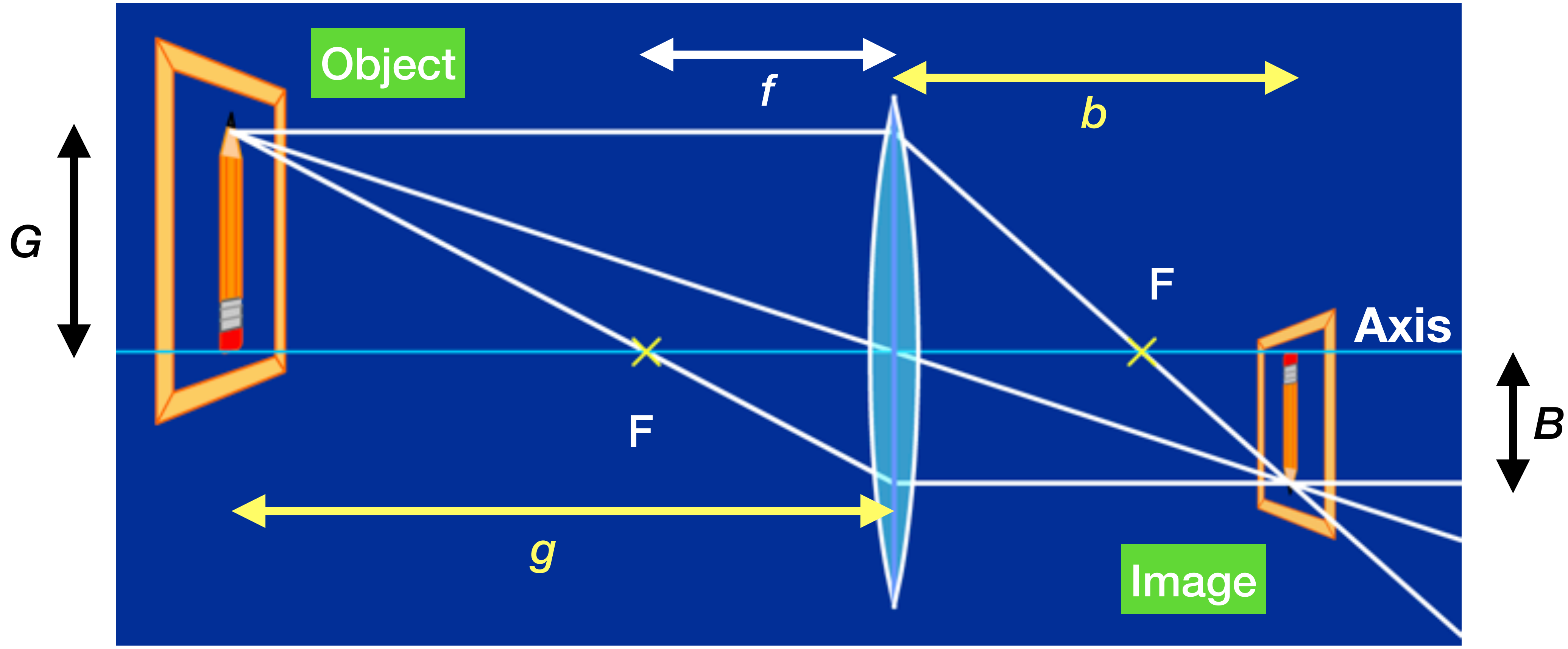
Sources: Wikipedia & https://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html

Lens laws

Using geometry, we obtain the lens equation for thin lenses

$$\frac{B}{G} = \frac{b}{g} \quad \text{and} \quad \frac{G}{B} = \frac{f}{b-f} \qquad (1)$$

$$\frac{1}{f} = \frac{1}{b} + \frac{1}{g} \quad \text{or} \quad f = \frac{b.g}{b+g} \qquad (2)$$



Sources: Wikipedia & https://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html

Images

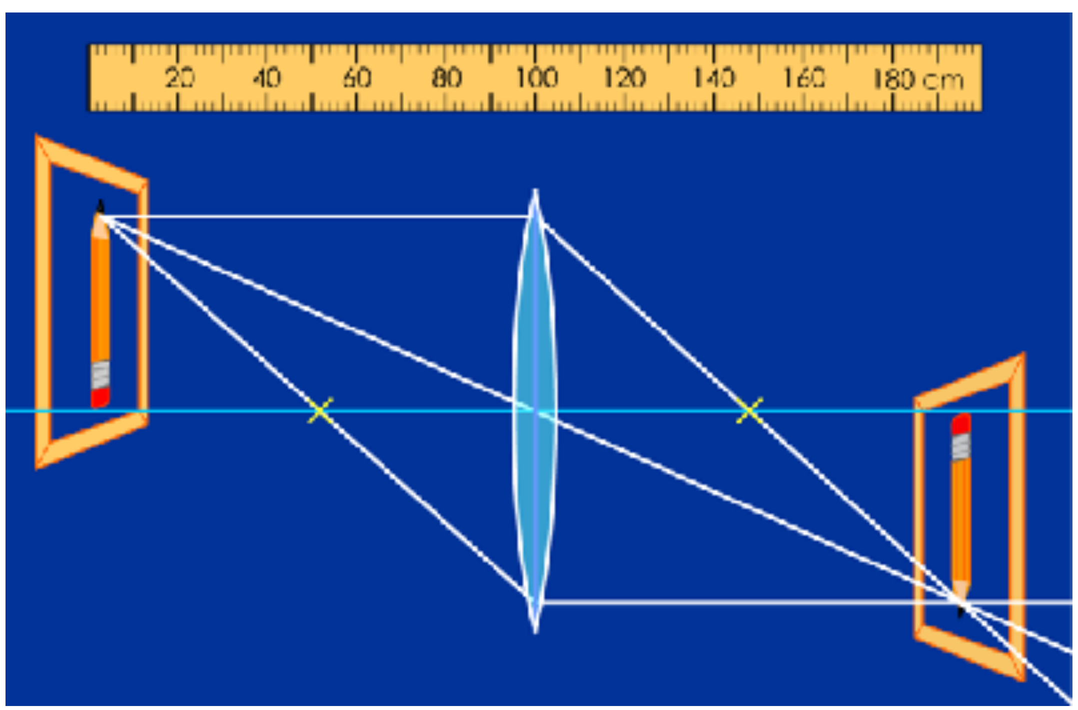
The imaging behaviour of the lens depends on whether the object is located outside the focal point, at the focal point, or inside the focal point, as shown in this table:

Object	**Image**			
Position *g*	**Type**	**Position**	**Orientation**	**Relative size**
∞	real	$b = f$	-/-	point
$\infty > g > 2f$	real	$f < b < 2f$	inverted	demagnified
$g = 2f$	real	$b = 2f$	inverted	equal size
$f < g < 2f$	real	$\infty > b > 2f$	inverted	magnified
$g = f$		∞		
$g < f$	virtual	$\lvert b \rvert > g$	upright	magnified

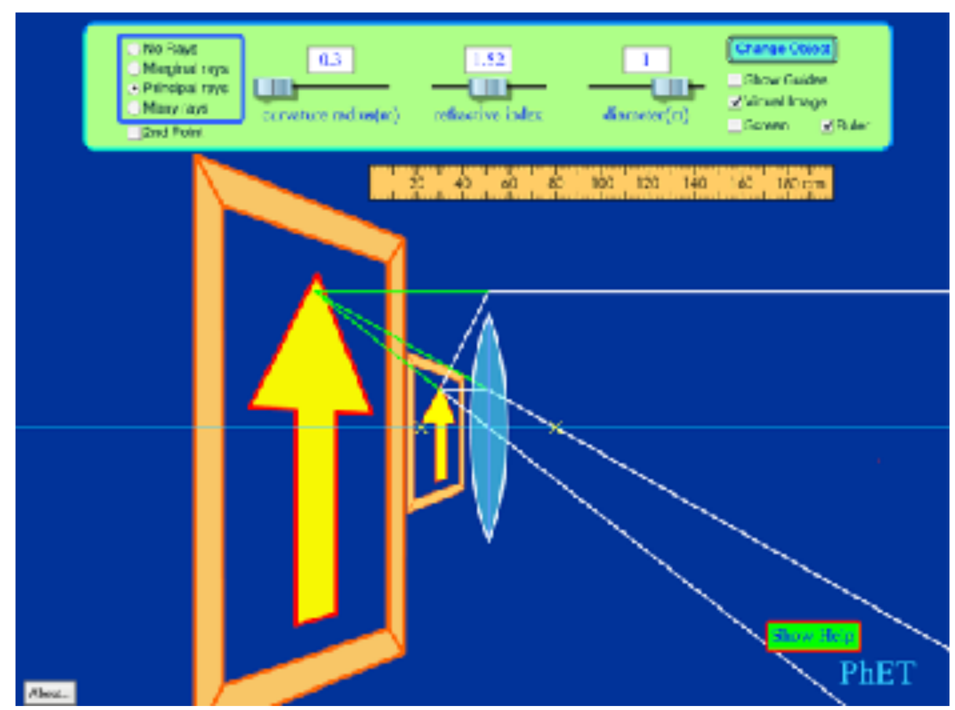
Images

Object	Image			
Position g	Type	Position	Orientation	Relative size
∞	real	b = f	-/-	point
$\infty > g > 2f$	real	f < b < 2f	inverted	demagnified
$g = 2f$	real	b = 2f	inverted	equal size
$f < g < 2f$	real	∞ > b > 2f	inverted	magnified
$g = f$		∞		
$g < f$	virtual	lbl > g	upright	magnified

$g = 2f$

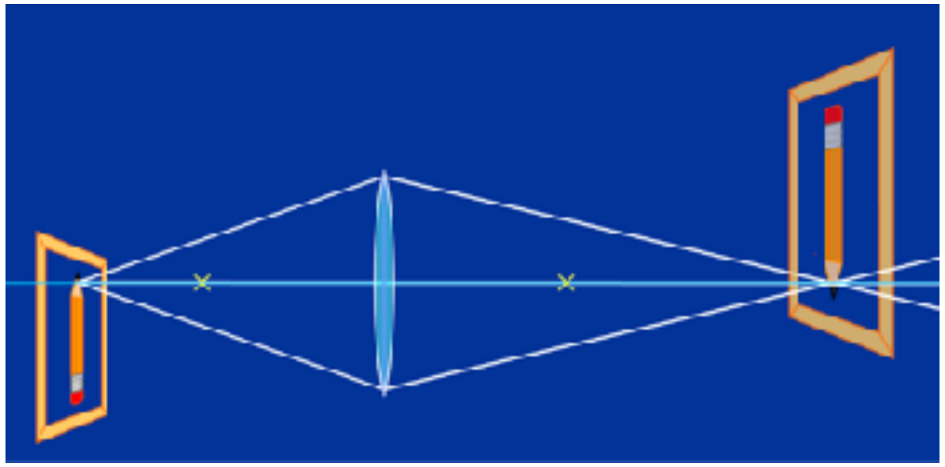


$g < f$

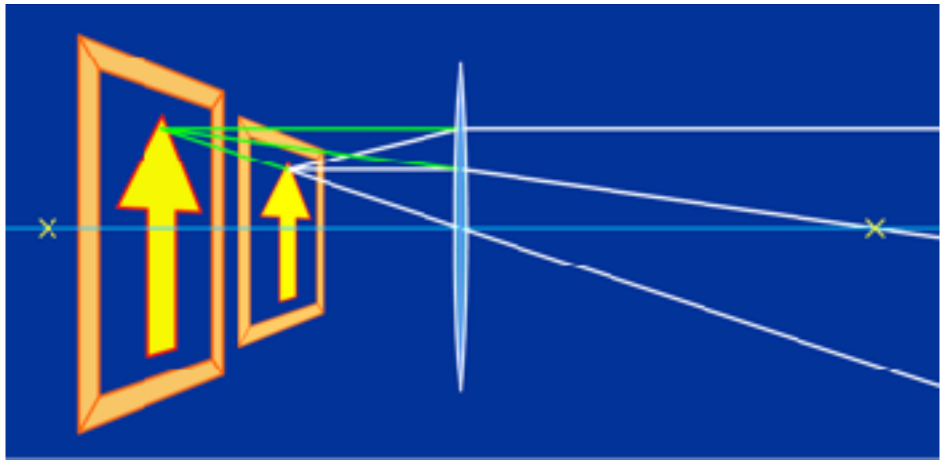


Real and virtual images

Real images are those where light actually converges



Virtual images are locations from where light appears to have converged.



Source: https://web.pa.msu.edu/courses/2000fall/PHY232/lectures/lenses/images.html