Optics

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Questions about Light

- What is light?
  - Four theories
- How is light created?
  - Hot matter emits light (Sun is an example.)
  - Accelerating charge produces light.
- How does light die?
  - Light gets absorbed by opaque materials.
- What does light do while it is living?
  - It travels in a straight line.
  - It interacts with matter.
  - It reflects off of metals.
  - It refracts into transparent materials.
  - It interferes and diffracts.

Four theories of light

- Light is a ray
  - Geometrical Optics
- Light is a wave (Young, 1803)
  - Wave Optics
- Light is an electromagnetic wave (Maxwell, 1865)
  - Classical Electromagnetic Theory (EM Theory)
- Light is a quantum field
  - Photon Theory (starting with Planck and Einstein, 1900–1905)
  - QED (Quantum Electrodynamics, 1949)

Light in vacuum

- Light travels at 3×10^8 m/s in vacuum
- More precisely, light travels at exactly 299,792,458 m/s in vacuum, because the meter is defined to be the distance that light travels in $\frac{1}{299792458}$ s.

$$c = 299,792,458 \text{ m/s} \approx 3 \times 10^8 \text{ m/s}$$

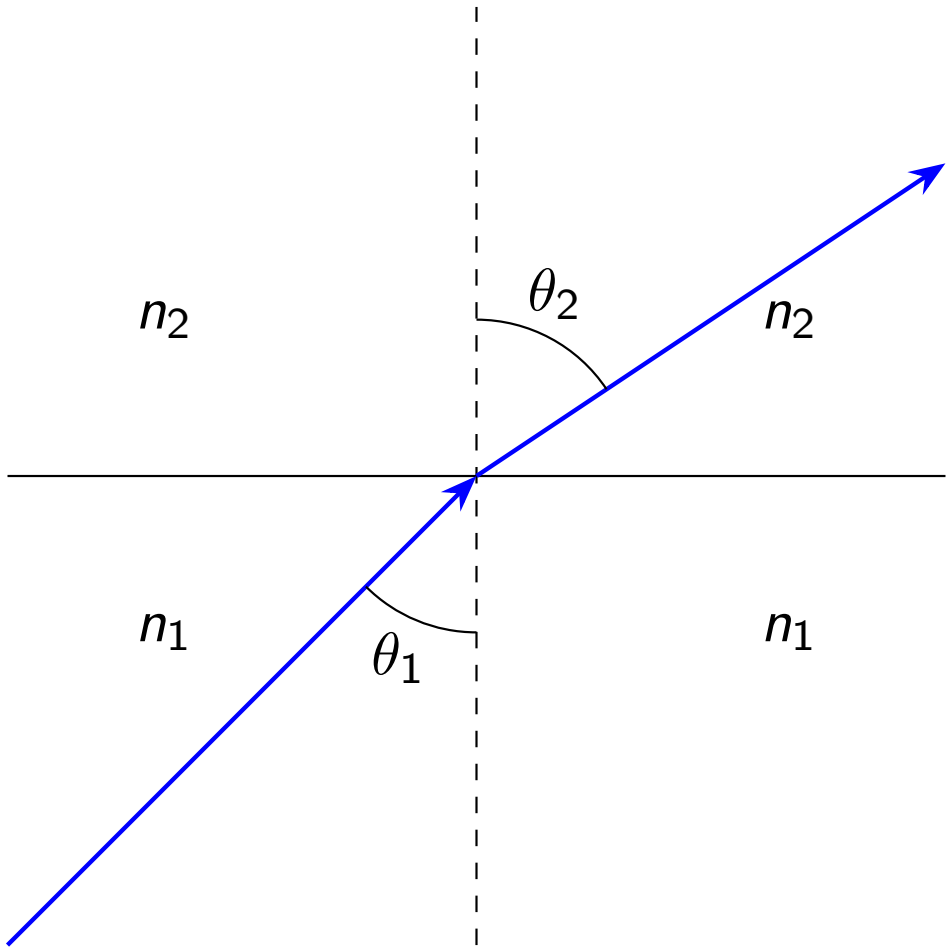
Light in transparent materials

- Light can travel in transparent materials, like water or glass, but it does so more slowly than in vacuum.
- The slowdown factor is called the *index of refraction* n of the material.

$$n = \frac{c}{v} \qquad\qquad v = \frac{c}{n}$$

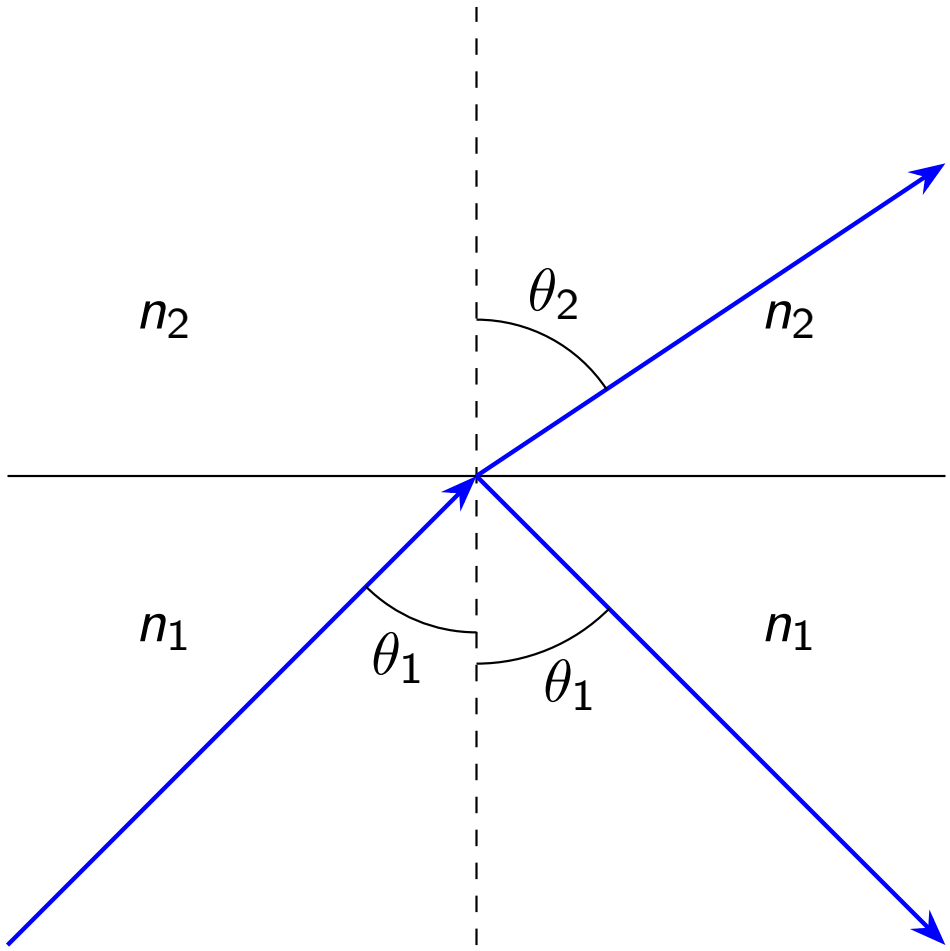
Medium	Index of refraction, n
Vacuum	1.0000
Air (at STP)	1.0003
Water	1.33
Lucite	1.51
Crown glass	1.52

Snell's law describes refraction



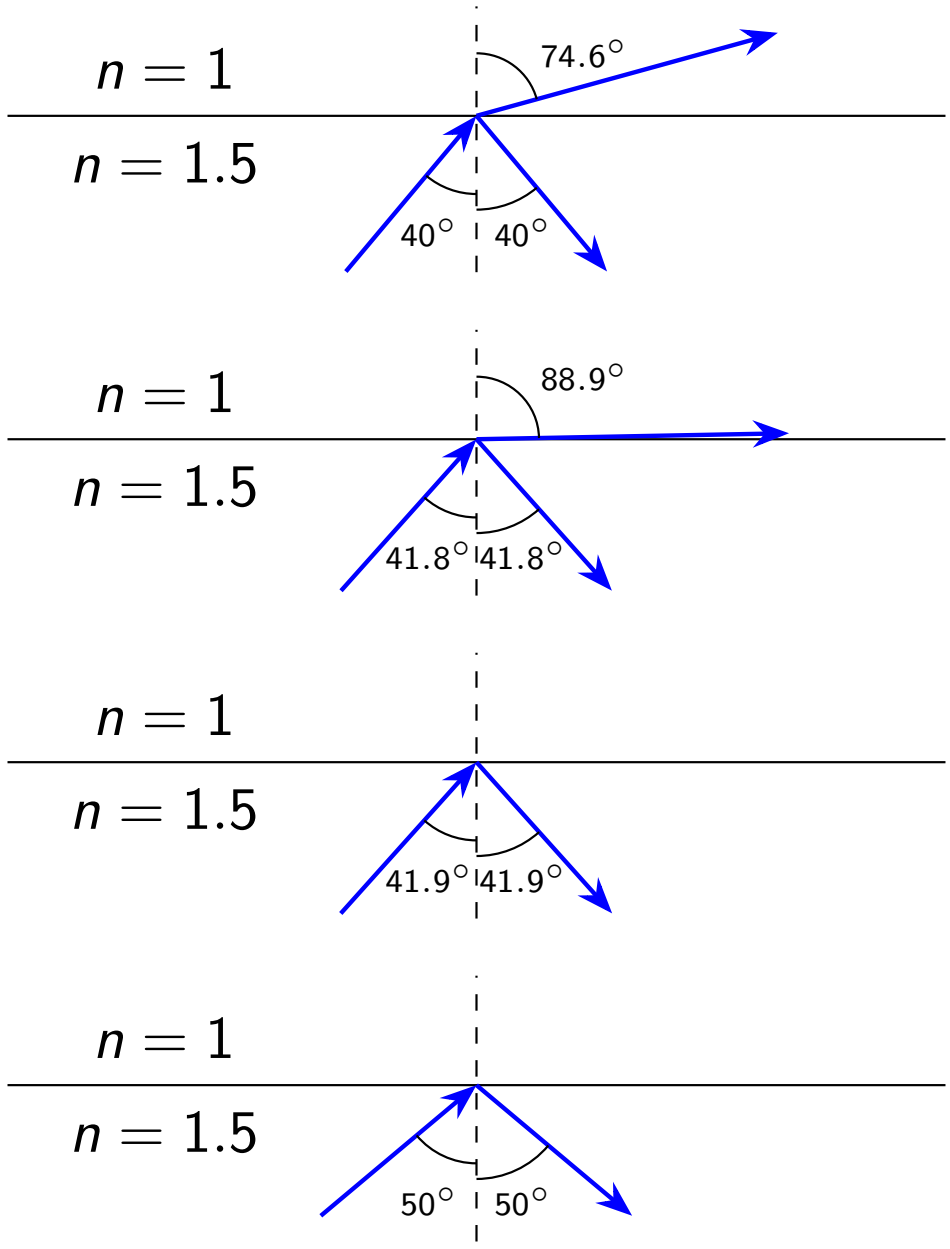
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

At a surface, light refracts and reflects.



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Total internal reflection: when there is no refracted ray.



The critical angle is the angle at which the refracted ray disappears.

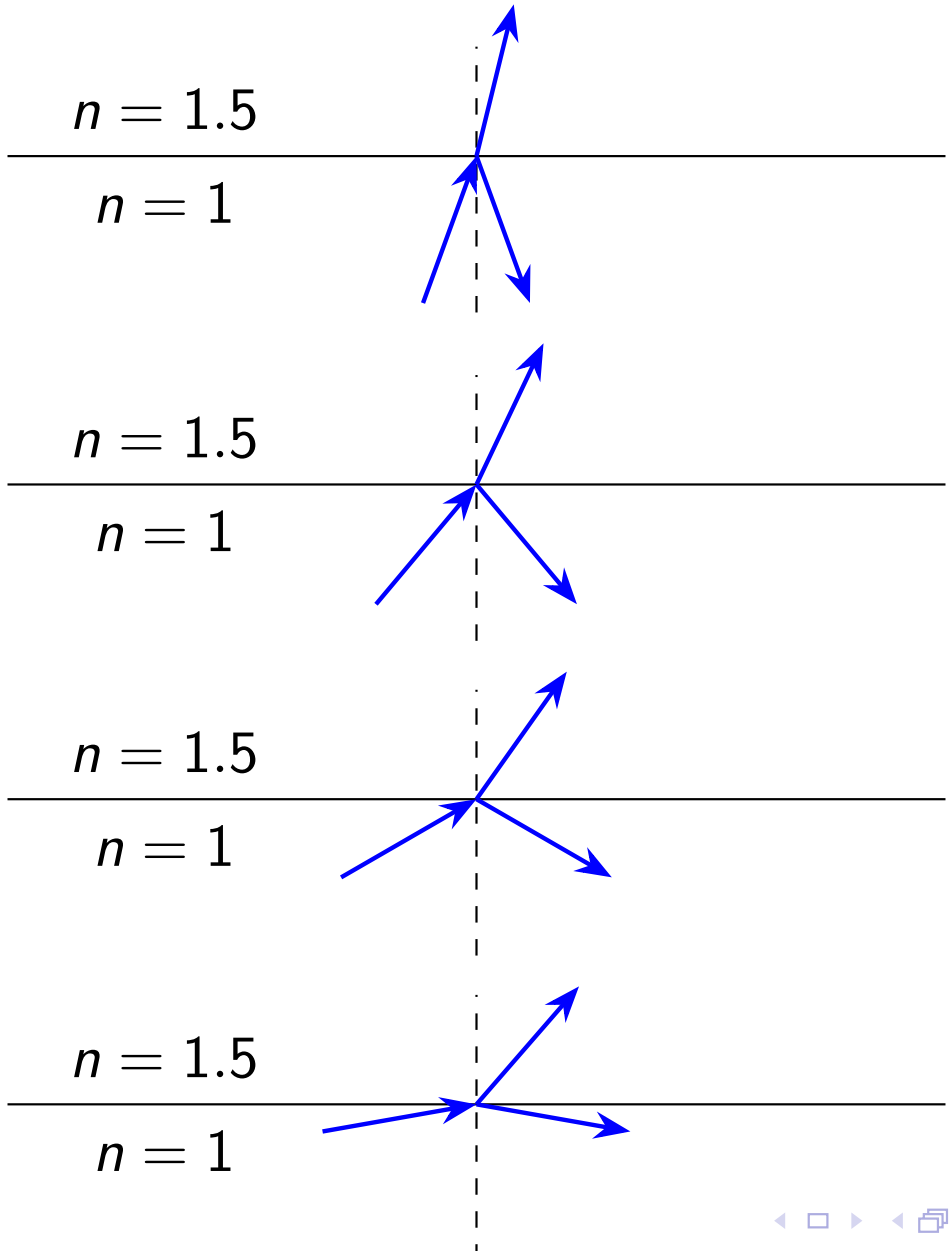
- With light starting in the higher-index material 1 (so $n_1 > n_2$), the critical angle is given by

$$\sin\theta_C = \frac{n_2}{n_1}$$

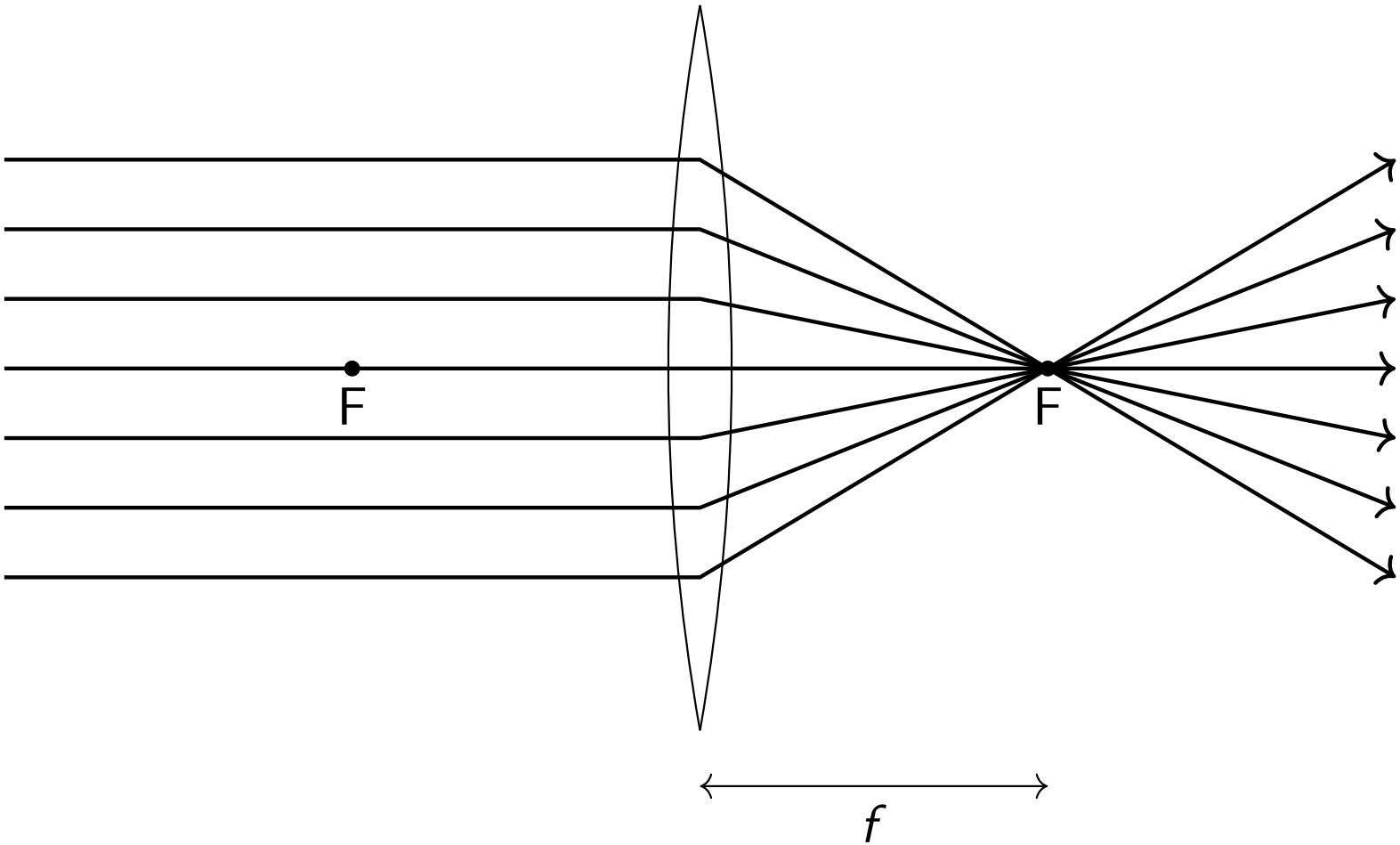
- If $n_1 = 1.5$ and $n_2 = 1$,

$$\theta_C = \sin^{-1}\left(\frac{1}{1.5}\right) = 41.81^\circ$$

You'll never get total internal reflection by starting in the low-index material.



A *converging lens* makes parallel rays converge.

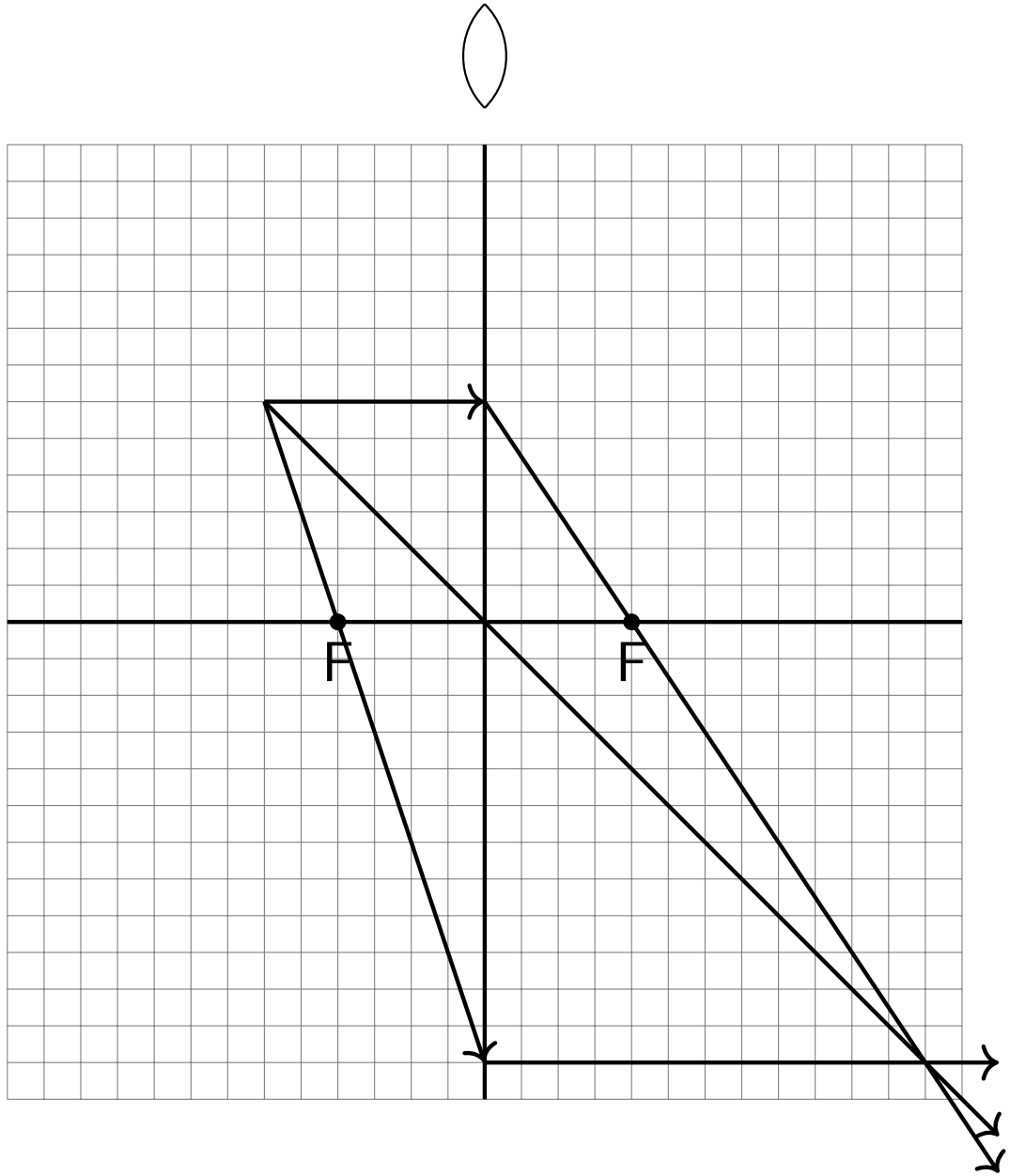


Ray Tracing Rules

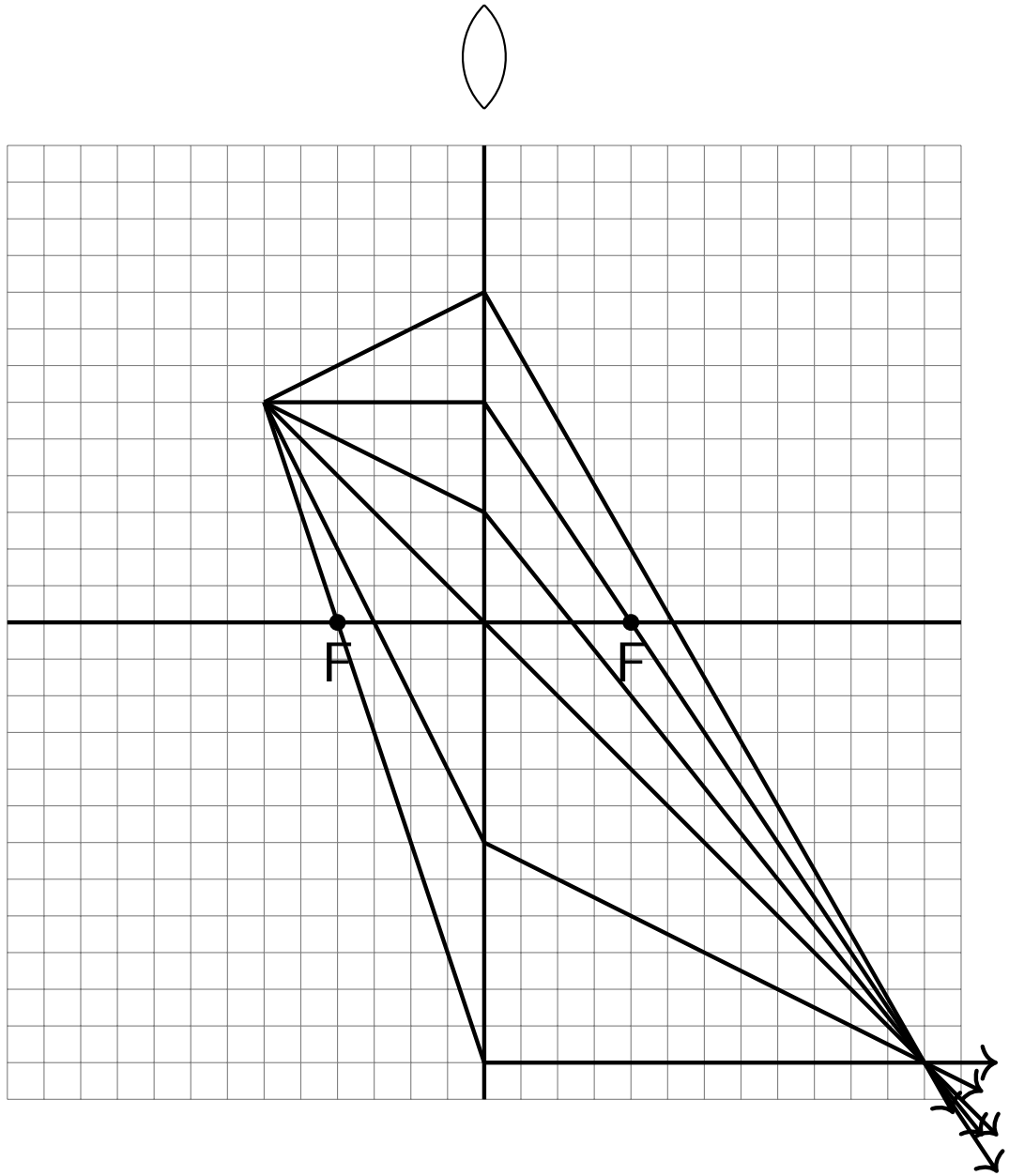
- Rule 1: A incoming parallel ray will exit
  - through the right-side focal point (for a converging lens)
  - away from the left-side focal point (for a diverging lens)
  - through the (left-side) focal point (for concave mirror)
  - away from the (right-side) focal point (for a convex mirror)
- Rule 2: A ray through the lens center goes straight. A ray through the mirror center bounces back the way it came.
- Rule 3: A incoming ray
  - through the left-side focal point (for a converging lens)
  - toward the right-side focal point (for a diverging lens)
  - through the (left-side) focal point (for concave mirror)
  - toward the (right-side) focal point (for a convex mirror)

  will exit parallel.

Converging lens, object outside focal point



Converging lens, object outside focal point, more rays

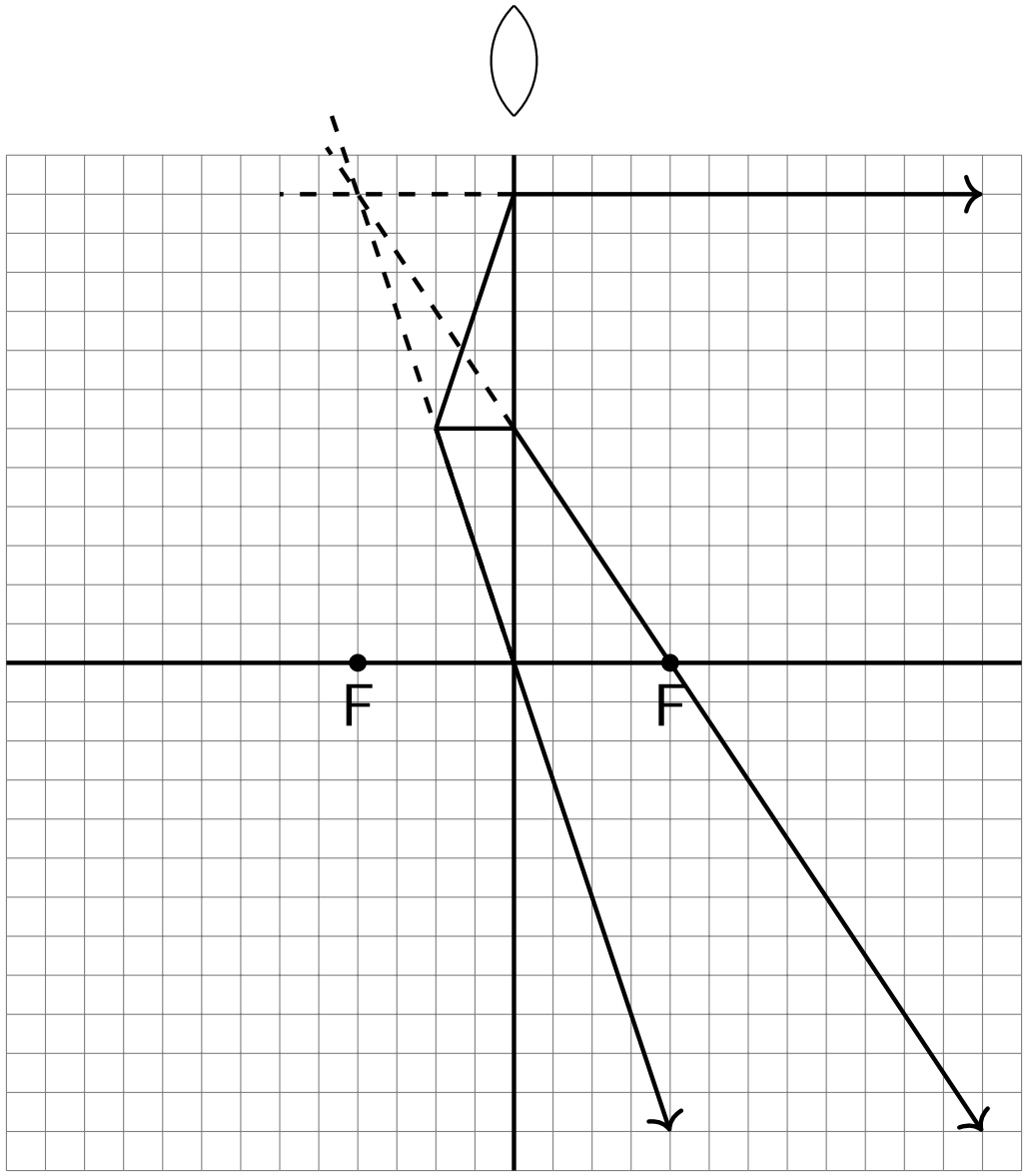


Thin lens equation

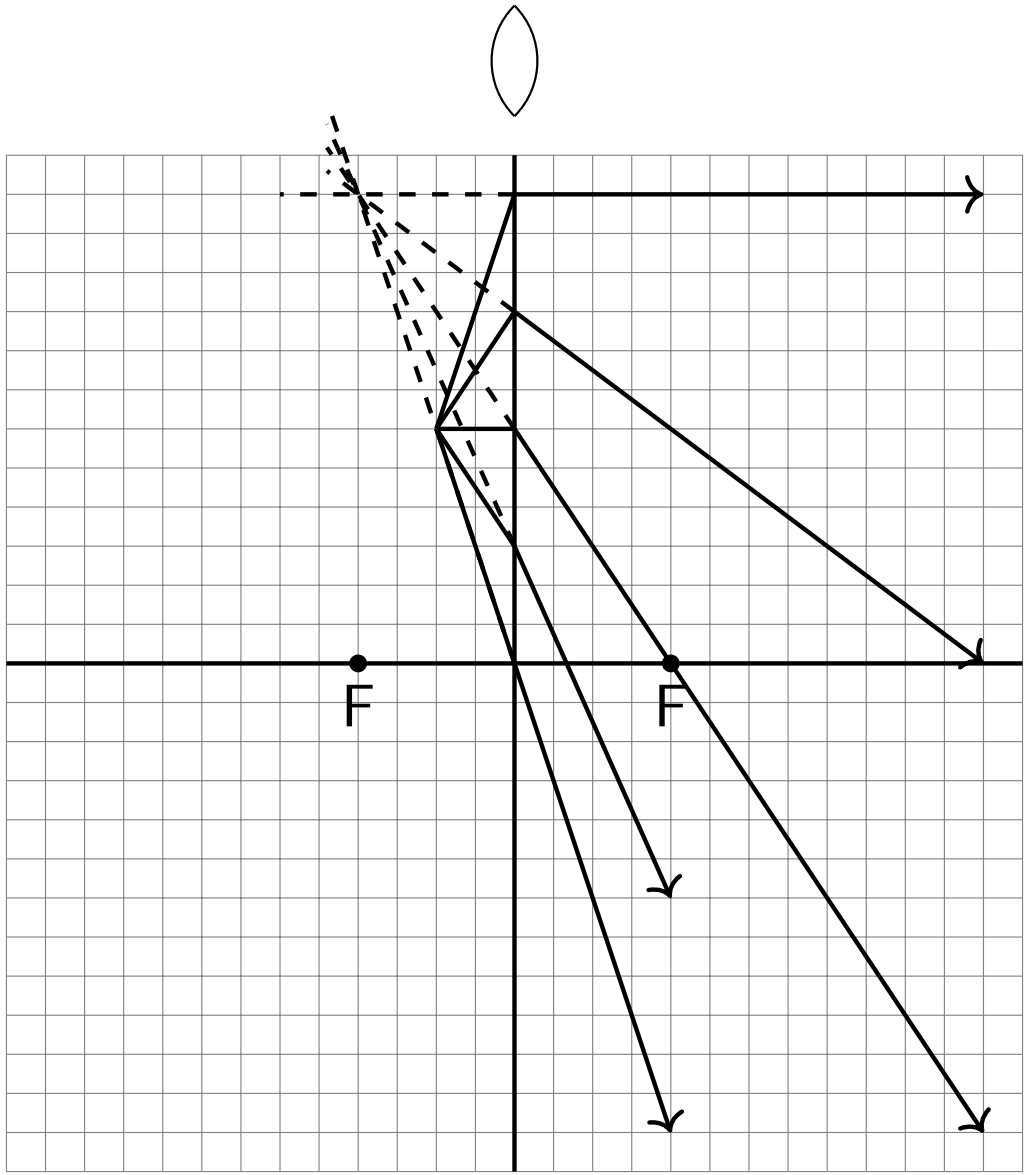
$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

- d_o is the *object distance*
- d_i is the *image distance*
- f is the *focal length* of the lens

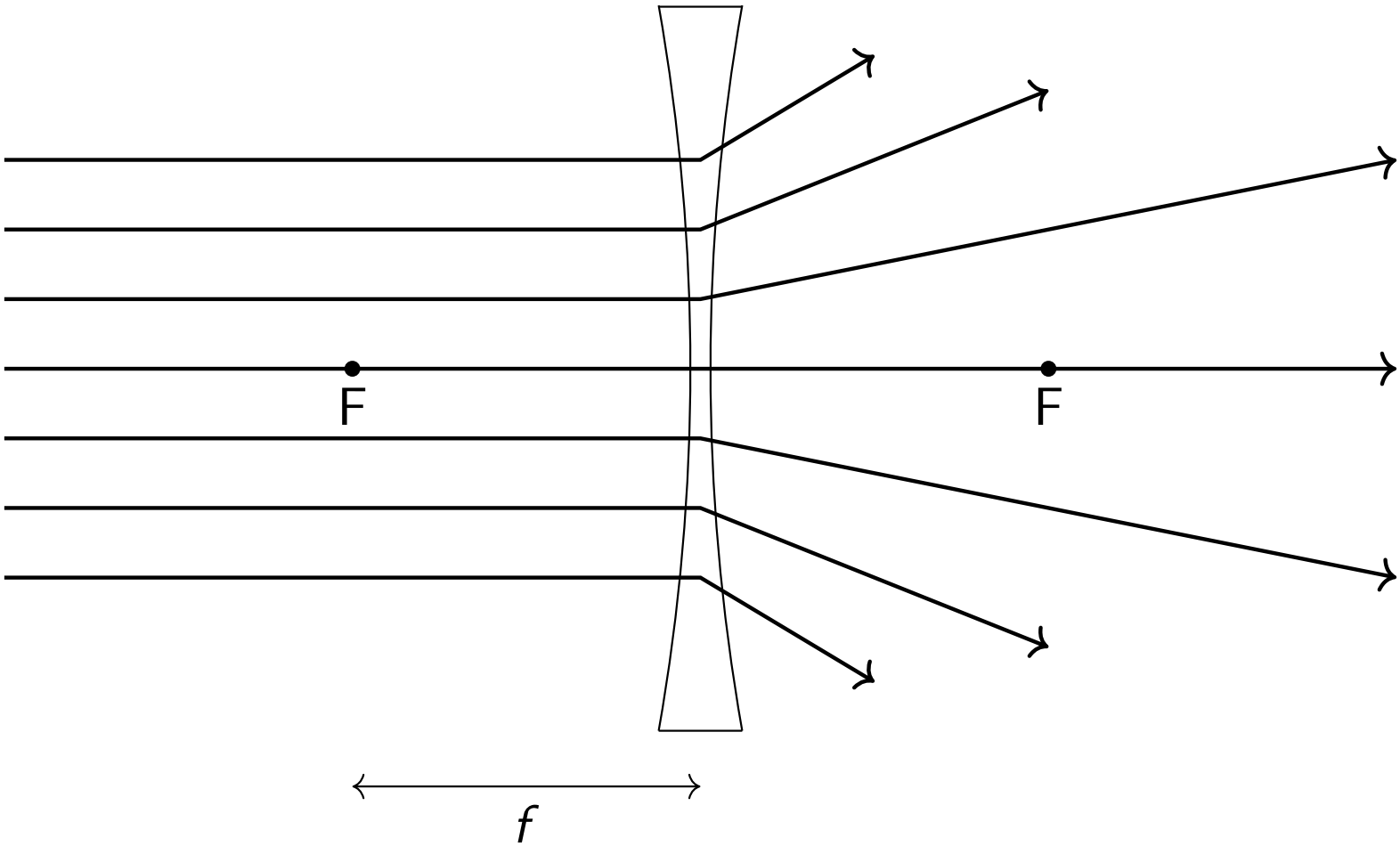
Converging lens, object inside focal point



Converging lens, object inside focal point, more rays

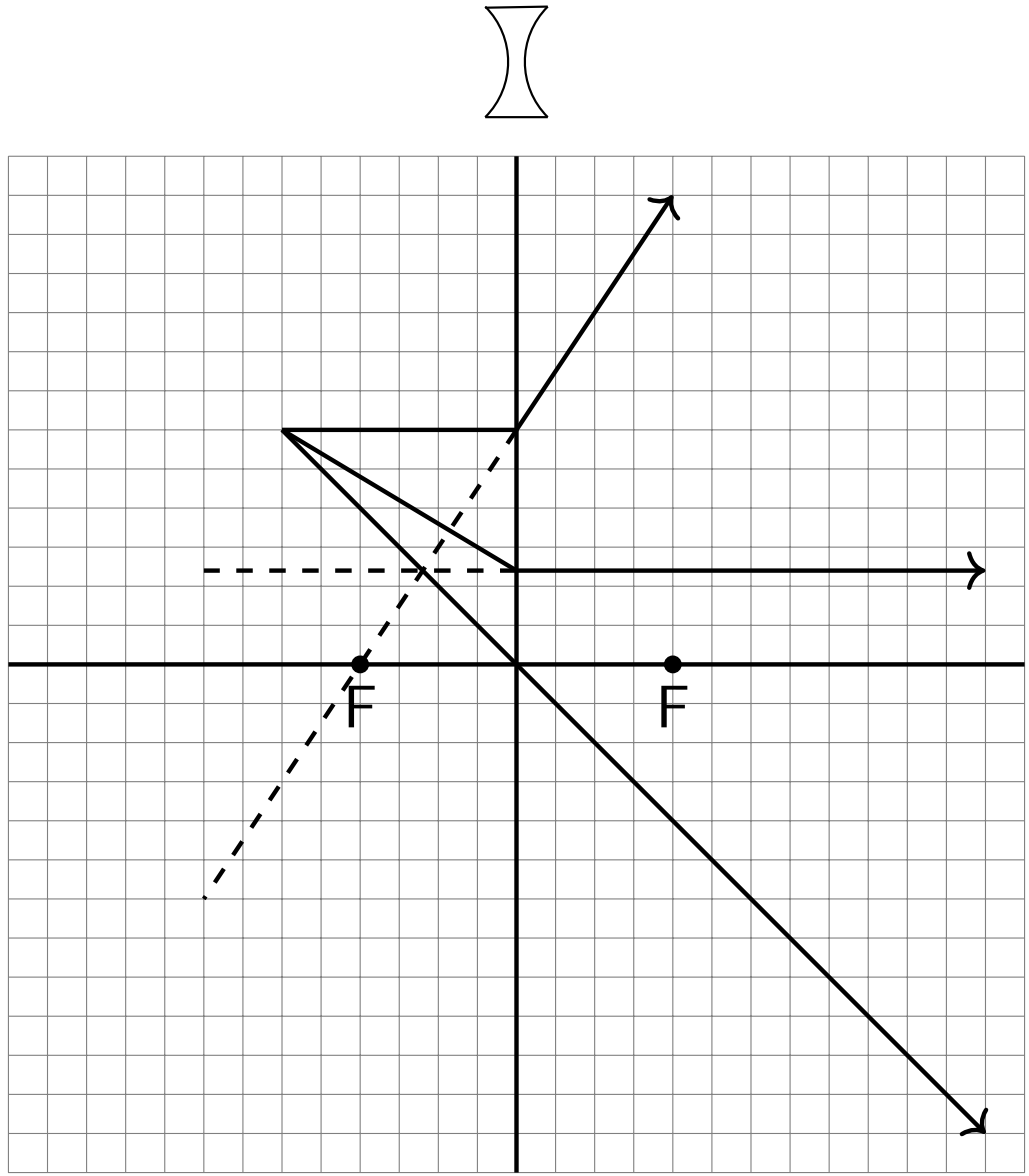


A *diverging lens* makes parallel rays diverge.

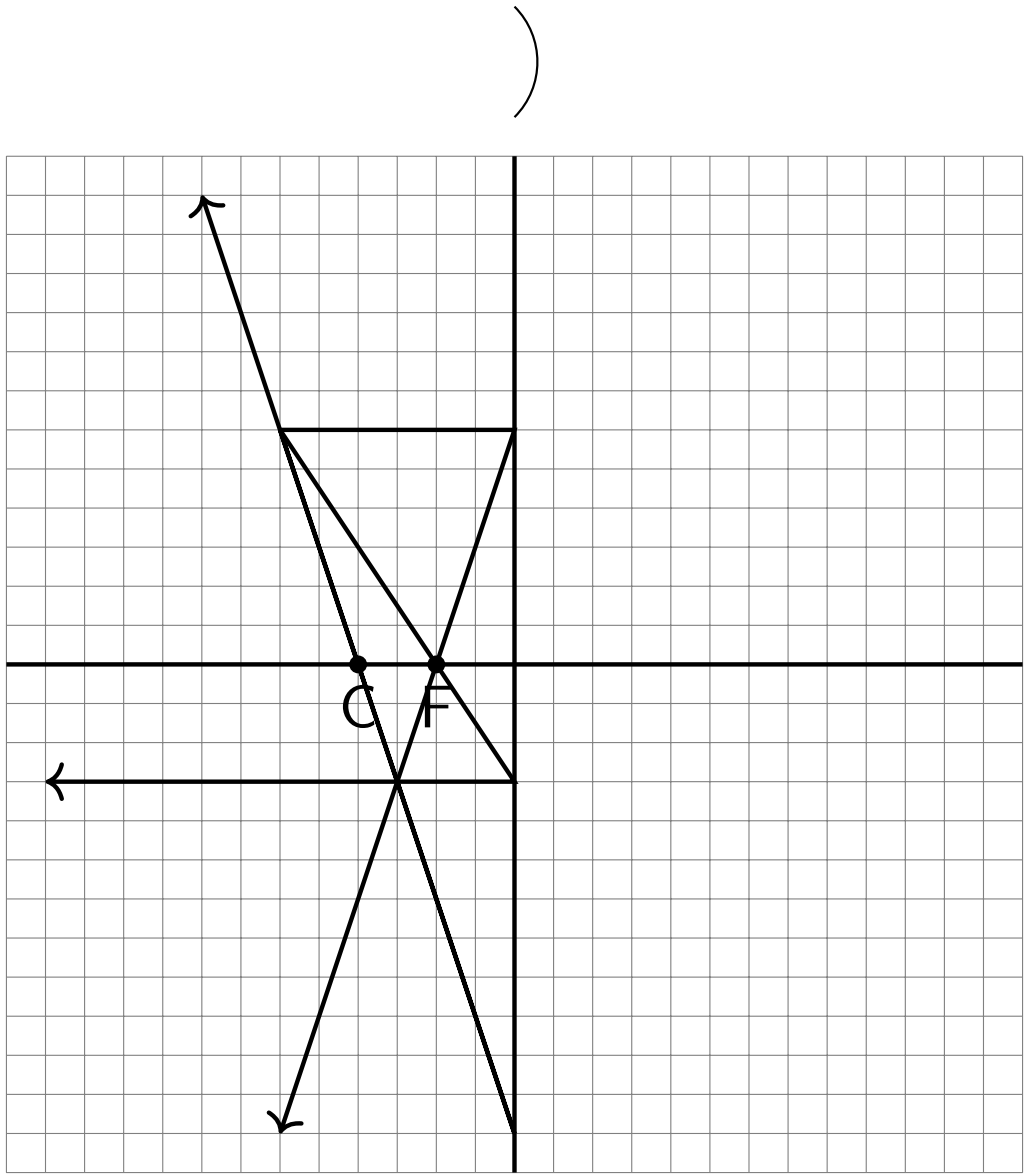


- The focal length f is negative for a diverging lens.

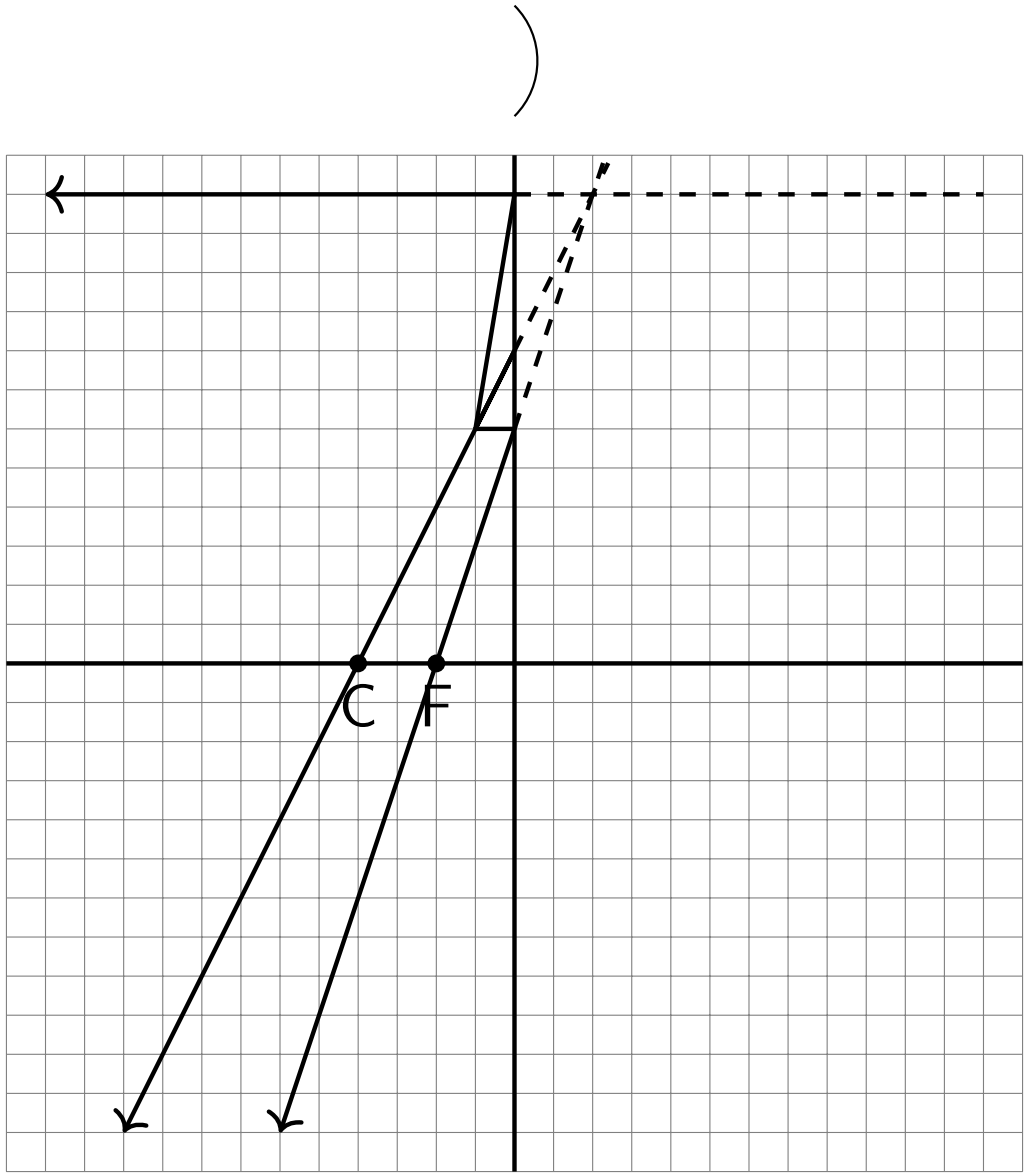
Diverging lens



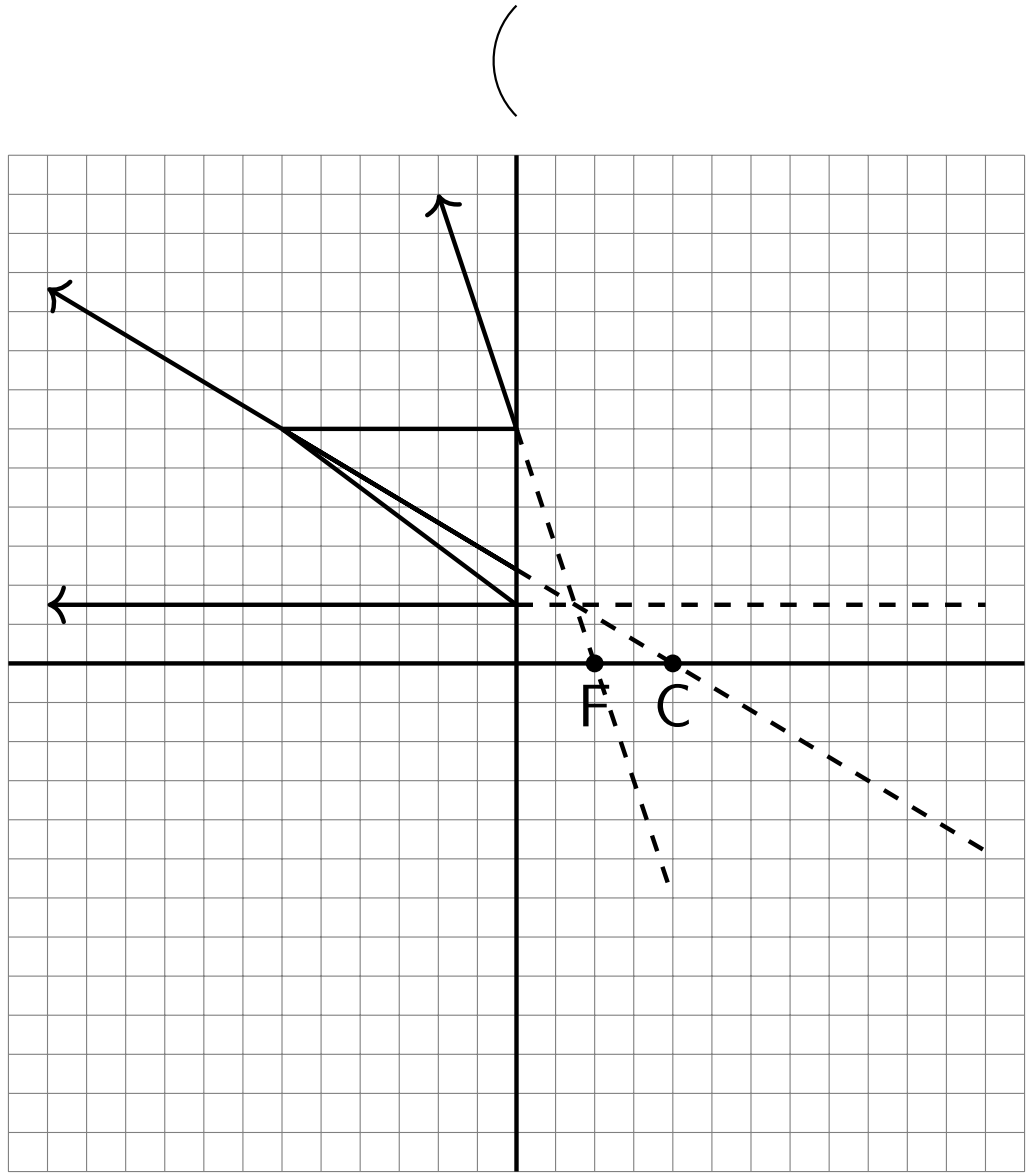
Concave mirror, object outside focal point



Concave mirror, object inside focal point



Convex mirror



Thin lenses and spherical mirrors

Lens/mirror	object location	image type
Converging lens	outside focal point	real, inverted image
Converging lens	inside focal point	virtual, upright image
Diverging lens	anywhere	virtual, upright image
Concave mirror	outside focal point	real, inverted image
Concave mirror	inside focal point	virtual, upright image
Convex mirror	anywhere	virtual, upright image