Announcements

- grade spreadsheets with exam 3 scores will be posted today on the Physics 2135 web site
- you need your PIN to find your grade

- preliminary exam average is about 68%
- scores ranged from 28 to 198

- exam 3 will be returned in recitation Thursday
- check that points were added correctly
- regrade requests are **due by next Thursday**

On a separate sheet of paper, explain the reason for your request. This should be based on the work shown on paper, not what was in your head. Attach to the exam and hand it to your recitation instructor by next Thursday.

Announcements

Physics 2135 schedule for the rest of the semester:

April 19 and 20: Lenses
April 24 and 25: Double Slit Interference
April 26 and 27: Thin Film Interference
May 1 and 2: Diffraction
May 3 and 4: Final Review

Friday, May 12, 10:00am to 12:00pm
- 50 point all multiple choice End Material Test
- 200 point all problem Final Exam
- You may take one, or both, or neither

Today's agenda:

Death Rays.
You must know when to run from Death Rays. ~~Maybe skip for now~~.

Refraction at Spherical Surfaces.
You must be able to calculate properties of images formed by refraction at spherical surfaces.

Thin Lenses: Concave and Convex Lenses, Ray Diagrams, Solving the Lens Equation.
You must understand the differences between these two kinds of lenses, be able to draw ray diagrams for both kinds of lenses, and be able to solve the lens equation for both kinds of lenses.

Lens Combinations, Optical Instruments.
You should be aware of this useful information, which will not be presented in lecture.

Archimedes' burning mirrors

Did Archimedes use mirrors to set aflame invading Roman ships that attacked the Greek city of Syracuse in 213 BC?

Archimedes' burning mirrors

- probably a myth, **BUT**
- it is possible under ideal condition

In 2005, MIT students set wooden "ships" on fire! Details here!

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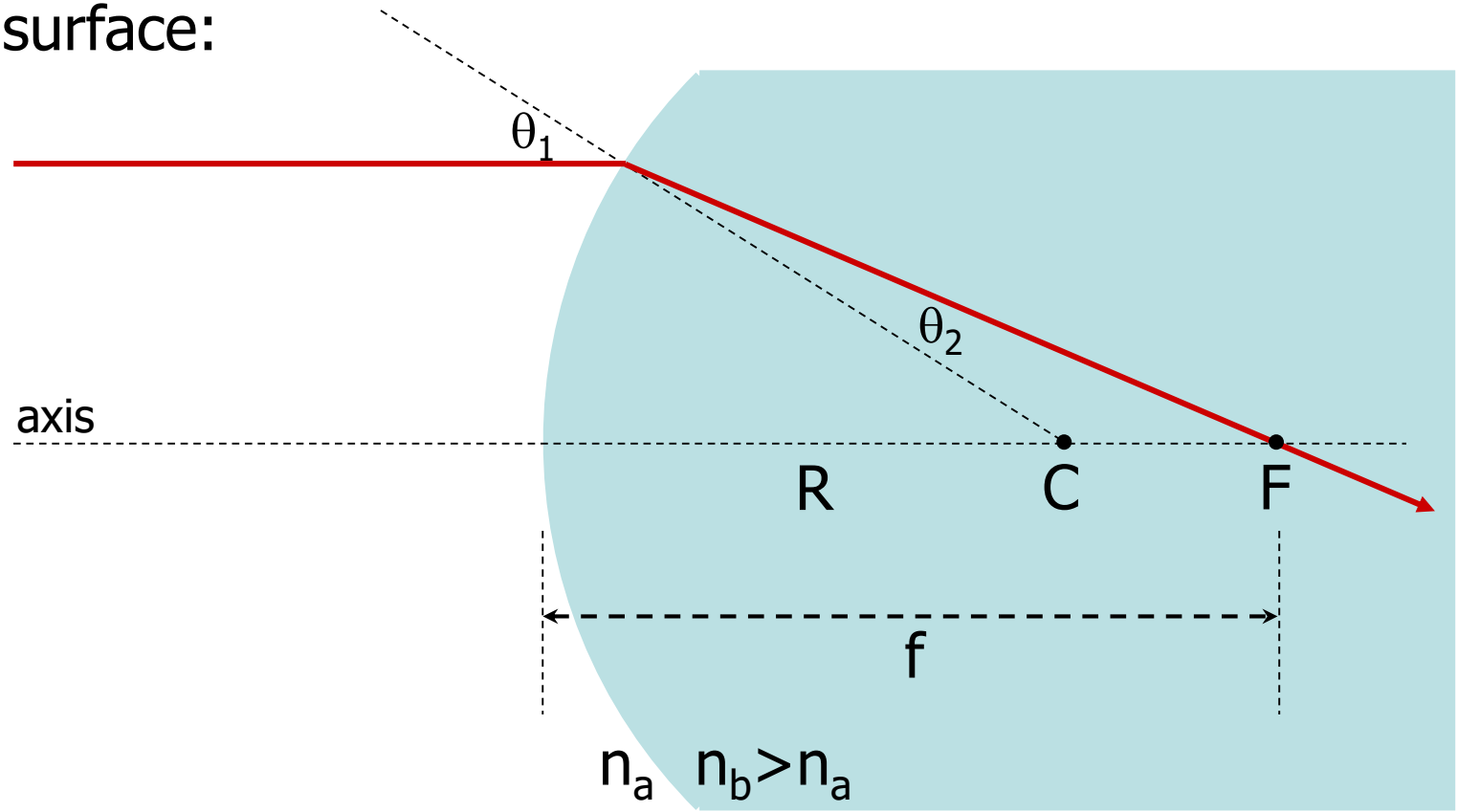
Refraction at Spherical Surfaces

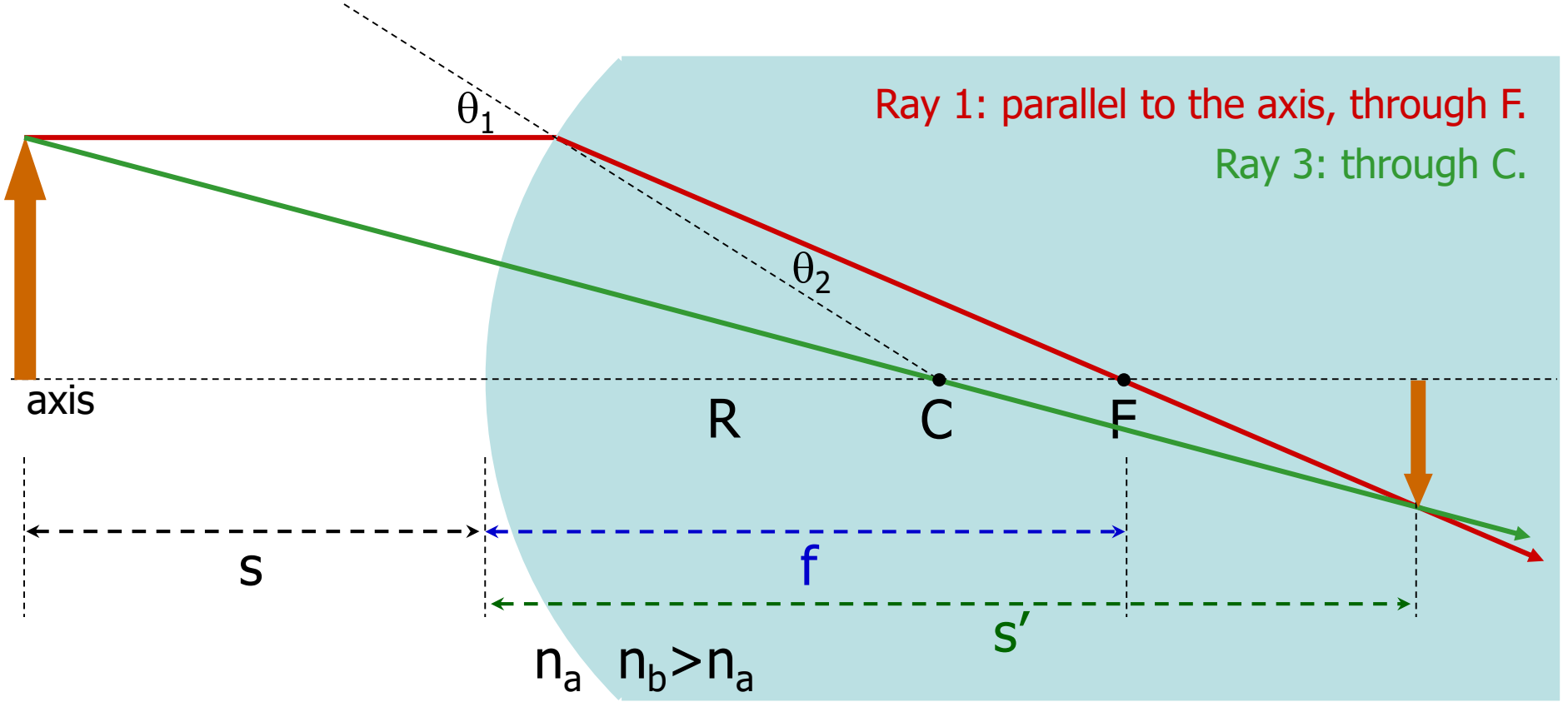
Convex surface:



Geometry: a light ray parallel to the axis passes through F.

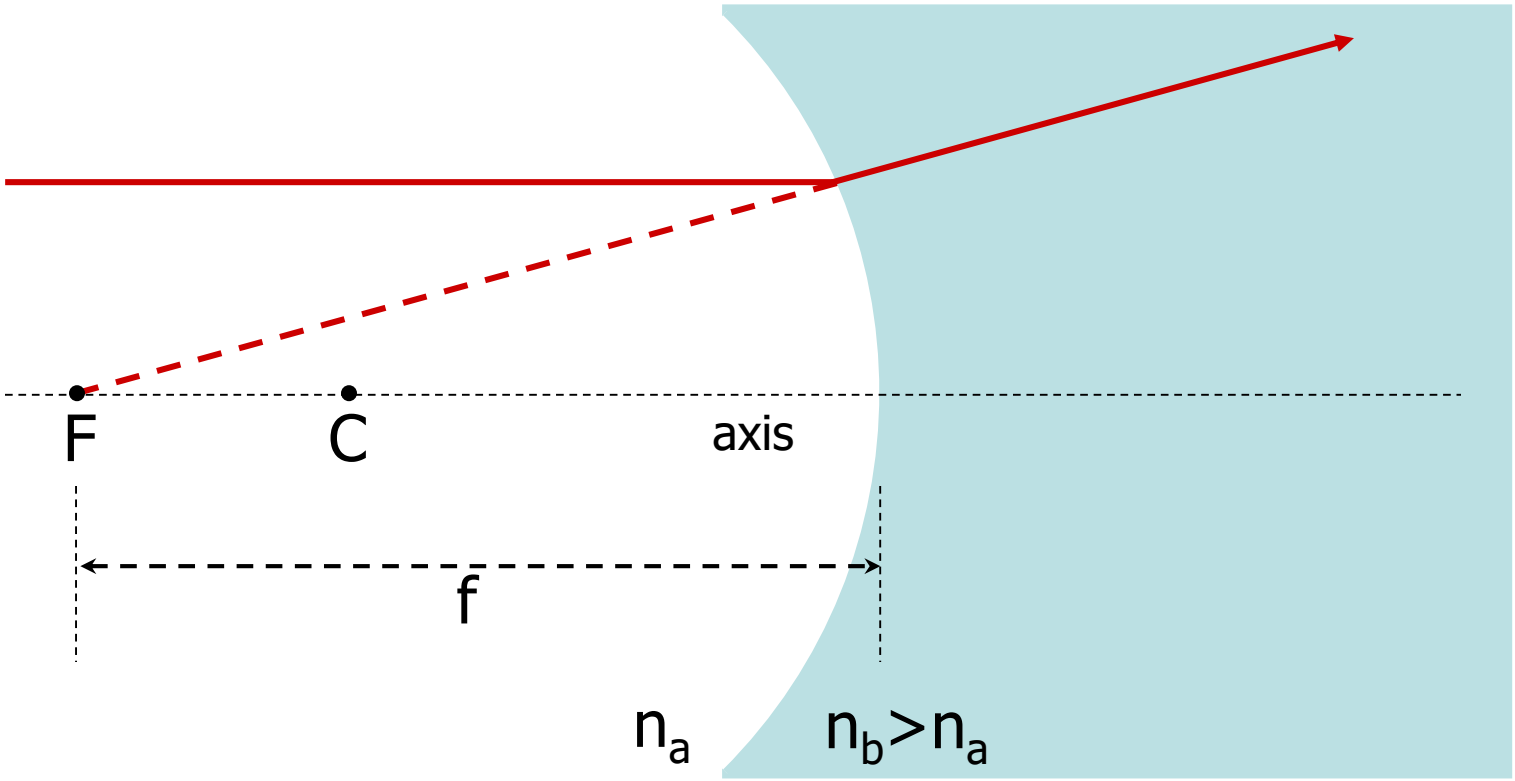
$$f = \left(\frac{n_b}{n_b - n_a} \right) R > R$$

An extended object will form an image inside the n_b medium.



This image is real and inverted.

Concave surface:



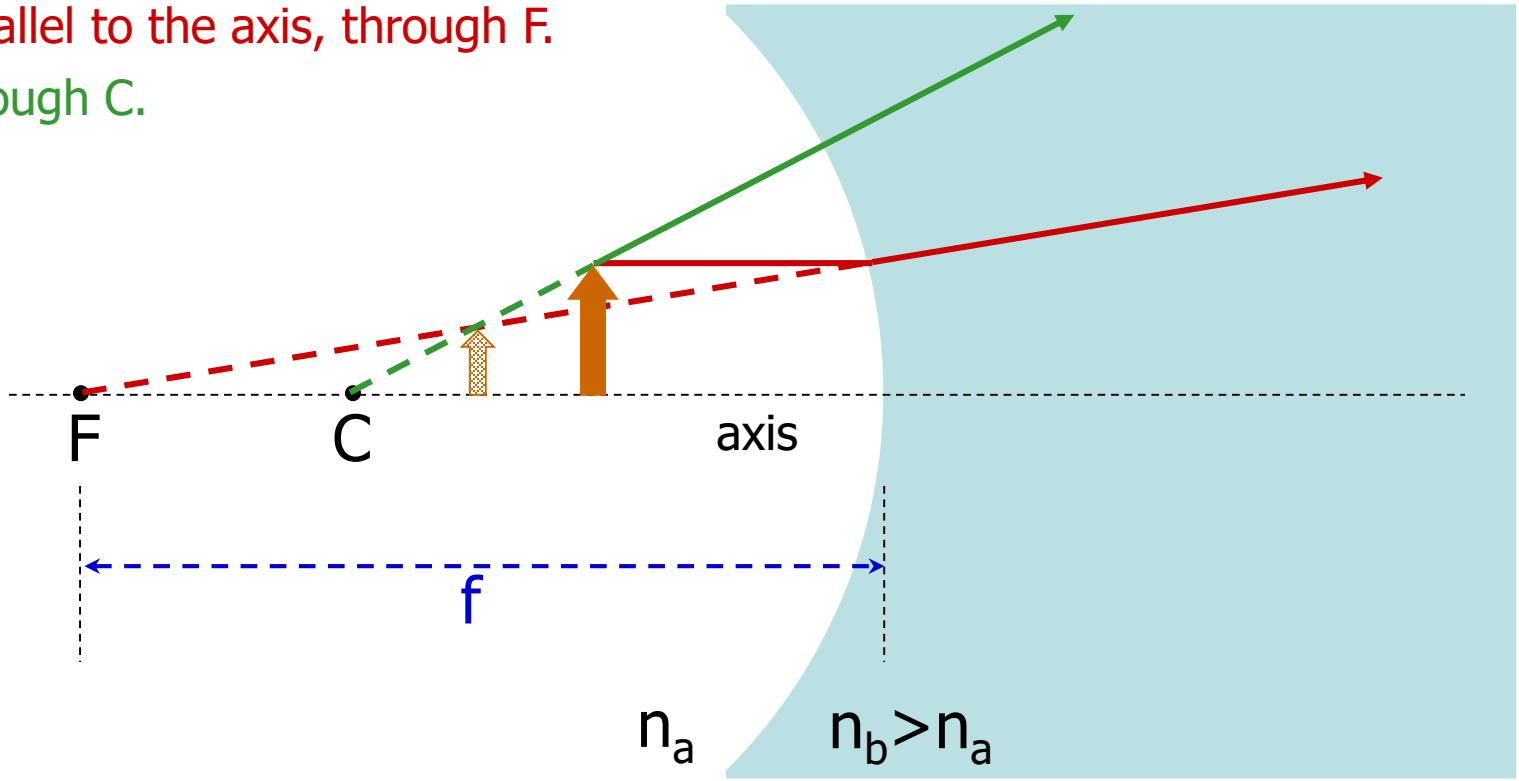
Geometry: a light ray parallel to the axis seems to have come from F.

$$f = \left(\frac{n_b}{n_b - n_a} \right) R > R$$

An extended object will form an image inside the n_a medium.

Ray 1: parallel to the axis, through F.

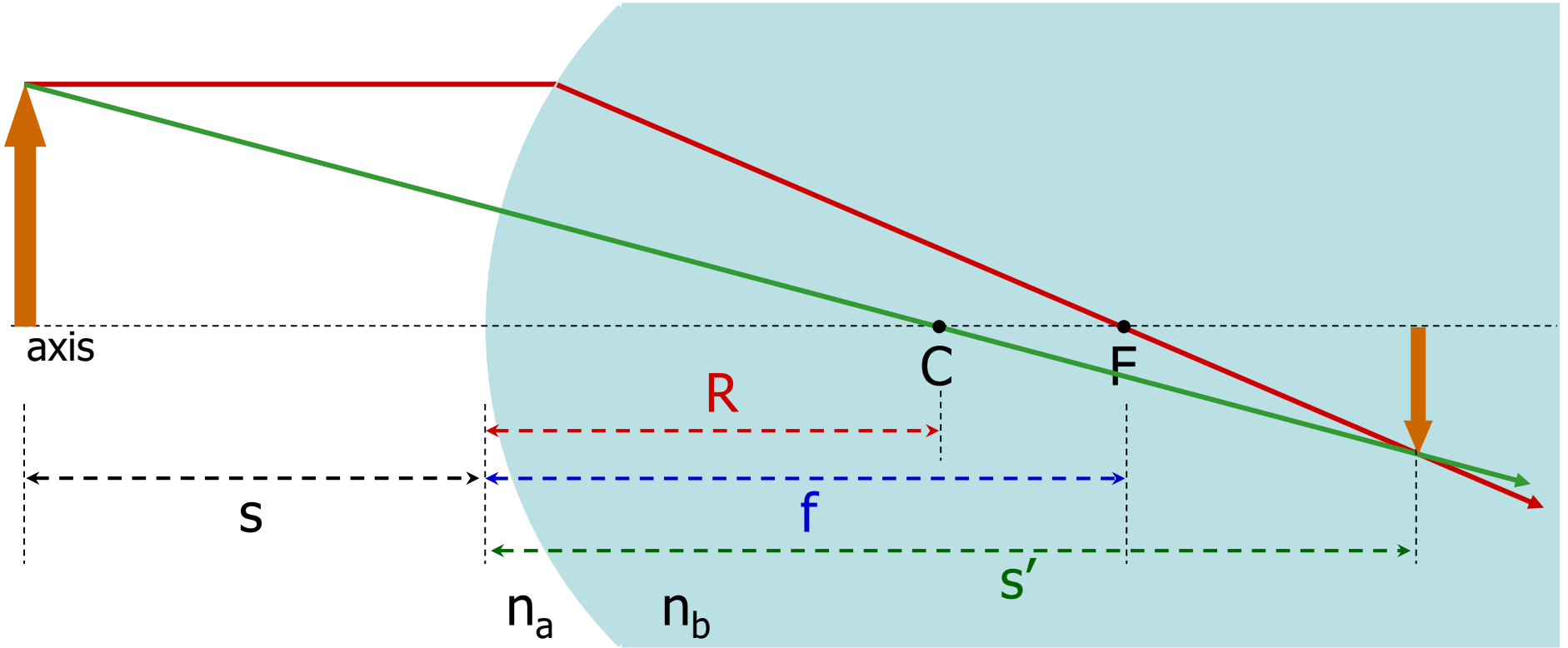
Ray 3: through C.



The image is virtual and upright.

There are three different places to put the object. The different images formed are always virtual and upright.

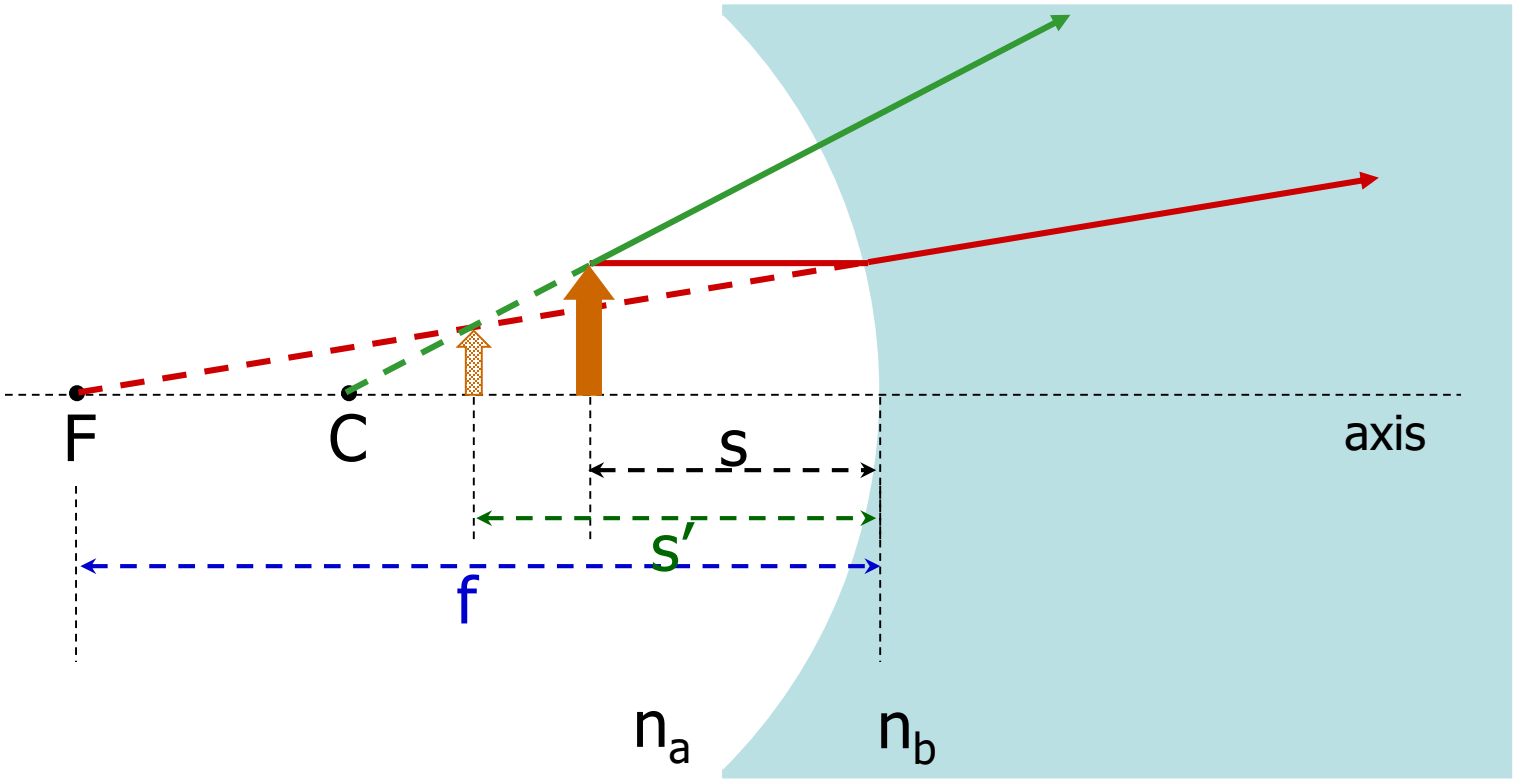
We can use geometry to derive an equation relating the image and source positions, and an equation for the magnification.



$$\frac{n_a}{s} + \frac{n_b}{s'} = \frac{n_b - n_a}{R}$$

$$m = \frac{y'}{y} = -\frac{n_a s'}{n_b s}$$

The same equations work for concave surfaces.



$$\frac{n_a}{s} + \frac{n_b}{s'} = \frac{n_b - n_a}{R}$$

$$m = \frac{y'}{y} = -\frac{n_a s'}{n_b s}$$

Approximations Were Used!

The equations in this section are excellent approximations if both the angles of incidence and refraction are small.

Recall: Sign Conventions

Object Distance. When the object is on the same side as the **incoming** light, the object distance is positive (otherwise is negative).

Image Distance. When the image is on the same side as the **outgoing** light, the image distance is positive (otherwise is negative).

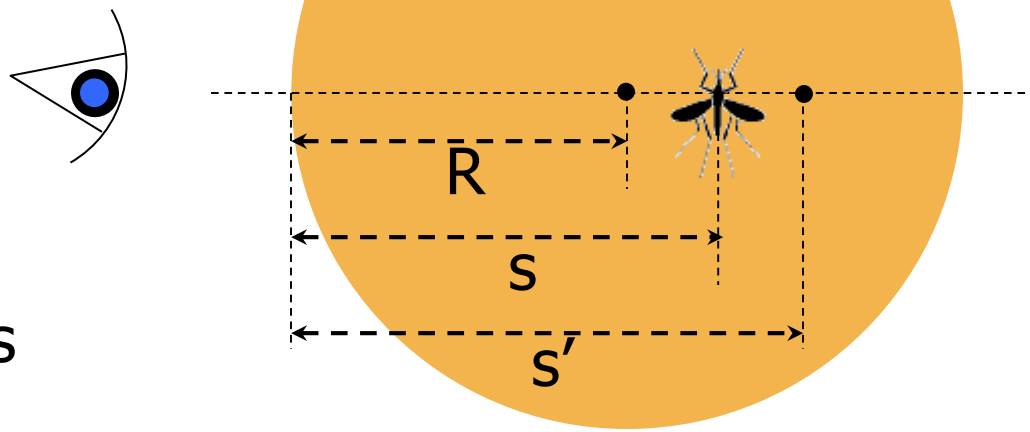
Radius of Curvature. When the center of curvature C is on the same side as the **outgoing** light, R is positive (otherwise is negative).

Example: a Jurassic mosquito is discovered embedded in an amber sphere which has an index of refraction of 1.6. The radius of curvature of the sphere is 3.0 mm. The mosquito is located on the principal axis and appears to be imbedded 5.0 mm into the amber. How deep is the mosquito really?

$$\frac{n_a}{s} + \frac{n_b}{s'} = \frac{n_b - n_a}{R}$$

The object is in the amber, so n_a=1.6 and n_b=1.

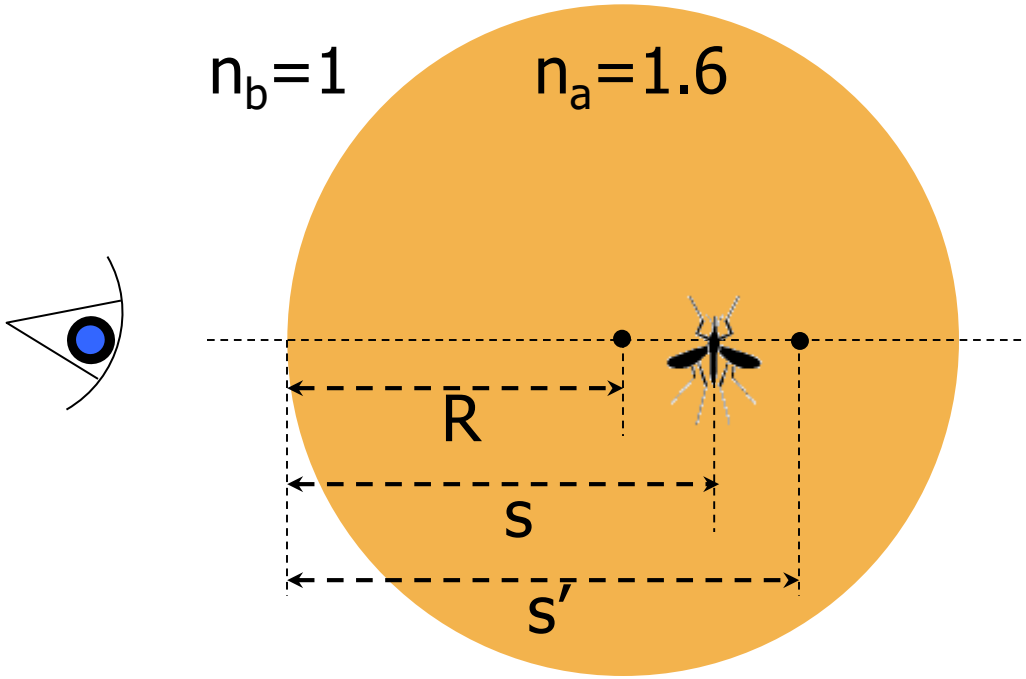
The image is in the medium from which the light radiates so s'=-5.0 mm.



R is negative because it is in the medium from which the light radiates. R=-3.0 mm.

$$\frac{1.6}{s}+\frac{1}{-5.0}=\frac{1-1.6}{-3}$$

$$s = 4\,\text{mm}$$



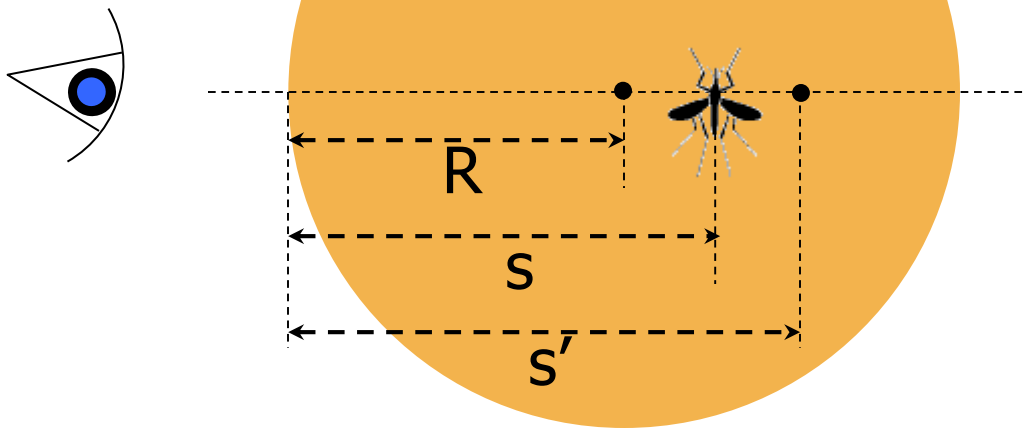
Example: a Jurassic mosquito is discovered embedded in an amber sphere which has an index of refraction of 1.6. The radius of curvature of the sphere is 3.0 mm. The mosquito is located on the principal axis and appears to be imbedded 5.0 mm into the amber. What is the magnification?

$$m = \frac{-n_a s'}{n_b s}$$

s=4 mm and s′=-5.0 mm.

n_a=1.6 and n_b=1

$$m = \frac{-(1.6)(-5)}{(1)(4)} = \frac{8}{4} = 2$$



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Death Rays.

You must know when to run from Death Rays.

Refraction at Spherical Surfaces.

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Thin Lenses: **Concave and Convex Lenses**, Ray Diagrams, Solving the Lens Equation.

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Lens Combinations, Optical Instruments.

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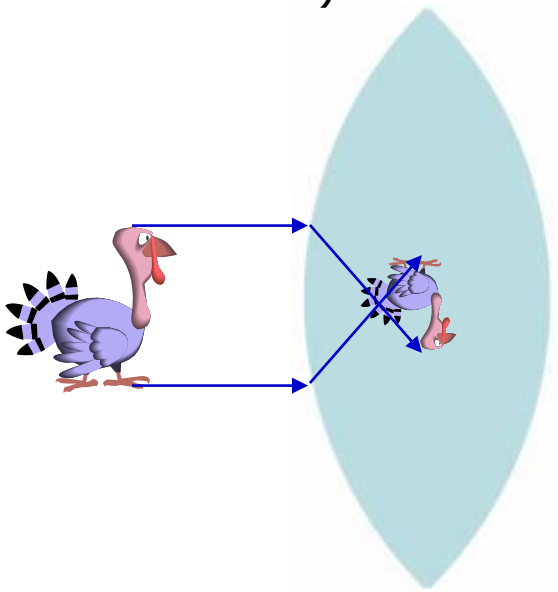
Thin Lenses

Simple lens: object made of single piece of transparent material of refractive material n>1

Compound lens: device combining several simple lenses (elements) (for example, camera lens may have 6 or more elements)

- simple lens has two surfaces, usually spherical
- light from object incident on first surface forms image, which becomes object for second surface

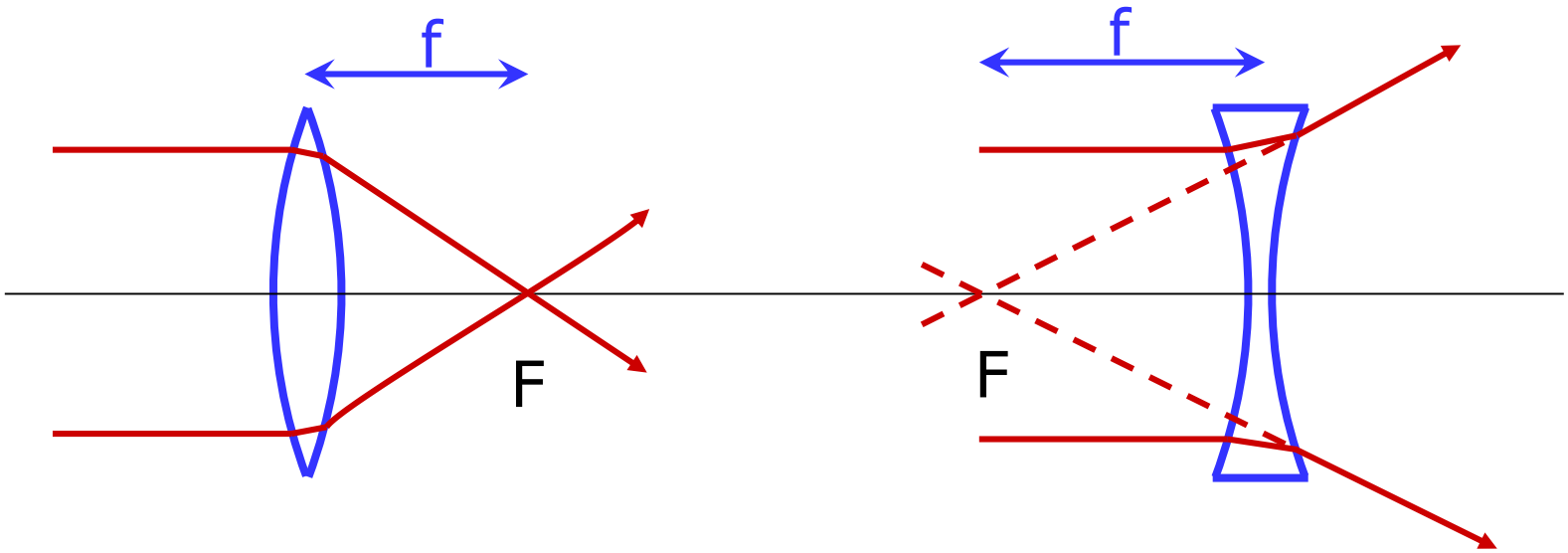


Thin lens:

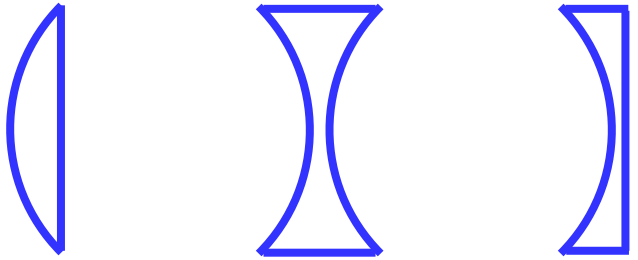
- thickness small compared to radii of curvature

This would NOT qualify as a thin lens.

Converging and Diverging Lenses

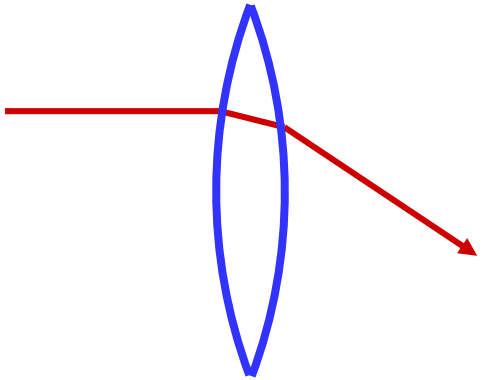


- converging lenses are thicker in the center
- diverging lenses are thicker at the edges

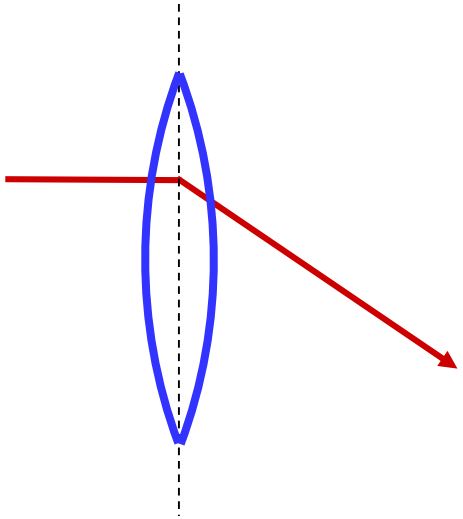


- there are focal points on both sides of each lens
- focal length f on both sides is the same

There are two surfaces at which light refracts. Our equations (provided later) "automatically" take care of this.



In your diagrams, simply draw the incident ray up to the center of the lens, then draw the refracted ray in its final direction.



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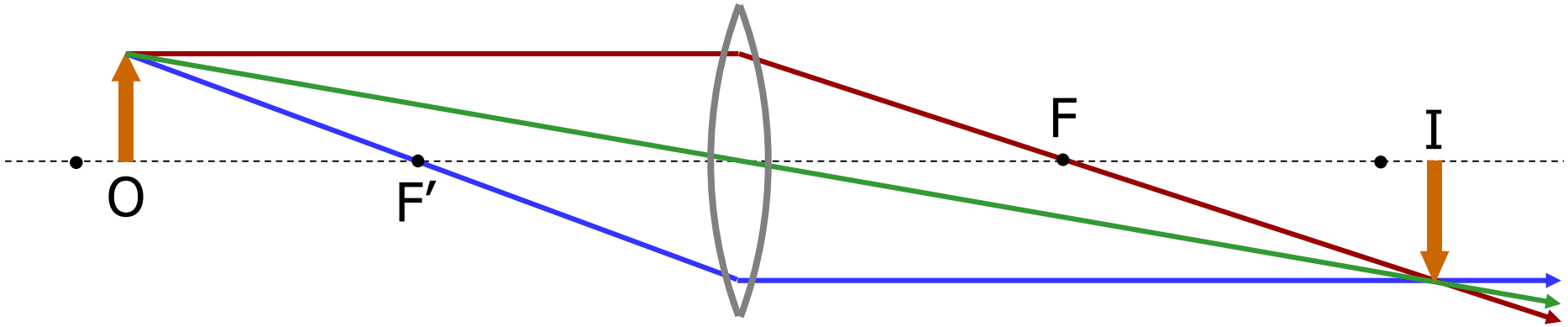
Ray Diagrams for Converging Lenses

Ray 1 is parallel to the axis and refracts through F.

Ray 2 passes through F′ before refracting parallel to the axis.

Ray 3 passes straight through the center of the lens.



object between f and 2f: image is real, inverted, enlarged

object outside of 2f: image is real, inverted, reduced

object inside of f: image is virtual, upright, enlarged (see example later)

Ray Diagrams for Diverging Lenses

Ray 1 is parallel to the axis and refracts as if from F.

Ray 2 heads towards F′ before refracting parallel to the axis.

Ray 3 passes straight through the center of the lens.

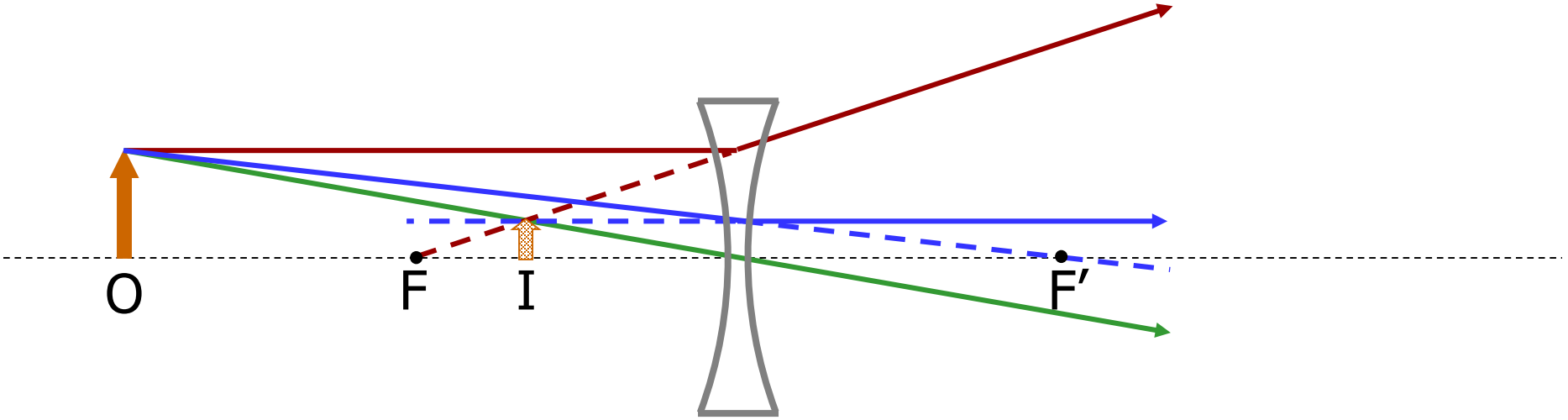
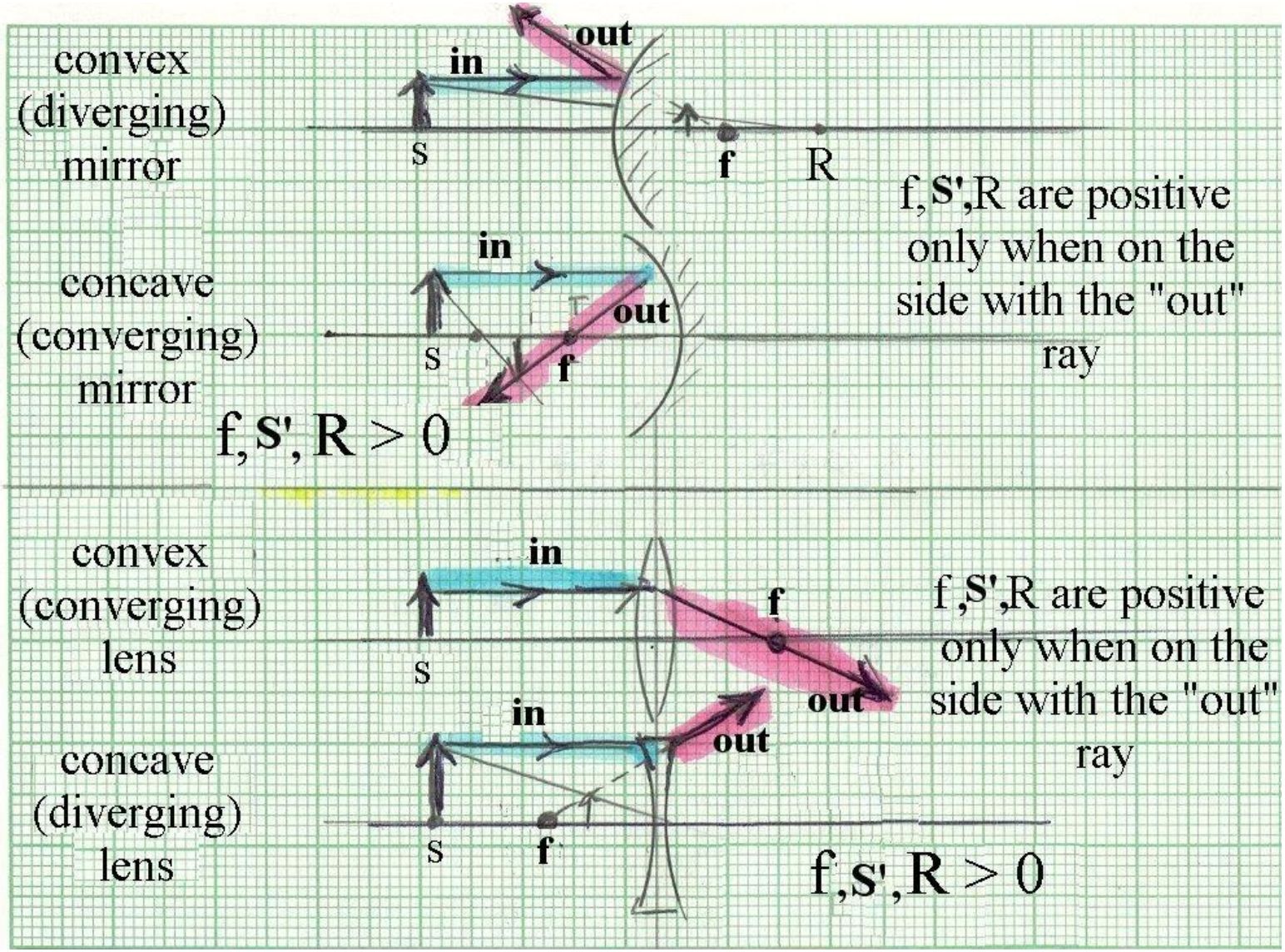


image is always virtual, upright and reduced

Handy quick reference card from Dr. Hale:



http://web.mst.edu/~hale/courses/Physics24/Quick.Reference.Cards/mirror.lens.table.pdf

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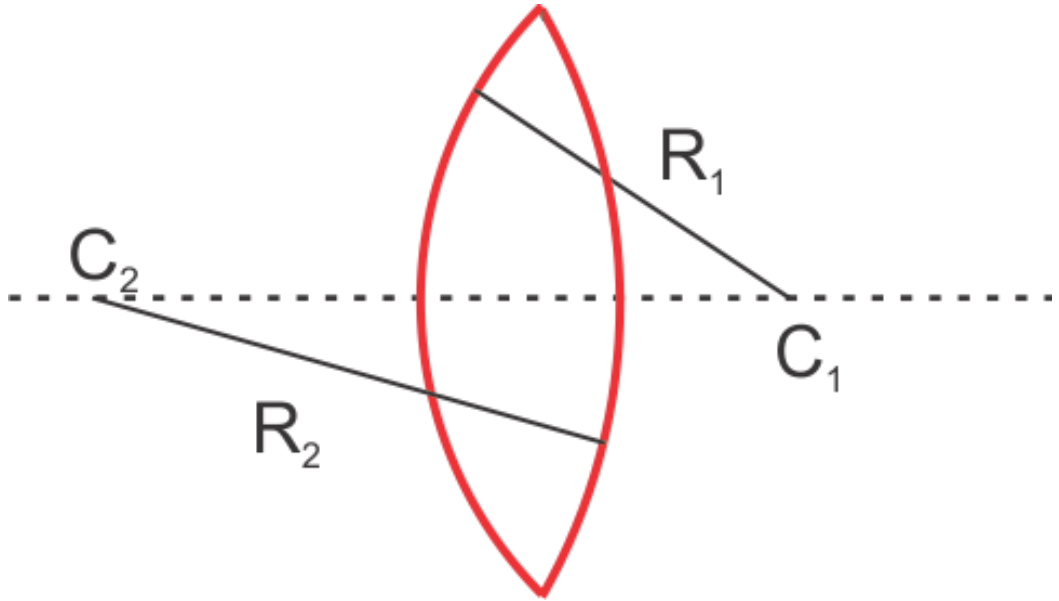
The Lensmaker's Equation

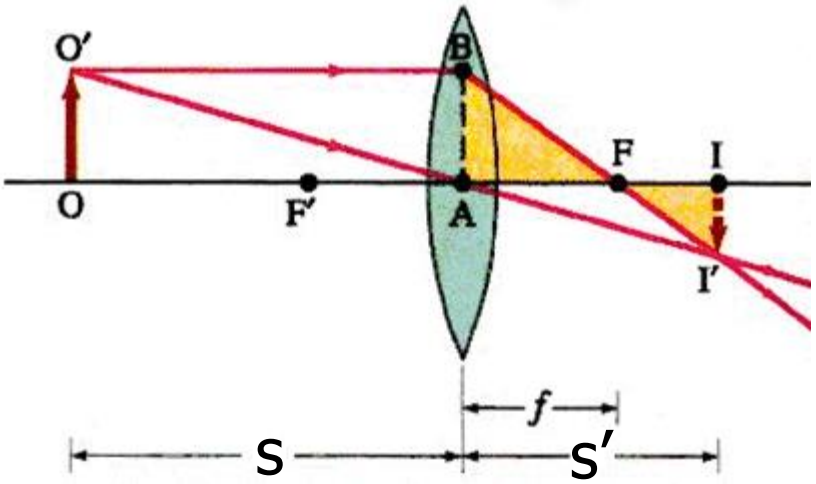


$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

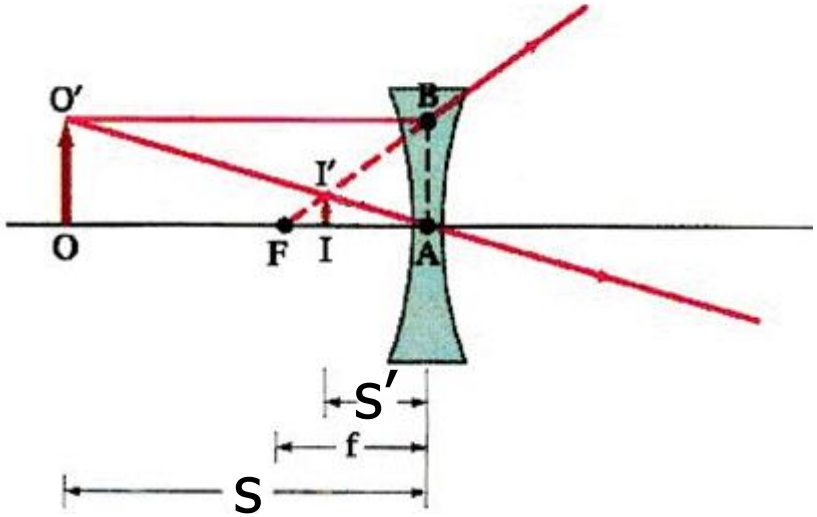
- material of refractive index n embedded in air
- surface 1 is surface hit by light first
- radii R_1 and R_2 must follow sign rules, here: $R_1>0$ and $R_2<0$
- **f>0 for converging** lens, **f<0 for diverging** lens

Imaging equations

Converging Lens



Diverging Lens

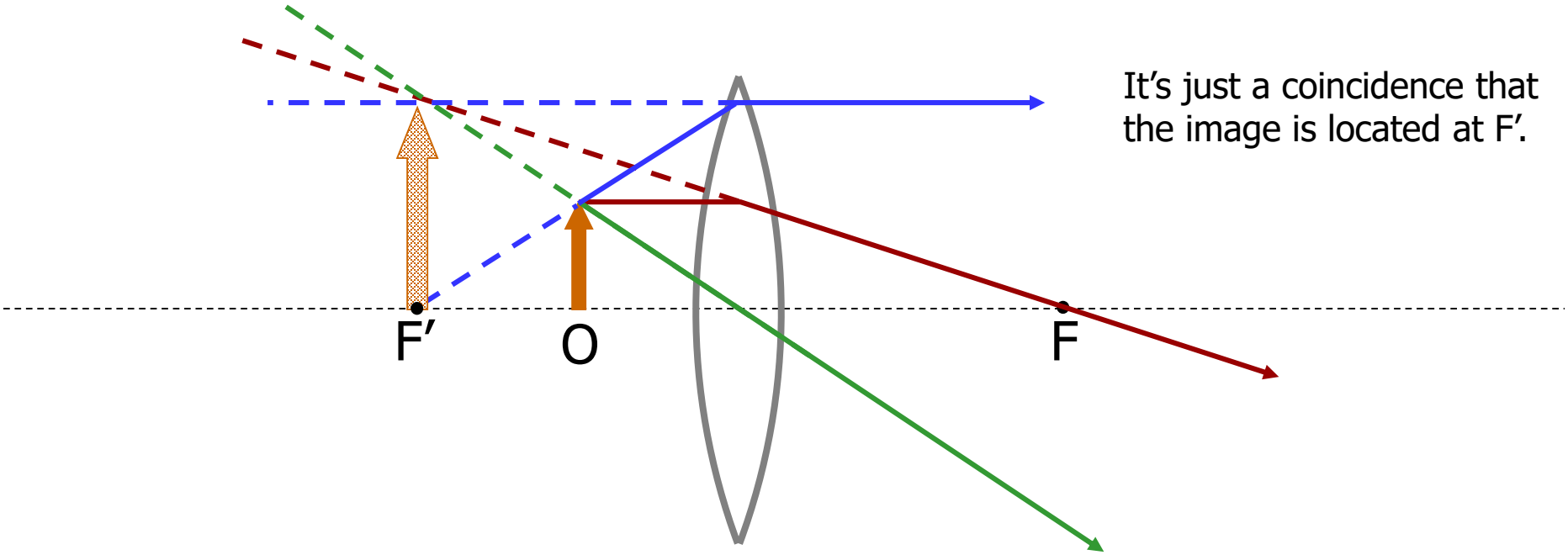


$$\frac{1}{s}+\frac{1}{s'}=\frac{1}{f}$$

$$M=\frac{y'}{y}=-\frac{s'}{s}$$

s, s′, f, y and y′ follow **same sign conventions** as for mirrors

Example: an object is located 5 cm in front of a converging lens of 10 cm focal length. Find the image distance and magnification. Is the image real or virtual?



$$\frac{1}{s'} = \frac{1}{f} - \frac{1}{s} = \frac{1}{+10} - \frac{1}{+5} = -\frac{1}{10} \qquad s' = -10 \qquad M = -\frac{s'}{s} = -\frac{-10}{5} = 2$$

Image distance is 10 cm, image is on side of lens light is coming from, so image is virtual. M=2 so image is upright.

Summary: Image formation for Lenses

Type	Focal length f	Object distance s	Image distance s’	Character	Orientation	Size
converging	f > 0	s > 2f	f < s’ < 2f	real	inverted	reduced
		f < s < 2f	s’ > 2f	real	inverted	enlarged
		s<f	s’<0	virtual	upright	enlarged
diverging	f < 0	s > 0	s’ < 0	virtual	upright	reduced

Summary of Sign Conventions

Object Distance. When the object is on the same side as the **incoming** light, the object distance is positive (otherwise is negative).

Image Distance. When the image is on the same side as the **outgoing** light, the image distance is positive (otherwise is negative).

(negative image distance ⇔ virtual image)
(positive image distance ⇔ real image)

Radius of Curvature. When the center of curvature C is on the same side as the **outgoing** light, R is positive (otherwise is negative).

Image height y' is positive if the image is upright