PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 24100
Electricity & Optics
Lecture 25 – Chapter 32 sec. 3,4

Fall 2012 Semester

Matthew Jones

ANNOUNCEMENT

***Exam 1**: Friday December 14, 2012, 8 AM – 10 AM

***Location:** Elliot Hall of Music

*Covers all readings, lectures, homework from Chapters 29 through 33.

*The exam will be multiple choice.

Be sure to bring your student ID card and a hand-written one-page (two sided) crib sheet plus the crib sheets that you prepared for exams 1 and 2.

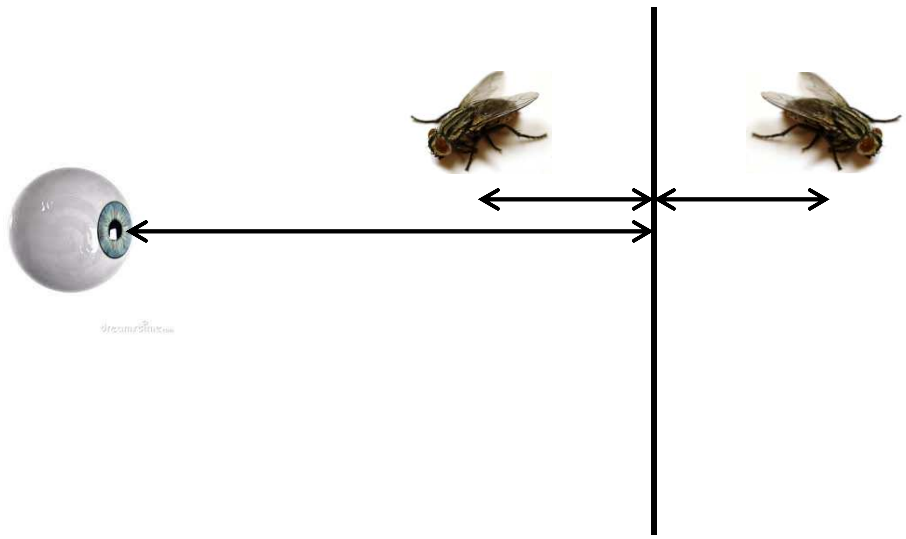
NOTE THAT FEW EQUATIONS WILL BE GIVEN – YOU ARE REMINDED THAT IT IS YOUR RESPONSIBILITY TO CREATE WHATEVER TWO-SIDED CRIB SHEET YOU WANT TO BRING TO THIS EXAM.

The equation sheet that will be given with the exam is posted on the course homepage. Click on the link on the left labeled "EquationSheet"

Question

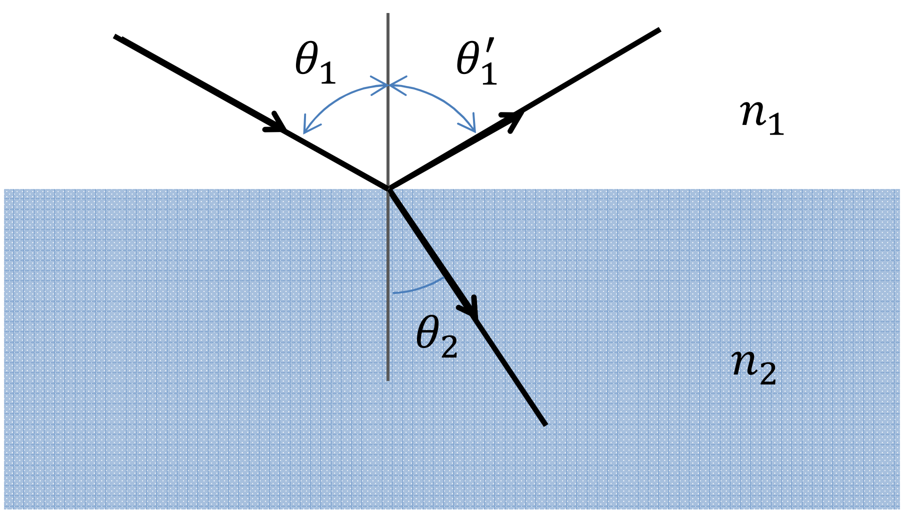
A fly at about eye level is 10 cm in front of a plane mirror; you are behind the fly, 30 cm from the mirror. What is the distance between your eyes and the apparent position of the fly's image in the mirror?

(A) 10 cm
(B) 20 cm
(C) 30 cm
(D) 40 cm
(E) 60 cm



Geometric Optics

- When the wavelength of light is much shorter than the sizes of objects it interacts with, we can ignore the wave-like nature and treat it as rays that propagate in straight lines.



Reflection:

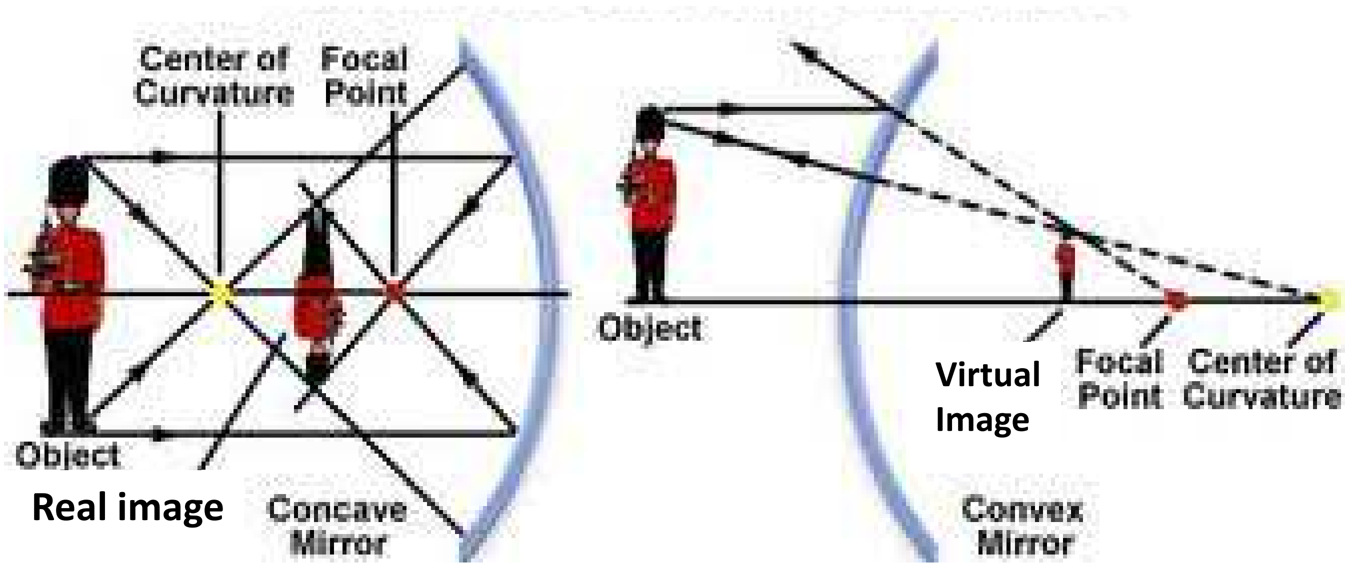
$$\theta_1' = \theta_1$$

Refraction:

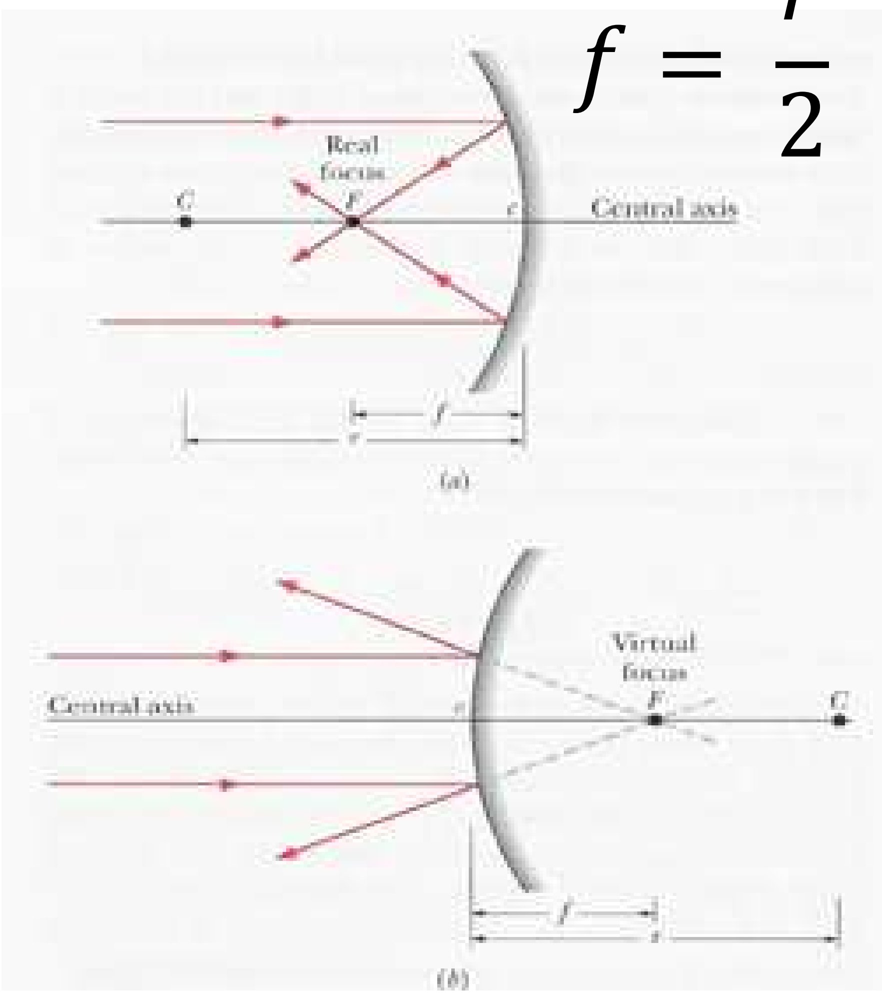
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Types of Images

- **Real Image**: light emanates from points on the image
- **Virtual Image**: light *appears* to emanate from the image



Focal Points of Spherical Mirrors



$$f = \frac{r}{2}$$

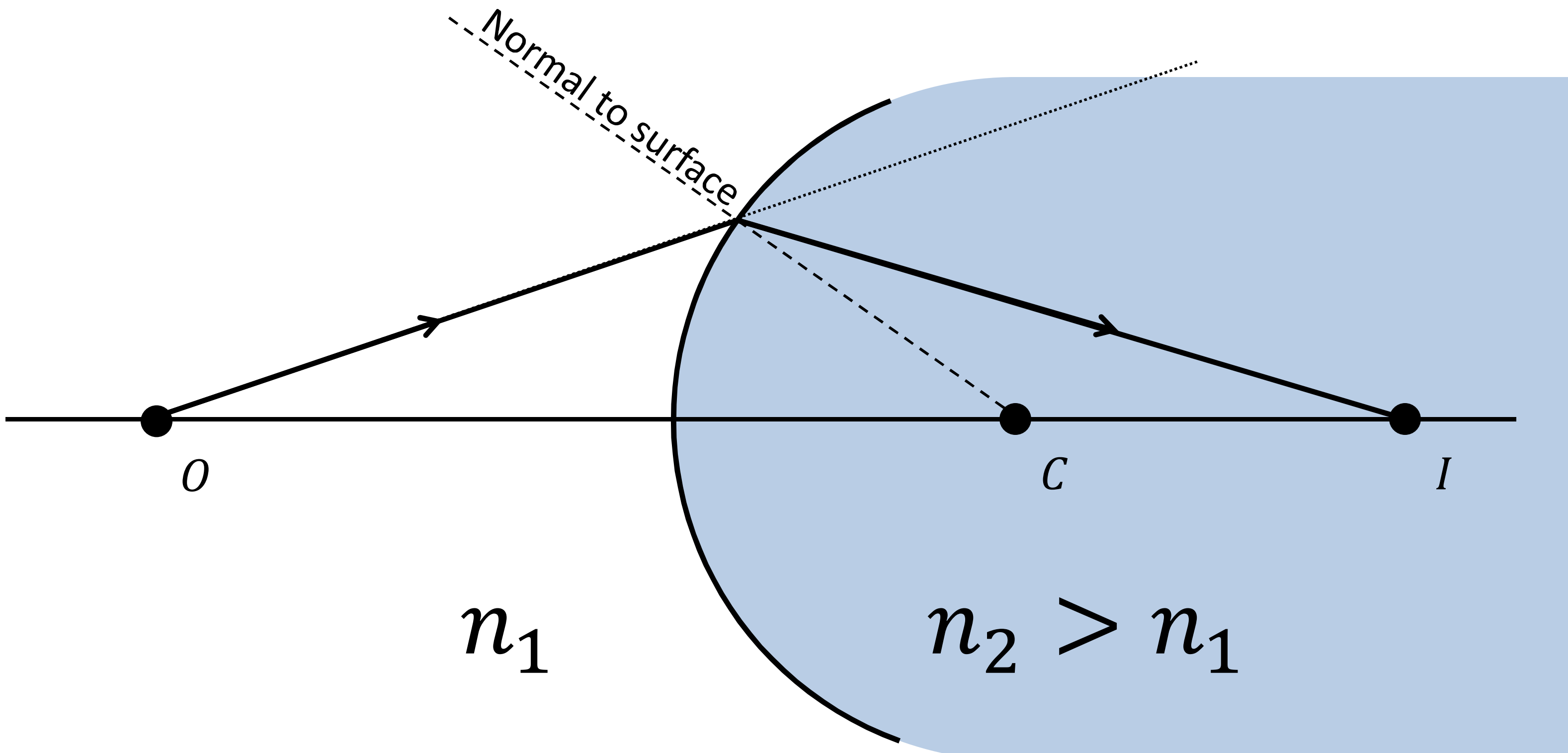
Sign convention:

- Concave:
  - Radius of curvature, $r > 0$
  - Focal length, $f > 0$
- Convex:
  - Radius of curvature, $r < 0$
  - Focal length, $f < 0$

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

Spherical Refracting Surfaces

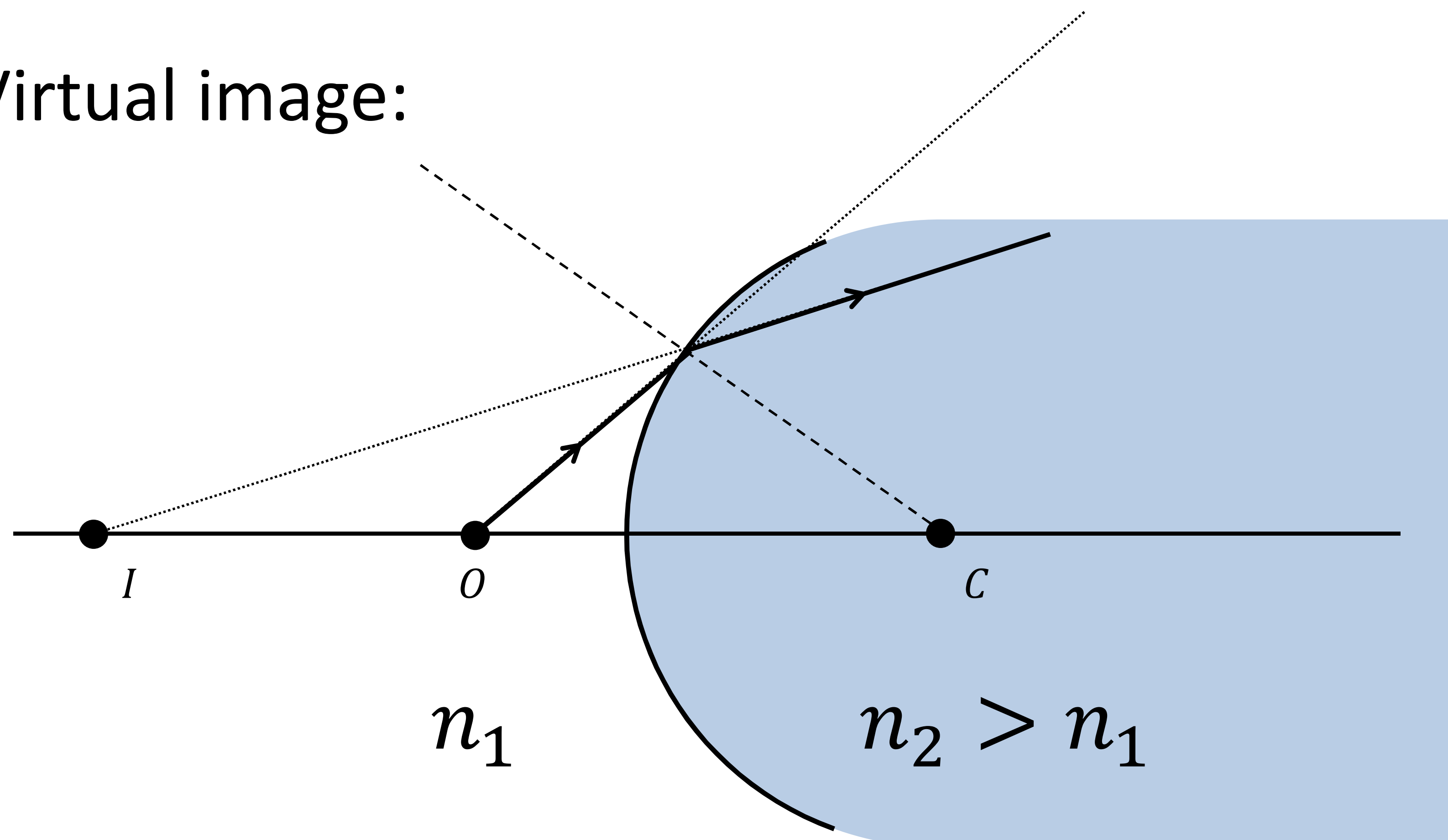
- Real image:



When the object is far from the surface, the refracted ray is directed towards the central axis forming a real image.

Spherical Refracting Surfaces

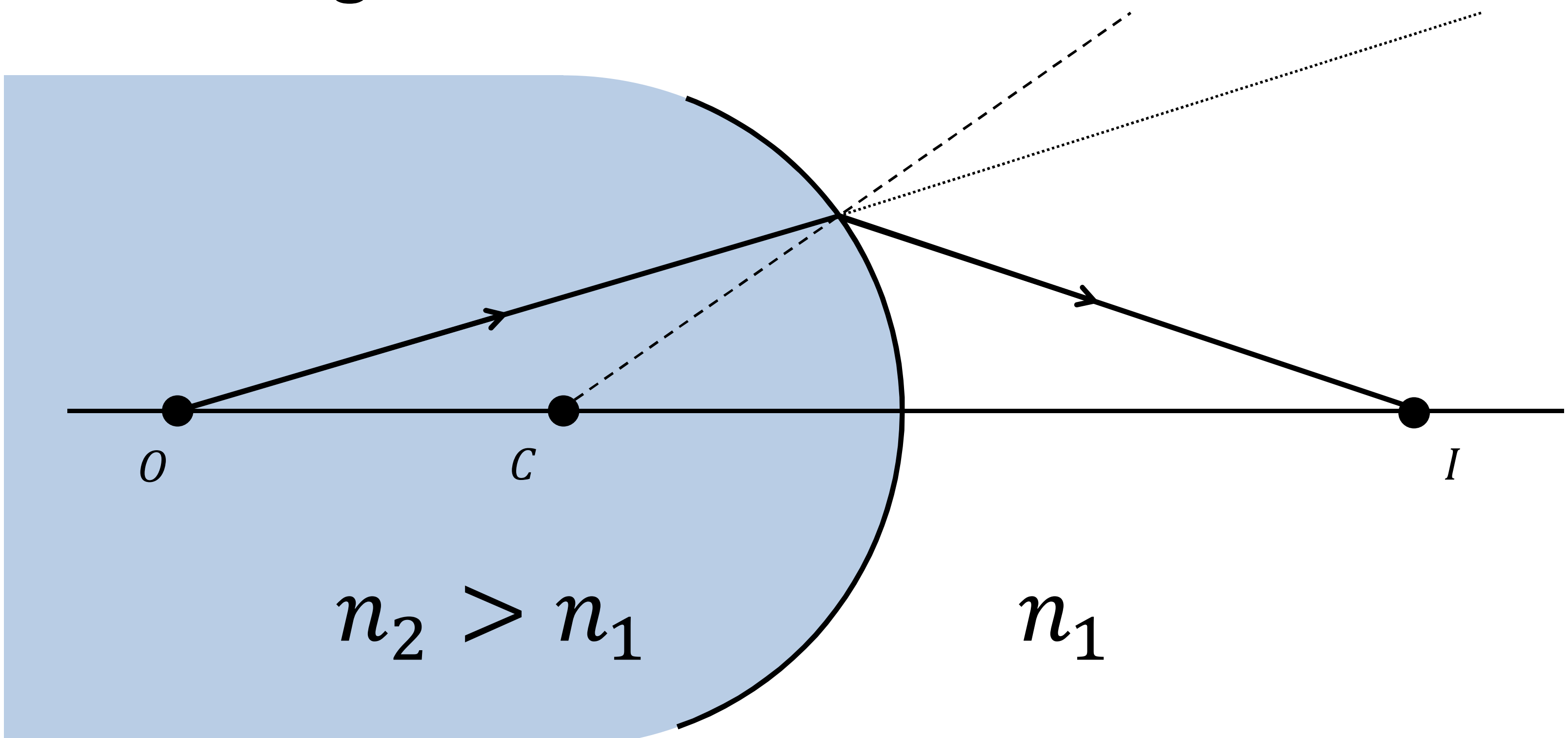
- Virtual image:



When the object is close to the surface, the refracted ray is directed away from the central axis forming a virtual image.

Spherical Refracting Surfaces

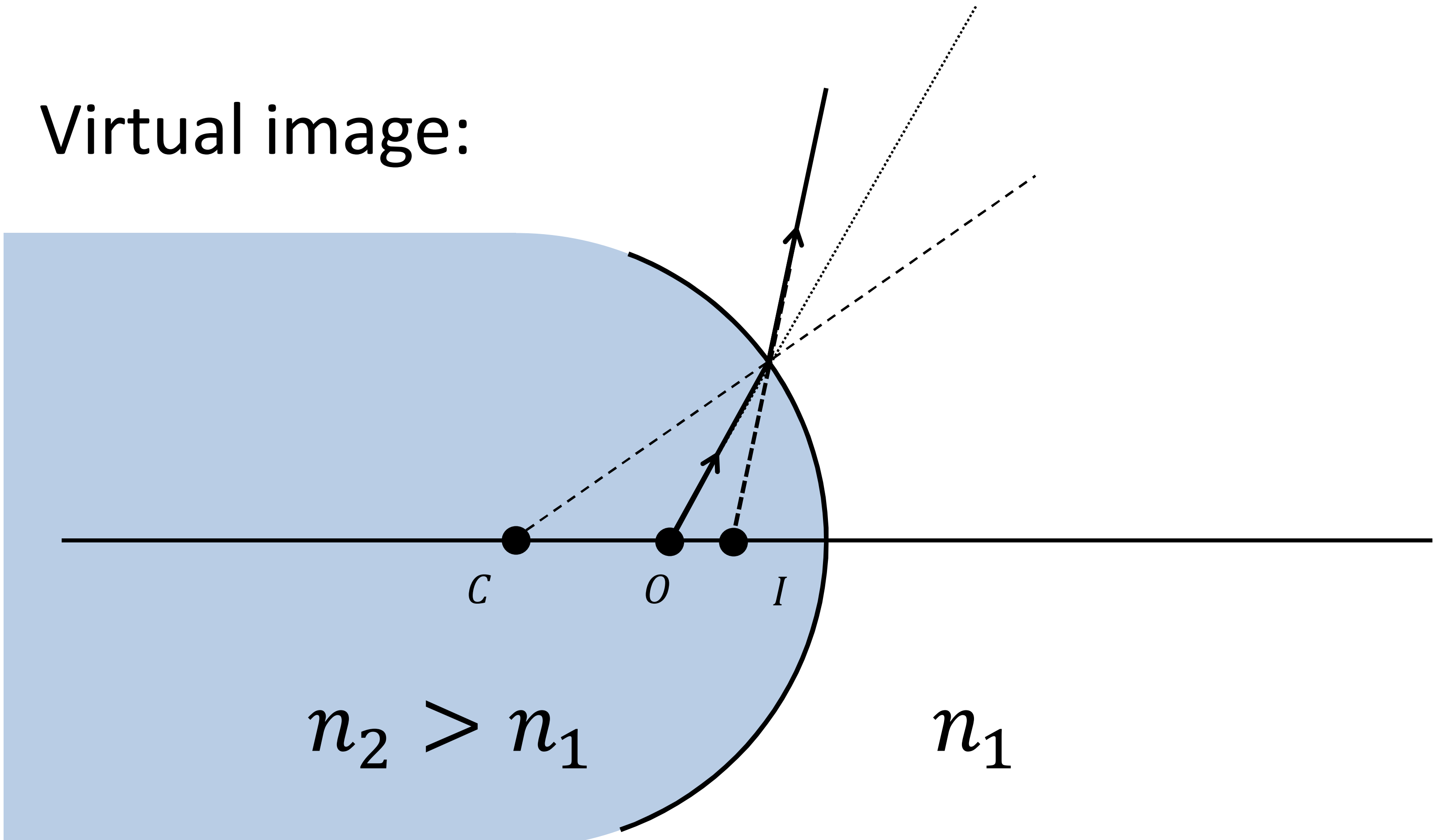
- Real image:



When the object is far from the surface, the refracted ray is directed towards the central axis forming a real image.

Spherical Refracting Surfaces

- Virtual image:

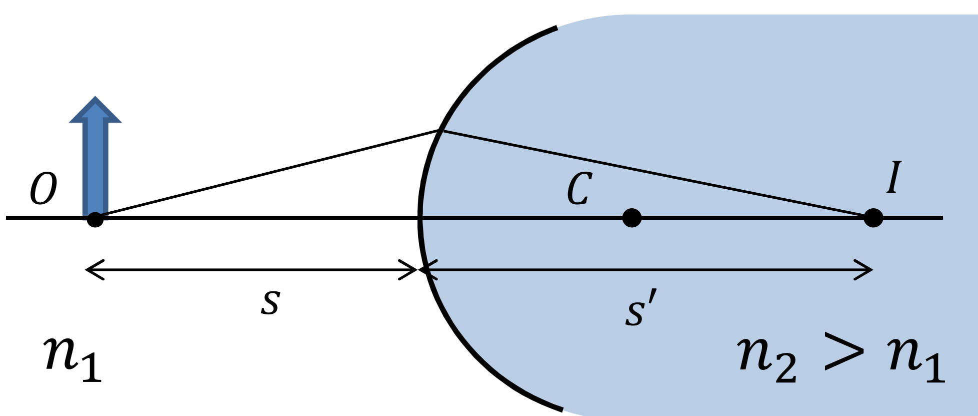


When the object is close to the surface, the refracted ray is directed away from the central axis forming a virtual image.

Small Angle Approximation

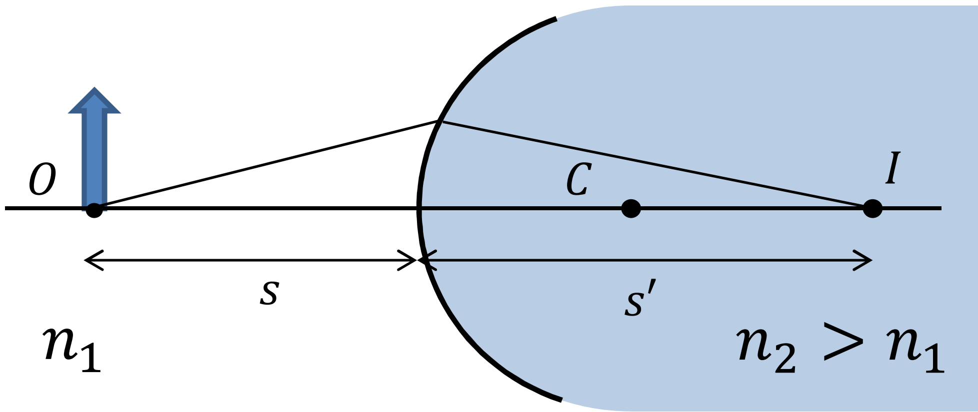
- When $\theta \ll 1$ then $\sin\theta \approx \theta$
  - – θ must be expressed in radians!
  - – When $\theta < 20°$ this is accurate to better than 1%
- Snell's Law:

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



$$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{r}$$

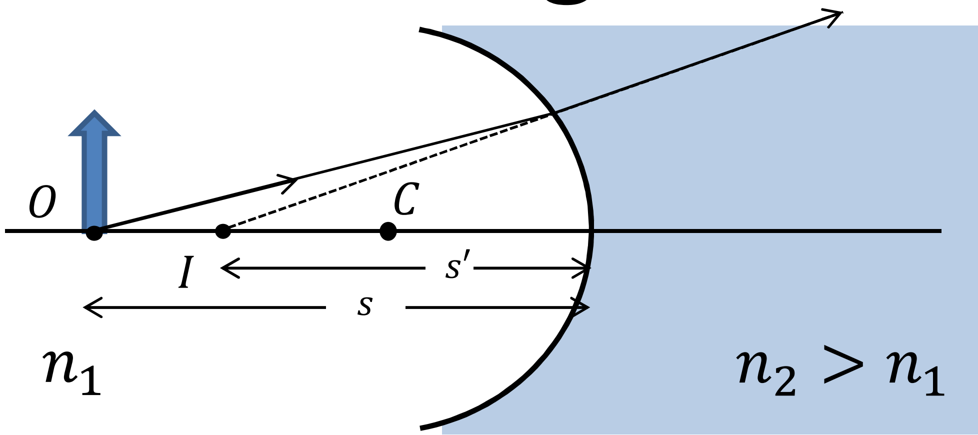
Sign Conventions



$$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{r}$$

- Convex surface:
  - s is positive for objects on the incident-light side
  - s' is positive for images on the refracted-light side
  - r is positive if C is on the refracted-light side

Sign Conventions

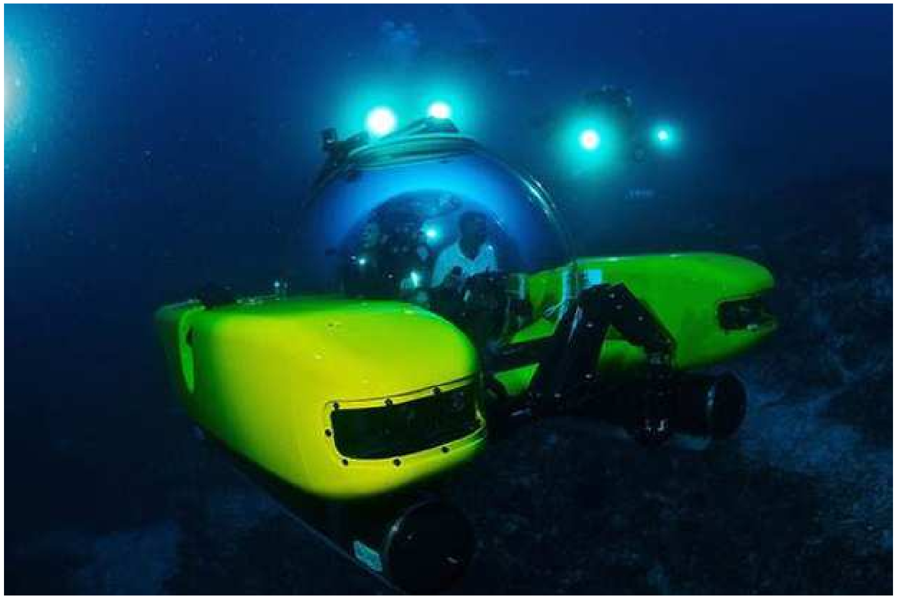


$$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{r}$$

(same formula)

- Concave surface:
  - s is positive for objects on the incident-light side
  - s' is negative for images on the incident-light side
  - r is negative if C is on the incident-light side

Question



You are looking out of the spherical window of a submarine at a sea creature that appears to be 1 meter away.

What signs should we use for r and s'?

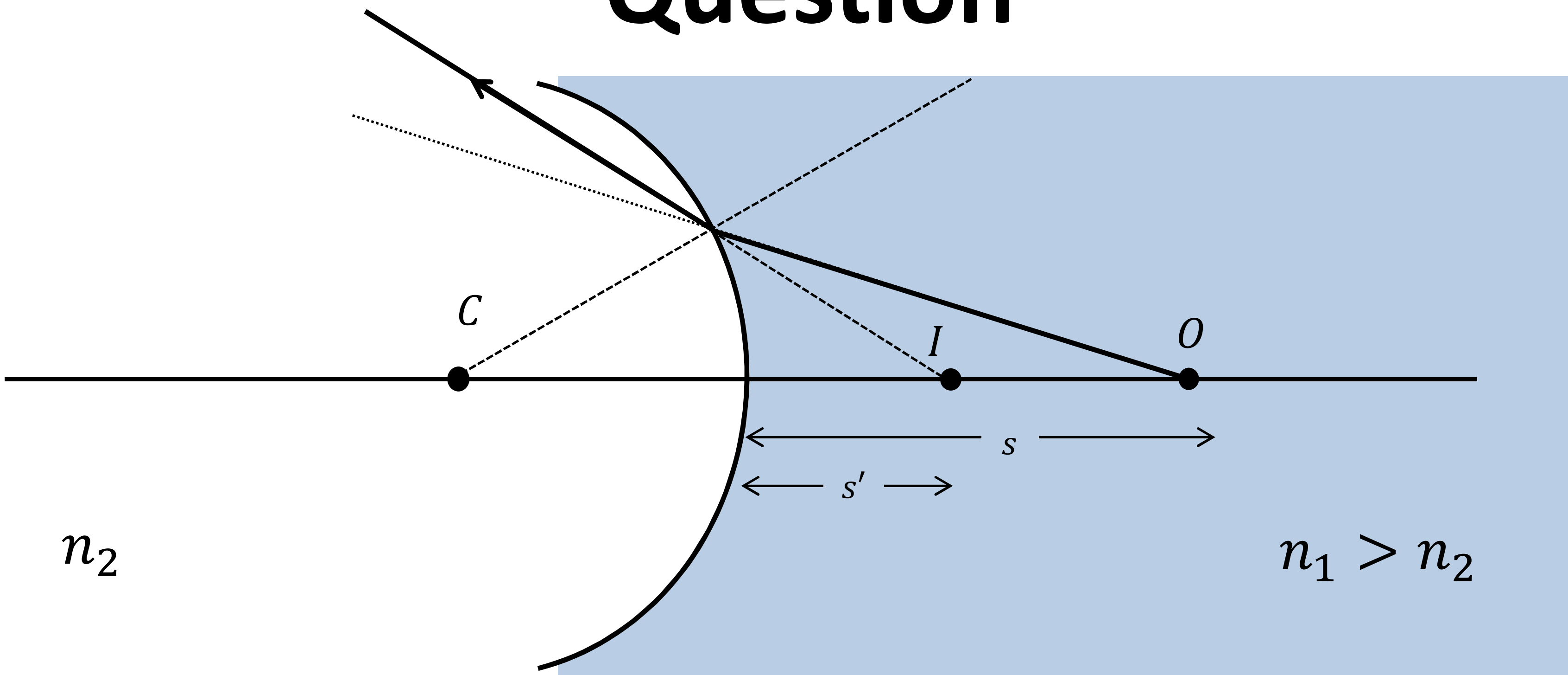
(a) + and +

(b) + and –

(c) – and +

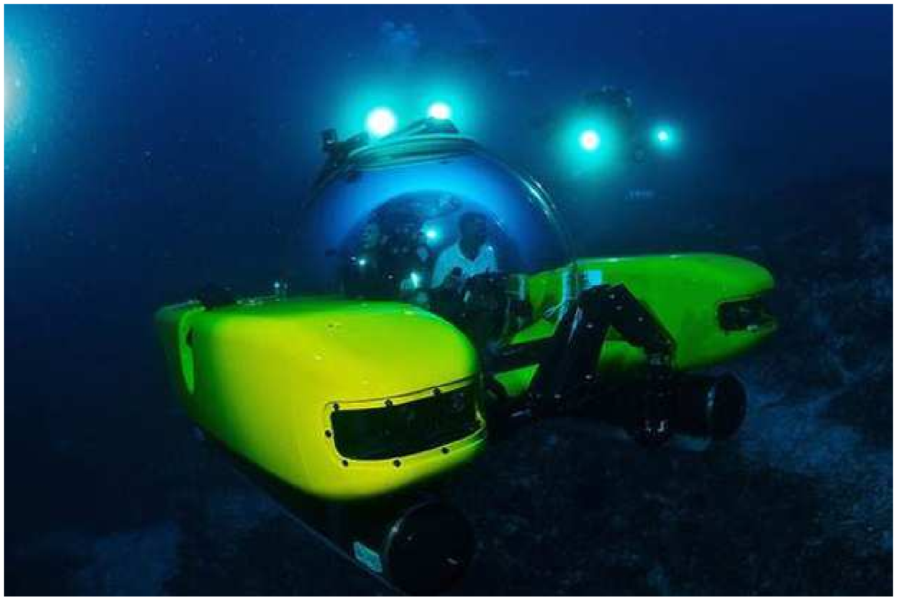
(d) – and –

Question



- The surface is convex, but $n_2 < n_1$
- C is on the refracted-light side: r is positive
- I is on the incident-light side: s' is negative
- *O is on the incident-light side: s is positive*

Example

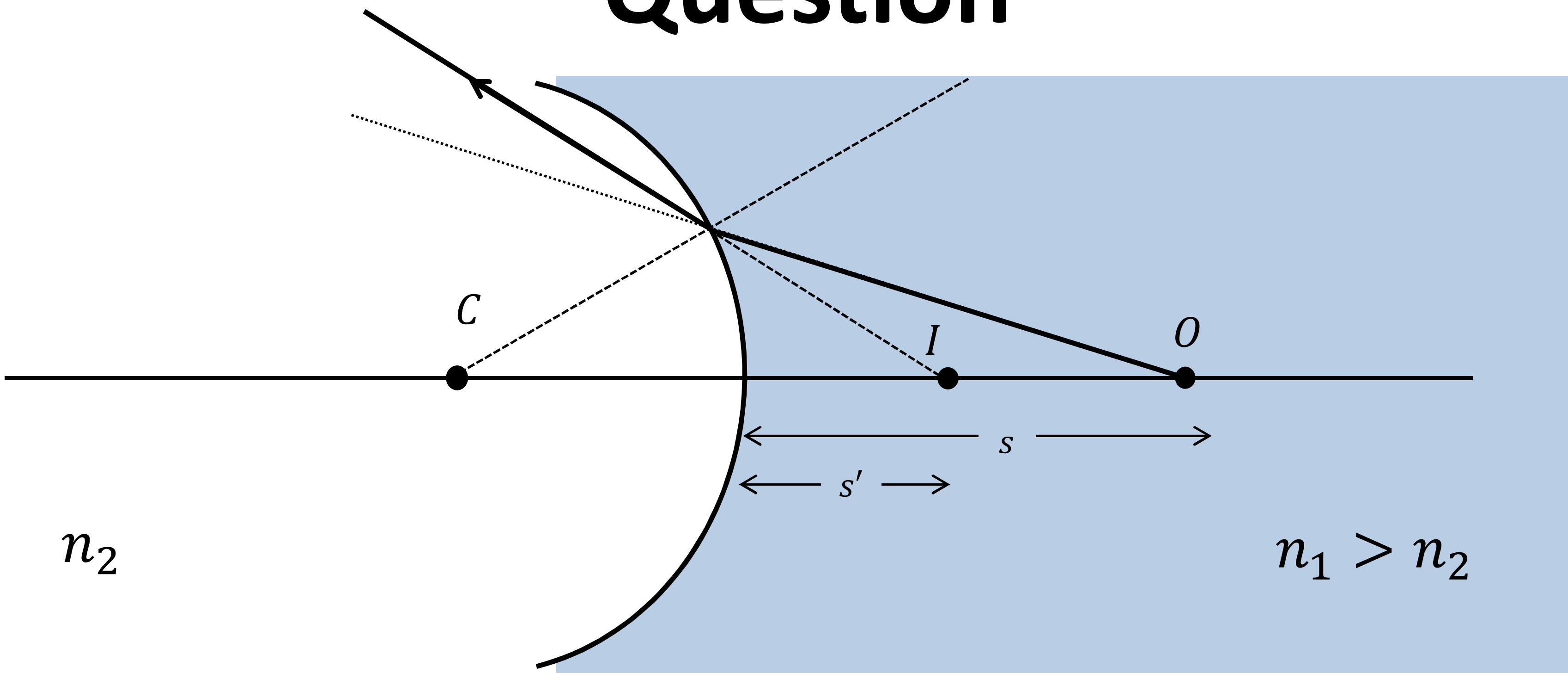


You are in a submarine looking out of a spherical window with a ***1 meter*** radius of curvature.

If a sea creature appears to be ***1 meter*** away, how far away is it really?

$$n_{air} = 1 \quad n_{water} = 1.333$$

Question



$$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{r}$$

$$\frac{1.333}{s} + \frac{1}{-1\,m} = \frac{1-1.333}{1\,m} \Rightarrow s = +2\,m$$

Magnification

- Using the same sign convention, the magnification is

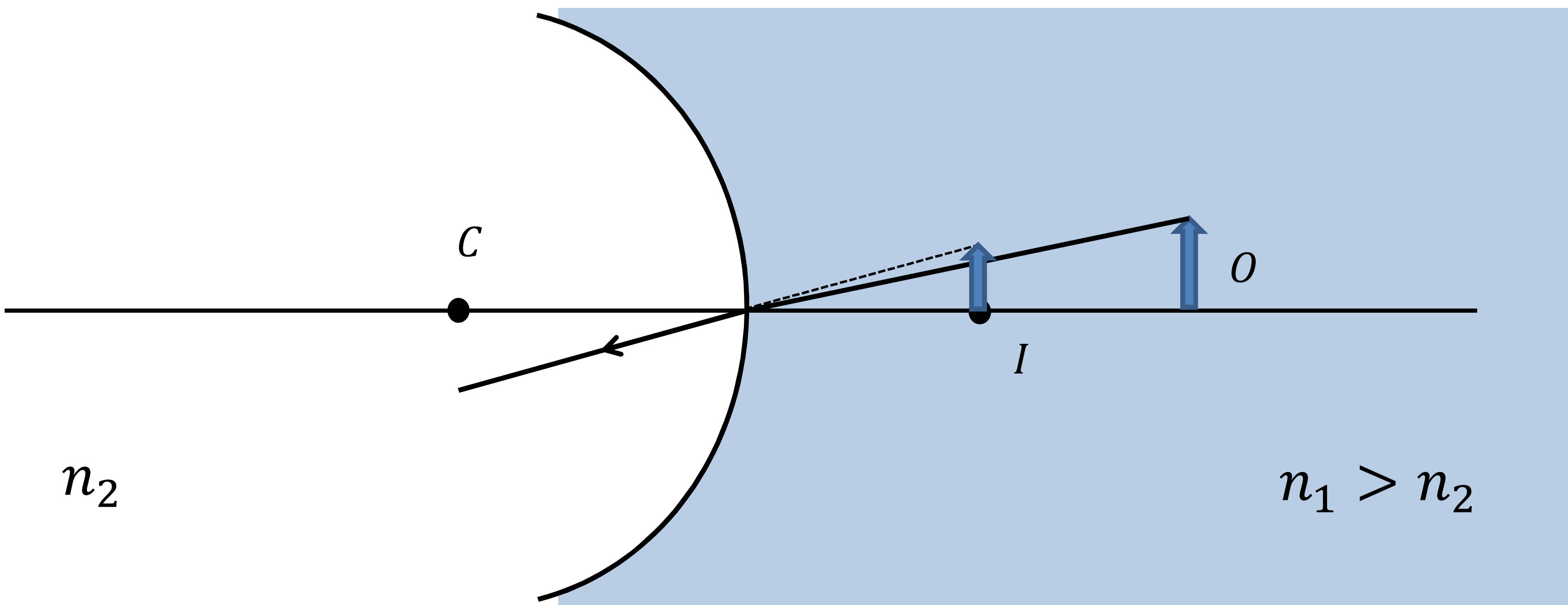
$$m = -\frac{n_1 s'}{n_2 s}$$

- For the previous example,

$$m = -\frac{1.33}{1}\frac{(-1\,m)}{(+2\,m)} = +0.66$$

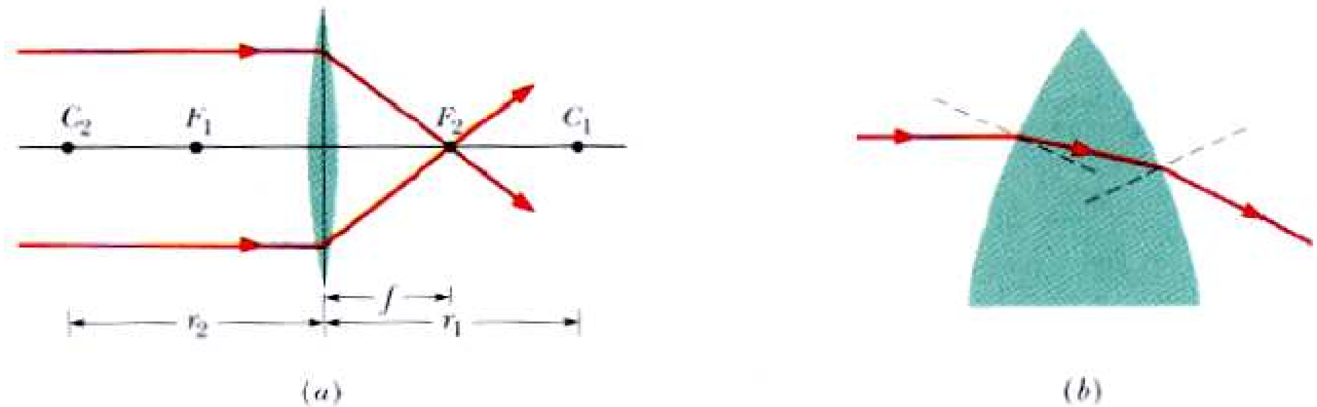
- The sea creature outside the submarine appears smaller than it really is.
- The image is not inverted.

Example



Thin Converging Lens

- Two refracting surfaces close together

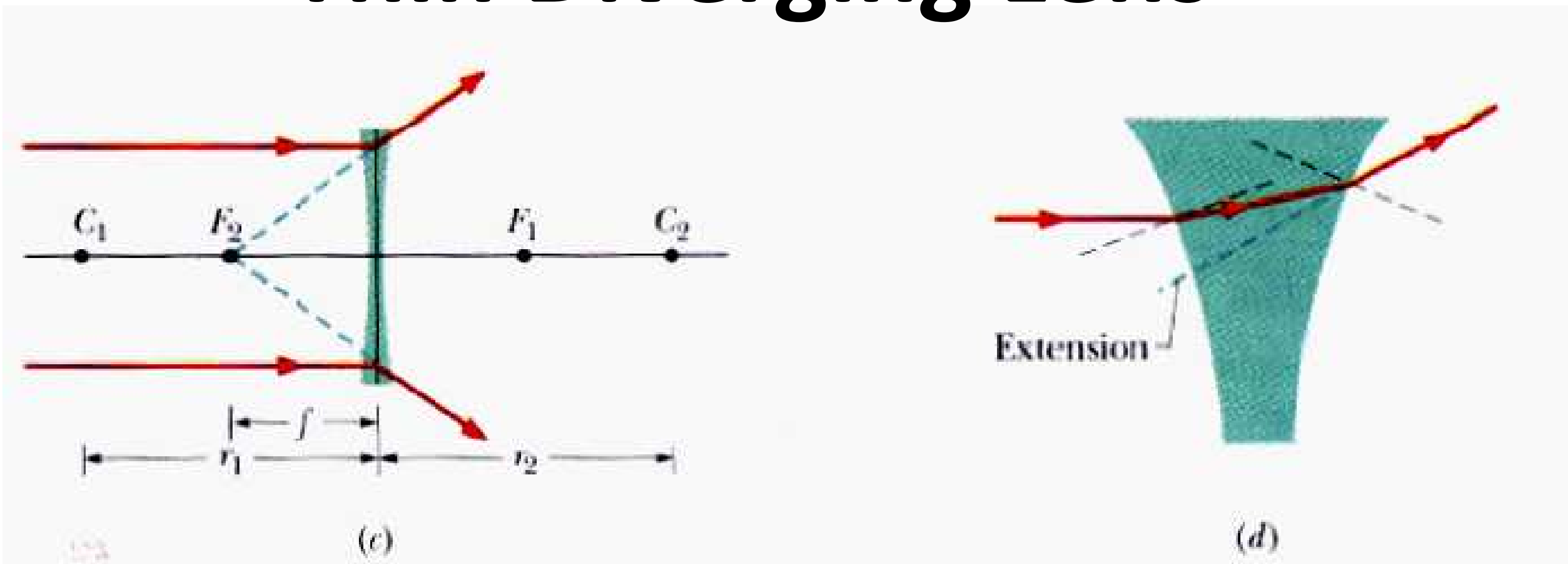


- For the front surface, C_1 is on the refracted-light side so r_1 is positive.
- For the back surface, C_2 is on the incident-light side so r_2 is negative.

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

f is positive
Image is real

Thin Diverging Lens

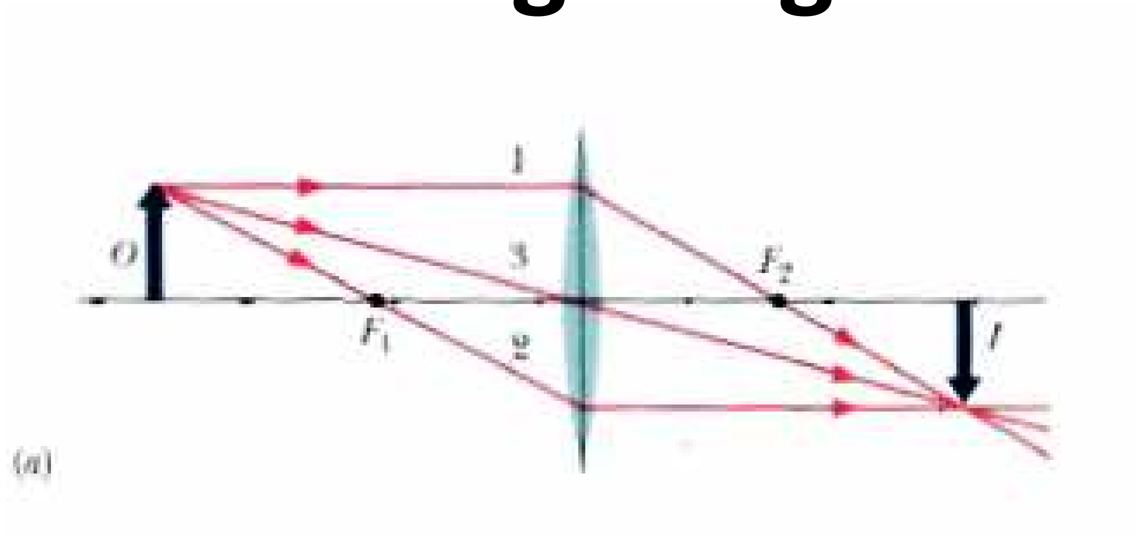


- For the front surface, C_1 is on the incident-light side so r_1 is negative.
- For the back surface, C_2 is on the refracted-light side so r_2 is positive.

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

f is negative
Image is virtual

Locating Images

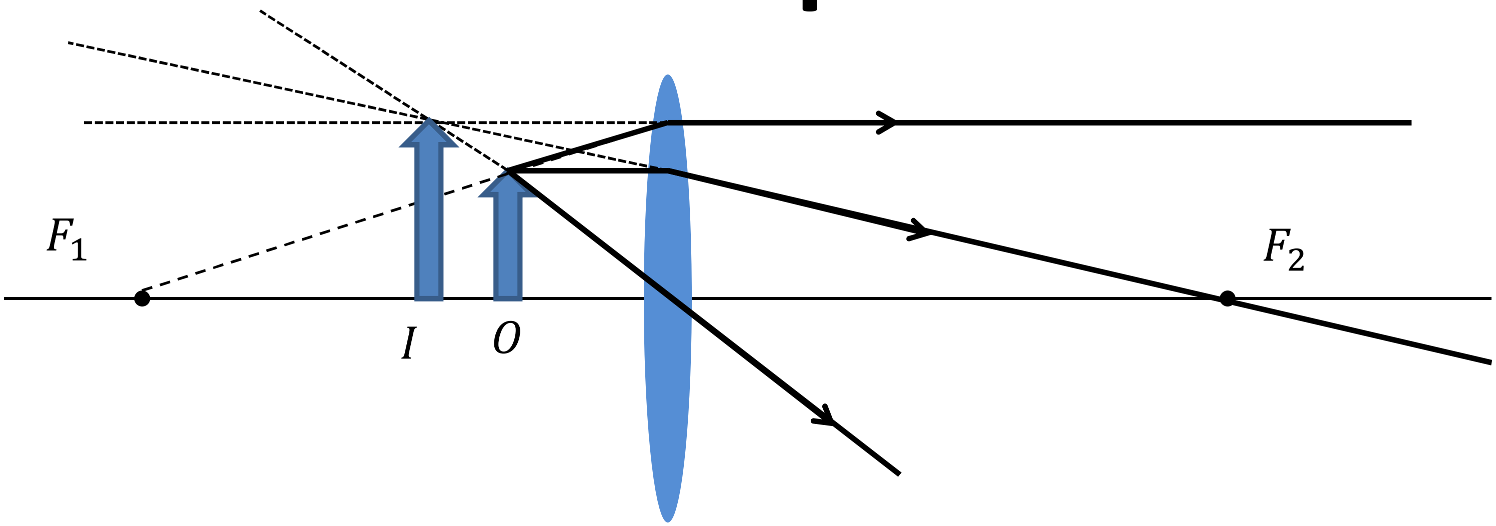


(1) A incident ray parallel to the central axis is refracted through F_2

(2) An incident ray passing through F_1 is refracted parallel to the central axis

(3) A ray passing through the lens on the central axis is not refracted

Example

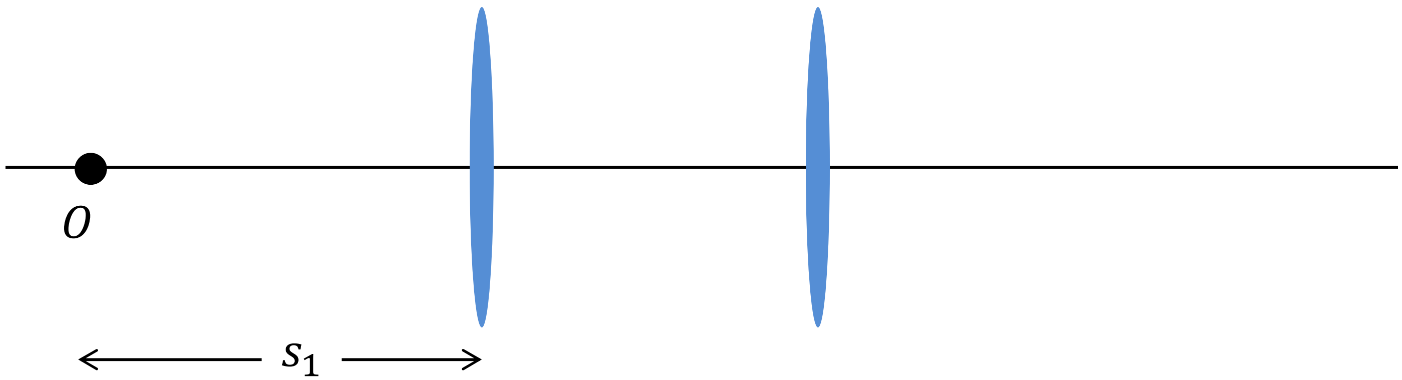


$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$ (thin lens equation)

$$m = \frac{y'}{y} = -\frac{s'}{s}$$ (magnification)

Two Lens Systems



- Calculate s_1' using $\frac{1}{f_1} = \frac{1}{s_1} + \frac{1}{s_1'}$
- Ignore the first lens, treat s_1' as the object distance for the second lens. Calculate s_2' using $\frac{1}{f_2} = \frac{1}{s_2} + \frac{1}{s_2'}$
- Overall magnification: $M = m_1 m_2 = \left(-\frac{s_1'}{s_1}\right)\left(-\frac{s_2'}{s_2}\right)$

Example: Two Lens System

A seed is placed in front of two thin symmetrical coaxial lenses (lens 1 & lens 2) with focal lengths f_1=+24 cm & f_2=+9.0 cm, with a lens separation of L=10.0 cm. The seed is 6.0 cm from lens 1. Where is the image of the seed?

Lens 1: $$\frac{1}{f_1} = \frac{1}{s_1} + \frac{1}{s_1'} \quad \Rightarrow \quad s_1' = -8\ cm$$

Image 1 is virtual.

Lens 2: Treat image 1 as O_2 for lens 2. O_2 is outside the focal point of lens 2. So, image 2 will be real & inverted on the other side of lens 2.

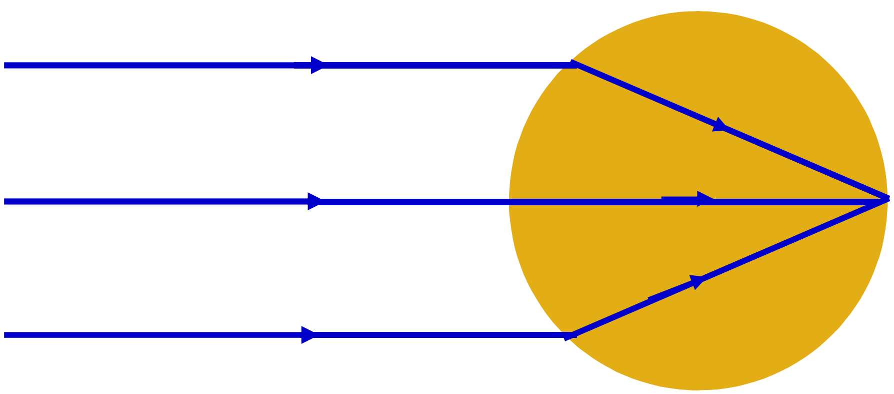
$$s_2 = L + |s_1'| = 18cm$$

$$\frac{1}{f_2} = \frac{1}{s_2} + \frac{1}{s_2'} \quad \Rightarrow \quad s_2' = 18.0cm$$

Image 2 is real.

Clicker Question

A beam of parallel light rays from a laser is incident on a solid transparent sphere of index of refraction n. If a point image is produced at the back of the sphere, what is the index of refraction of the sphere?



(A) 0

(B) 0.5

(C) 1.0

(D) 1.5

(E) 2.0