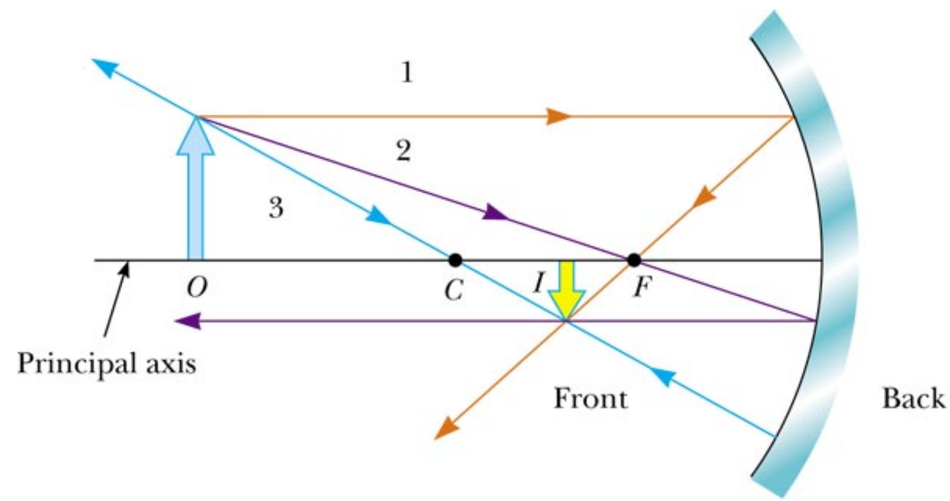
Physics 294H

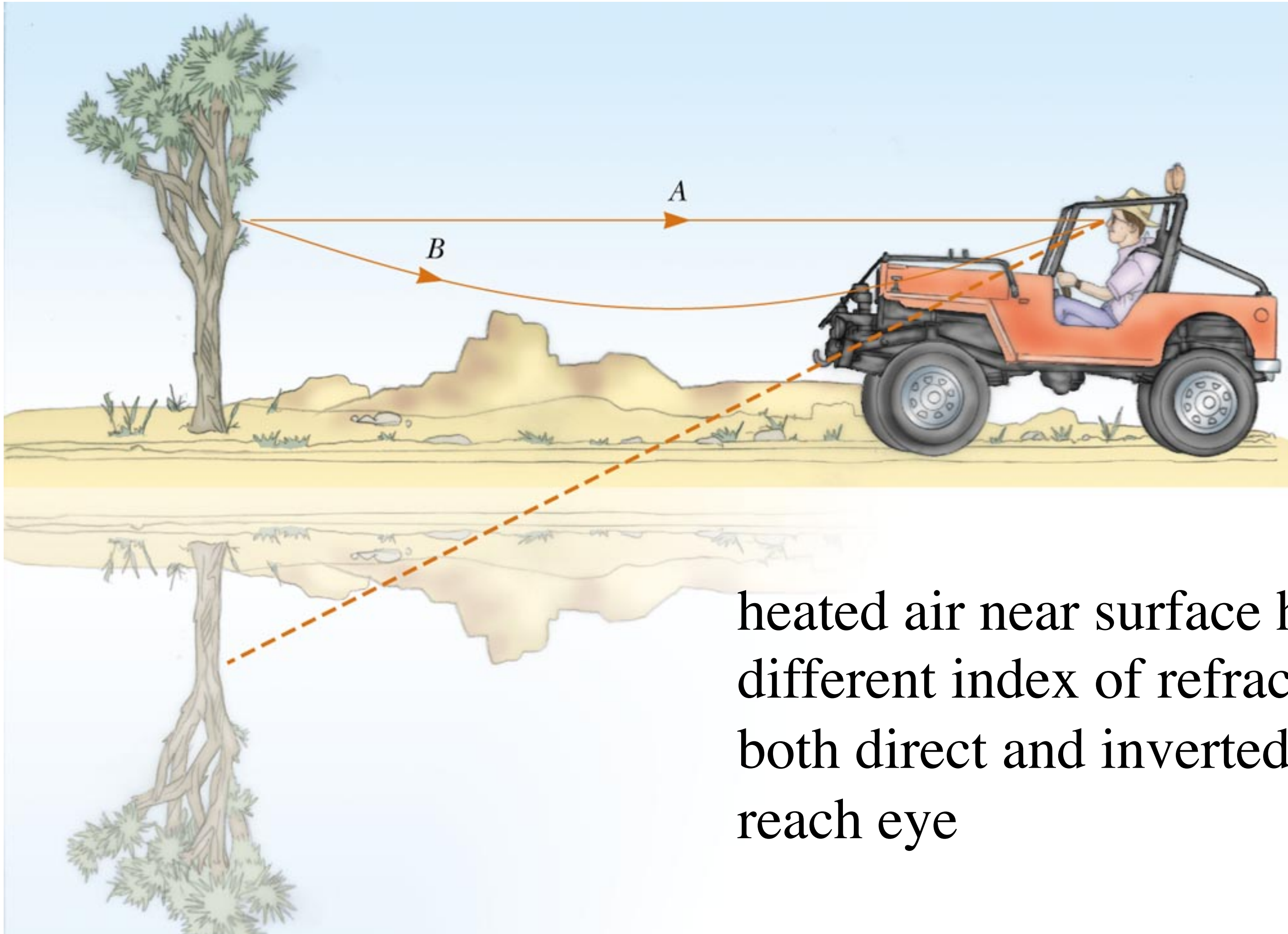
- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Help-room hours: 12:40-2:40 Monday (note change); 3:00-4:00 PM Friday**
  - **36.73 hand-in problem for next Wed**
- Quizzes by iclicker (sometimes hand-written)
- Average on 2nd exam (so far)=71/120
- **Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS**
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

Example

- A dime 40 cm away from, and on the optical axis of, a concave, spherical mirror produces an image 10 cm away from the mirror.
- If the dime is moved on the axis to 20 cm from the mirror, where will the image move? How large is the radius of curvature of the mirror?



Refracted images: Mirages



heated air near surface has a different index of refraction; both direct and inverted image reach eye

Flat refracting surfaces

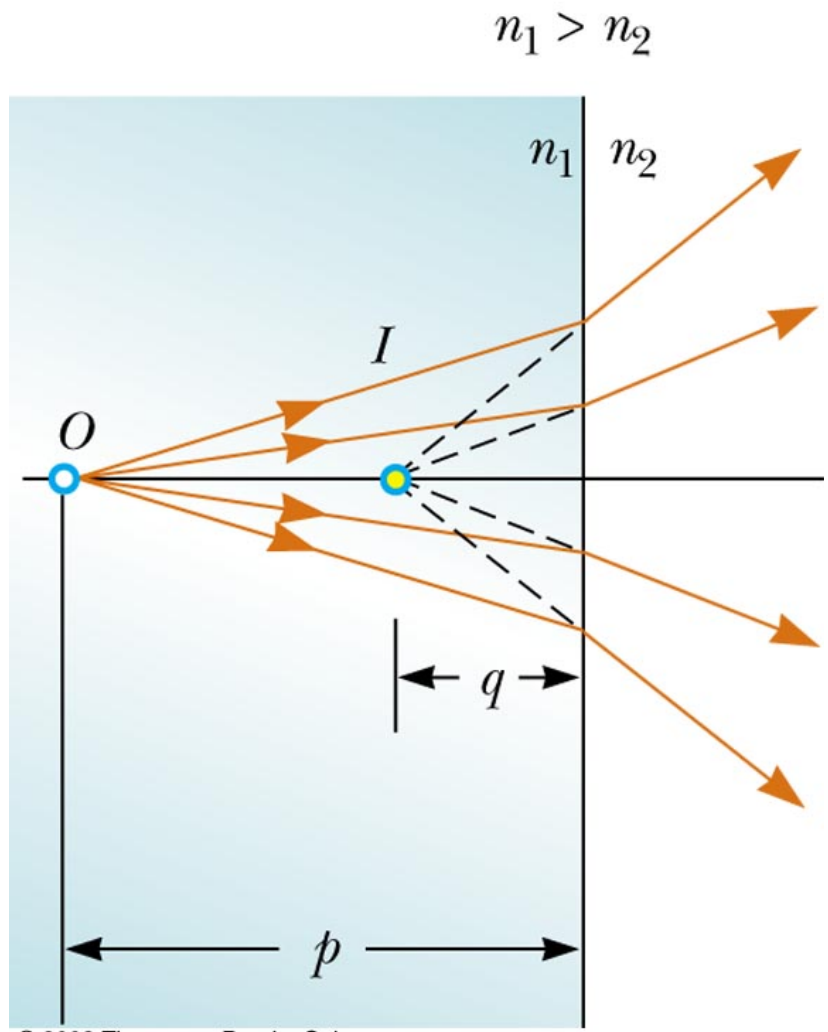
- If the refracting surface is flat, then R approaches infinity

$$\frac{n_1}{p}+\frac{n_2}{q} = \frac{n_2-n_1}{R}$$

$$\frac{n_1}{p} =- \frac{n_2}{q}$$

$q = -n_2/n_1\ p$

- The image of a flat refracting surface is on the same side of the surface and the image distance is smaller than the object distance



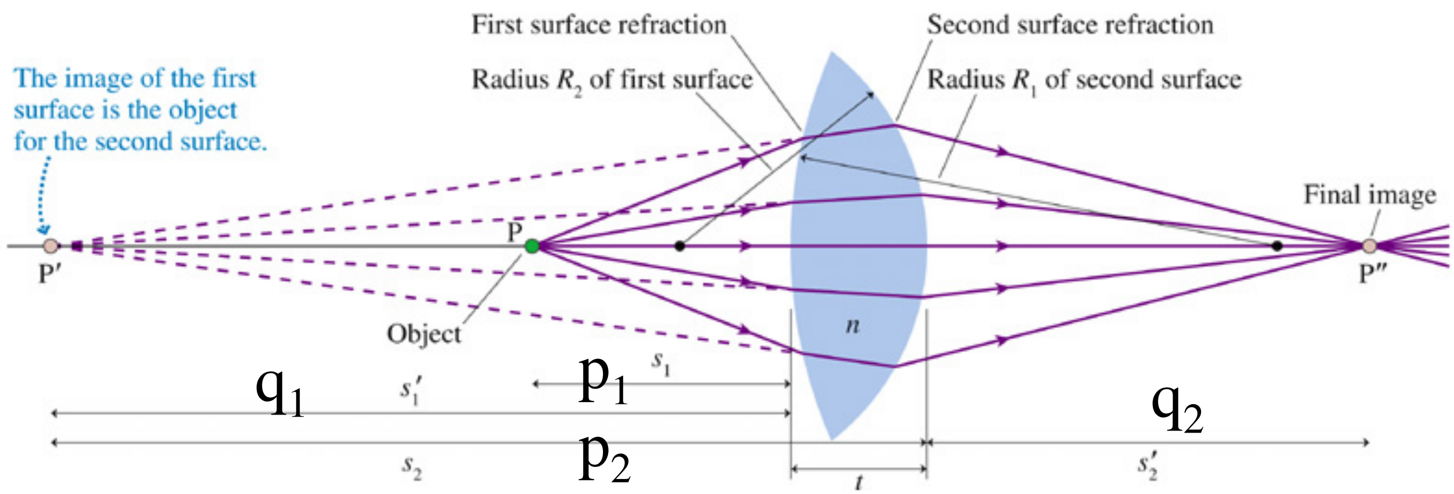
Lenses

- A lens consists of two spherical surfaces having radii of curvature R_1 and R_2
- Assume the lens material has an index of refraction n, has thickness t, and is in air
- An object is at point P a distance p_1 to the left of the lens
- The refraction from the first surface creates a virtual image at P'
- We can solve for the distance q_1

$$\frac{1}{p_1} + \frac{n}{q_1} = \frac{n-1}{R_1}$$

- The image at P' becomes the object for the second surface
  - one trick: q_1 is negative so $p_2 = t - q_1$
  - 2nd trick: $n_1 = n$, $n_2 = 1$

$$\frac{n}{t-q_1} + \frac{n}{q_2} = \frac{1-n}{R_2}$$



Lenses

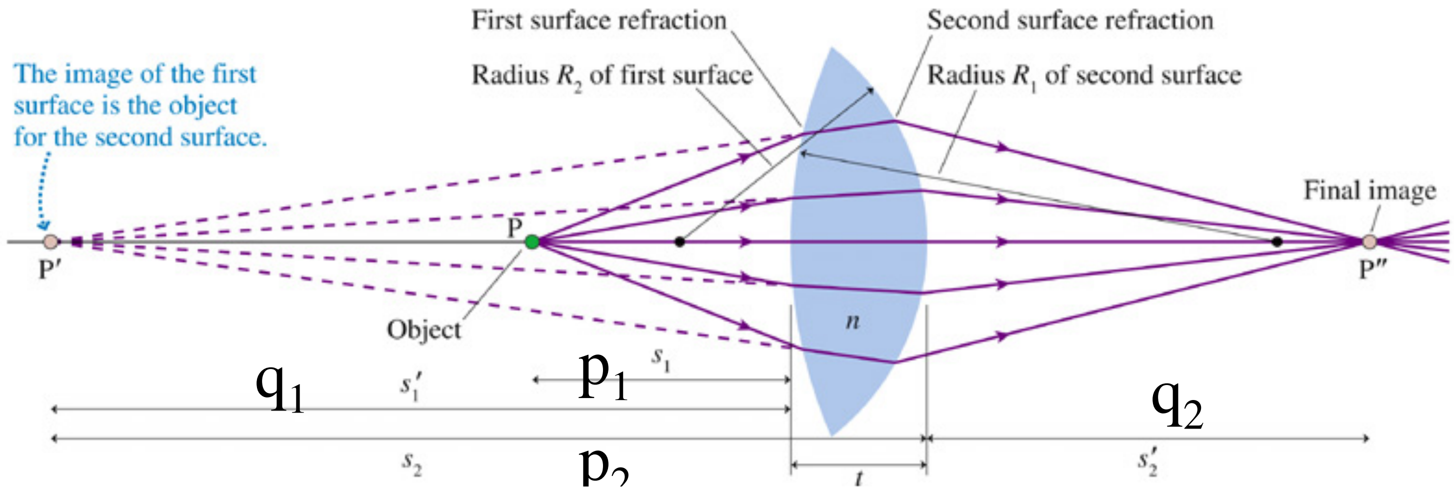
- For thick lens, we can solve the two equations in sequence

$$\frac{1}{p_1} + \frac{n}{q_1} = \frac{n-1}{R_1}$$

Find the image distance q_1

$$\frac{n}{t-q_1} + \frac{n}{q_2} = \frac{1-n}{R_2}$$

Use that image distance as the object distance p_2, then solve for q_2



Lenses

- For thick lens, we can solve the two equations in sequence

$$\frac{1}{p_1}+\frac{n}{q_1}=\frac{n-1}{R_1}$$

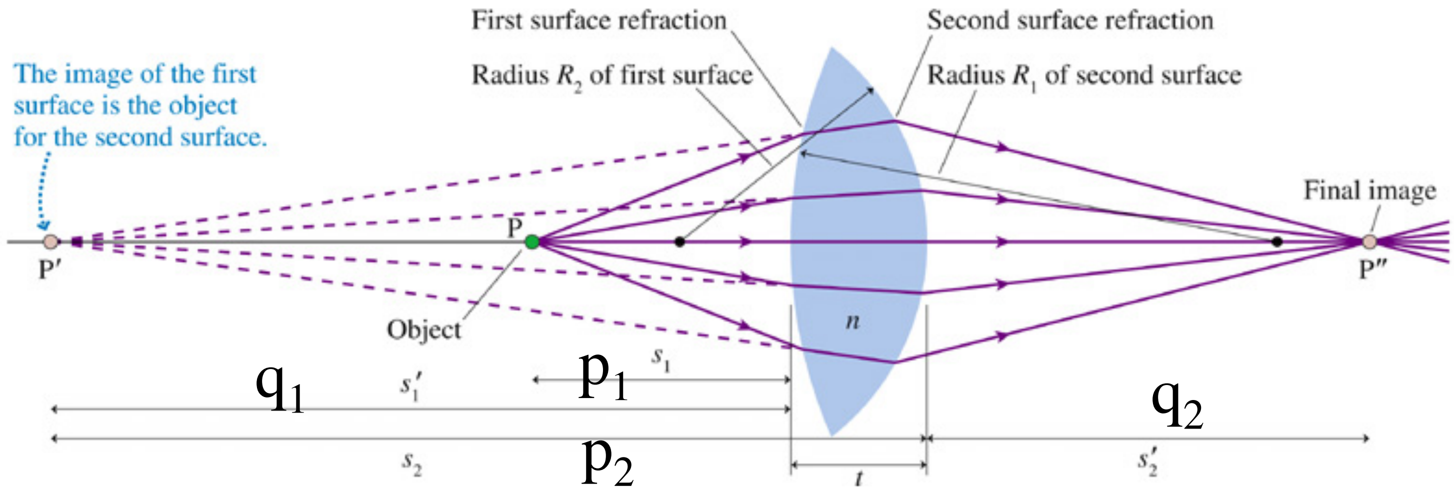
$$\frac{n}{t-q_1}+\frac{n}{q_2}=\frac{1-n}{R_2}$$

$$\frac{-n}{q_1}+\frac{1}{q_2}=\frac{1-n}{R_2}=-\frac{n-1}{R_2}$$

- I'm going to add these two equations

- But we're lazy, so we'll take the limit as t->0 (thin lens)

$$\frac{1}{p_1}+\frac{1}{q_2}=\frac{n-1}{R_1}-\frac{n-1}{R_2}=(n-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$



Thin Len equation

- Remember this equation from the previous transparency

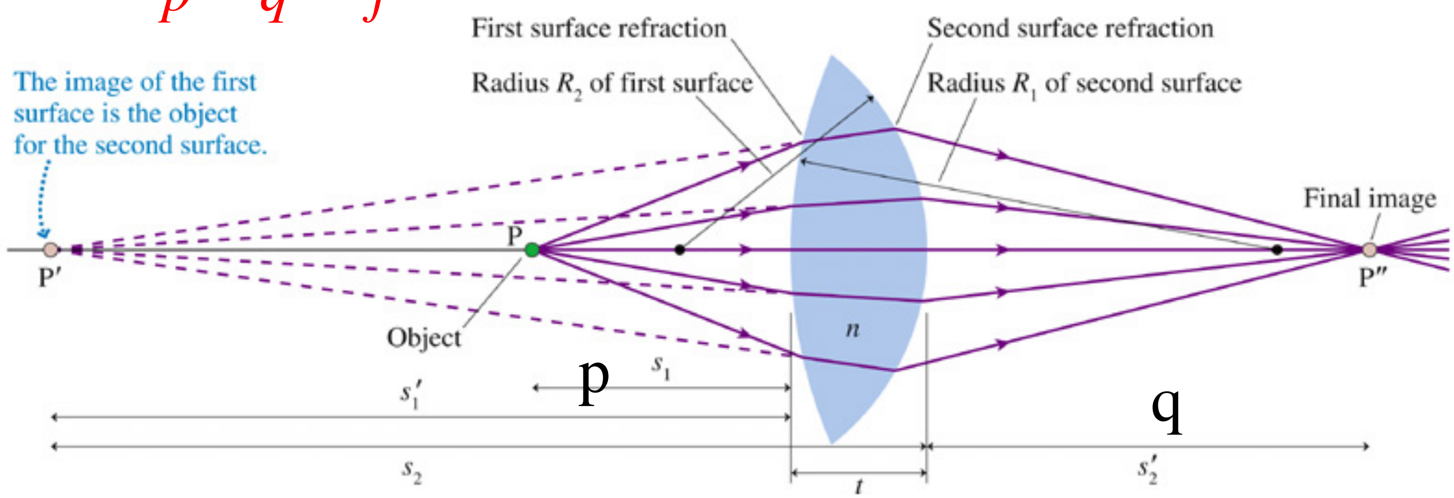
$$\frac{1}{p_1}+\frac{1}{q_2}=\frac{n-1}{R_1}-\frac{n-1}{R_2}=(n-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

- Let's forget subscripts
  - p_1=p=object distance
  - q_2=q=image distance

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$$

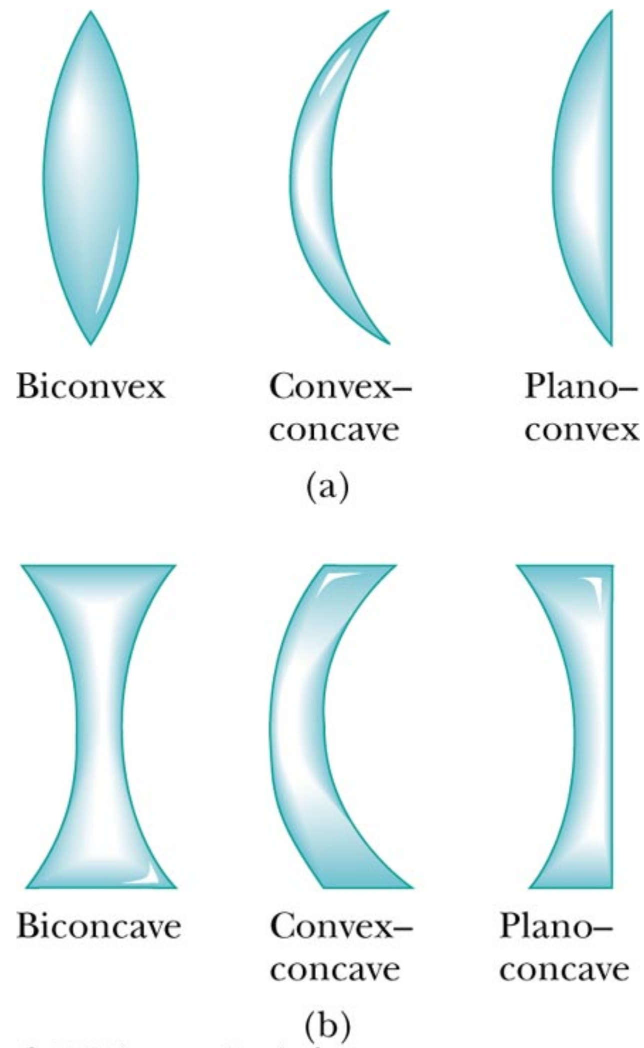
- The focal length of the lens is given by (lensmaker's equation)

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



Thin lenses

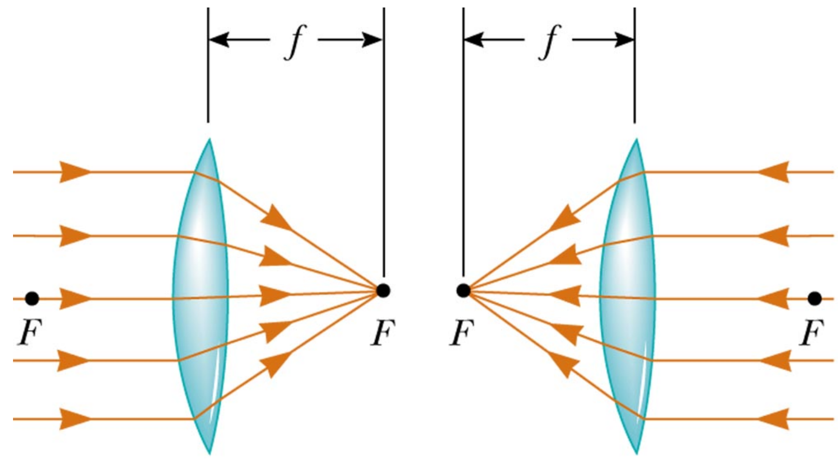
- Typically have 2 refracting surfaces back to back, relatively close together
  - i.e. a thin lens
- Thin lenses are very useful
  - many students here are wearing thin lenses
- Several different types of lenses, depending on curvature of both surfaces
  - if lens is thicker in middle then on edges, it's a converging lens; if thicker at the edges, it's a diverging lens



I know, more definitions.

Focal point

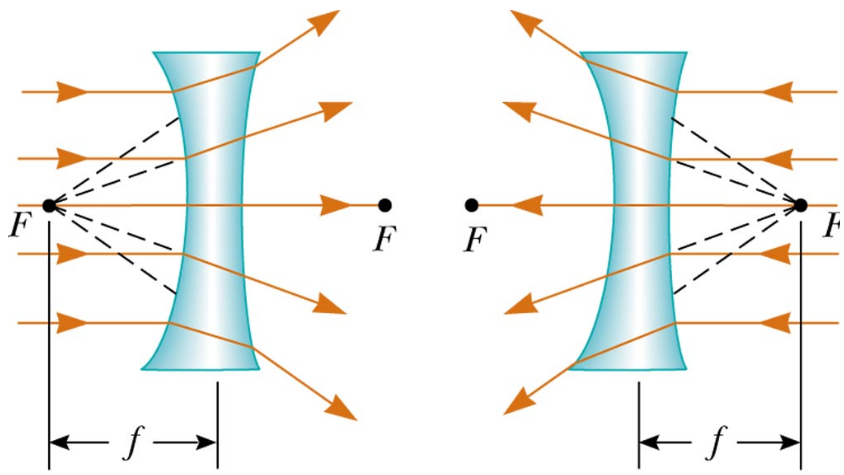
- As for mirrors, it's useful to define a focal point, and a focal length
  - the point where parallel rays converge
  - note focal point on either side of a lens
  - we are assuming thin lenses, so ignore thickness of lens in calculating f



(a)

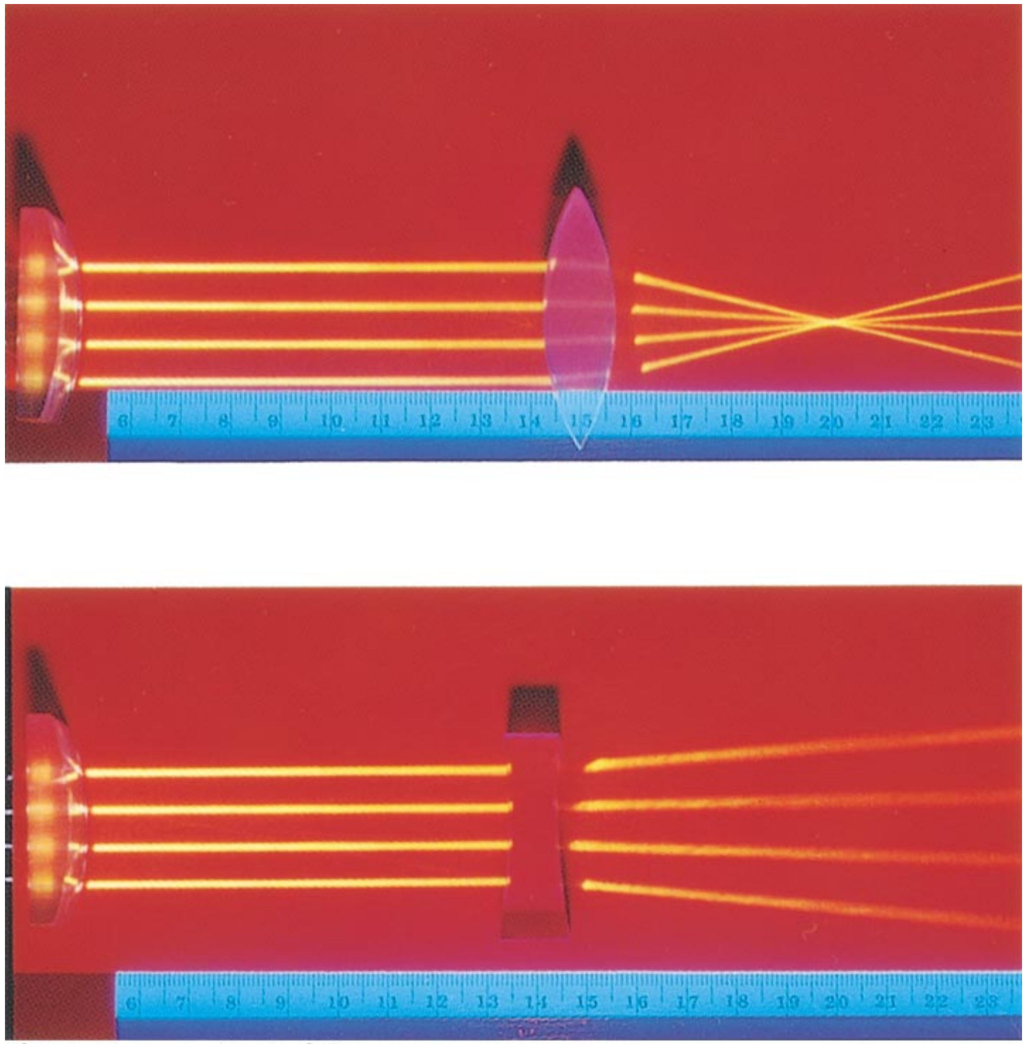
Diverging lenses

- Can also define focal point and focal length for diverging lenses
- Note that image is a virtual image, on same side of lens as source of light

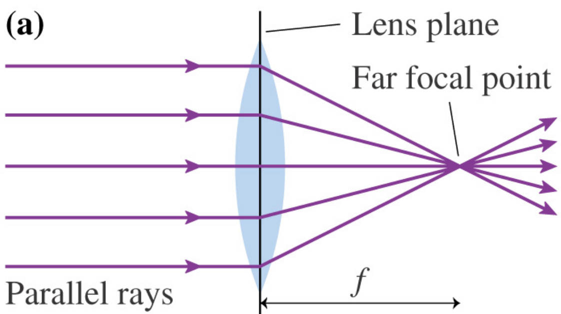


(b)

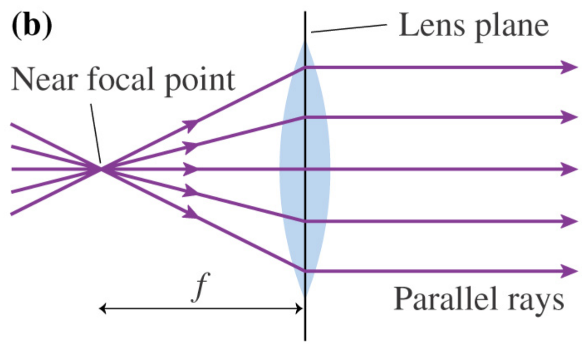
Lenses



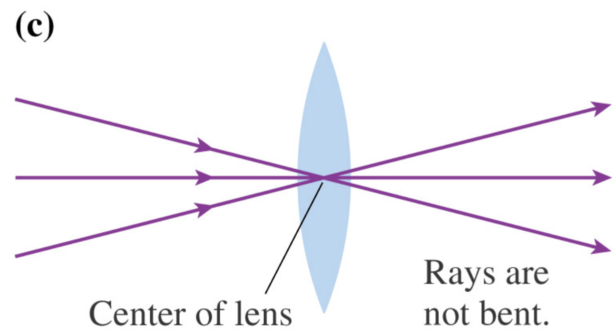
Thin lenses: ray tracing



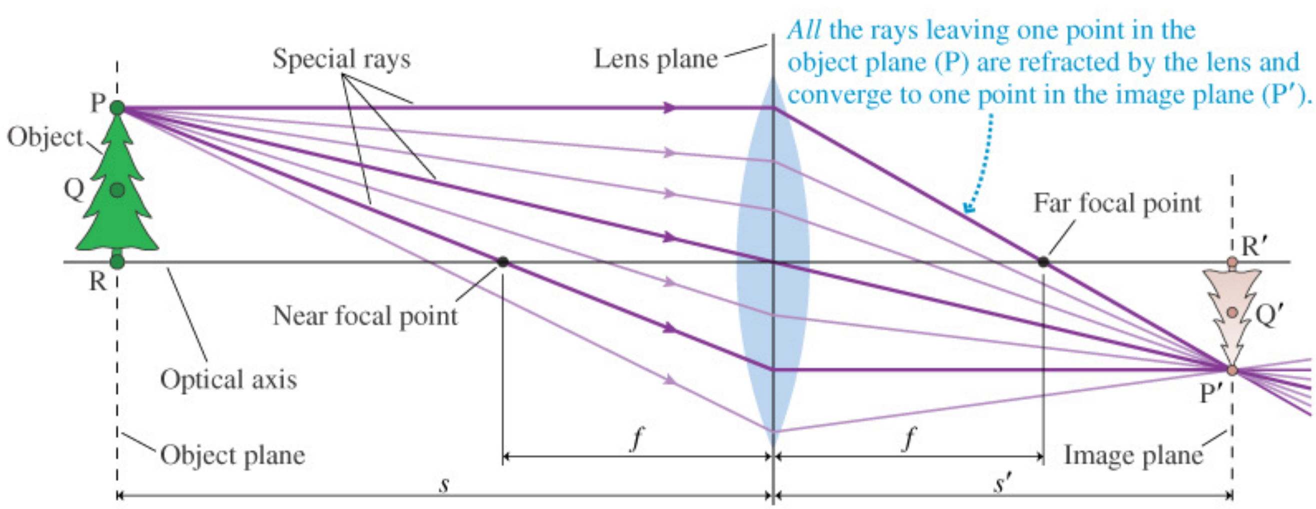
Any ray initially parallel to the optical axis will refract through the focal point on the far side of the lens.



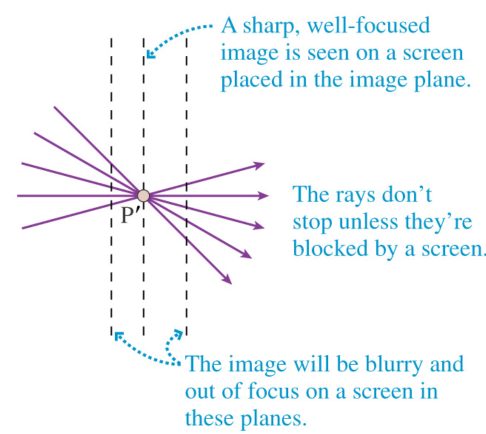
Any ray passing through the near focal point emerges from the lens parallel to the optical axis.



Any ray directed at the center of the lens passes through in a straight line.



p q



More definitions (for thin lenses)

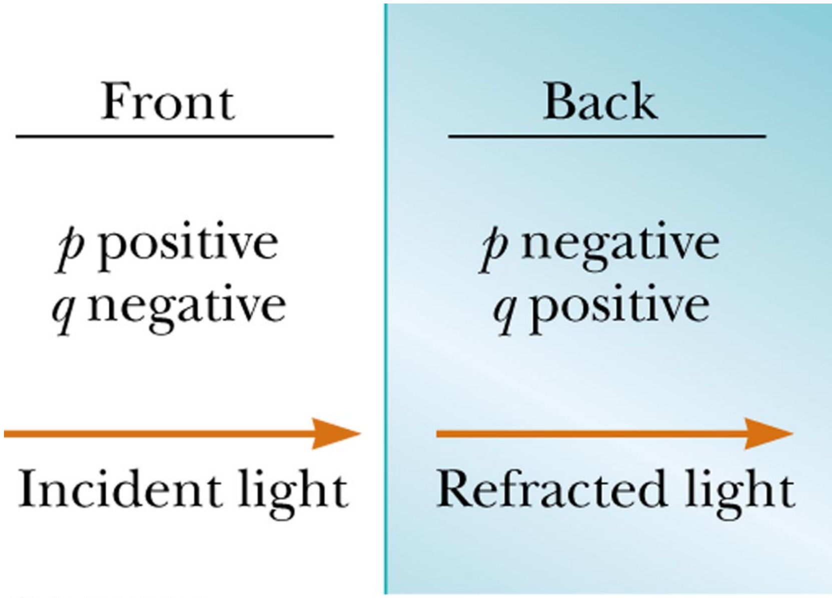
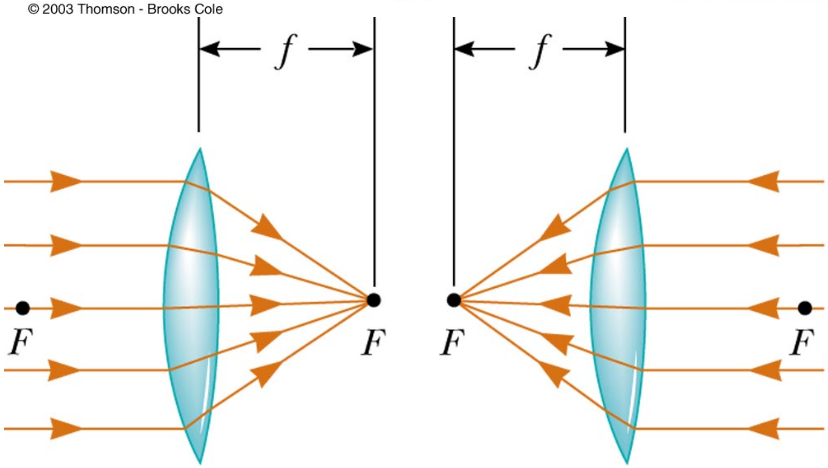
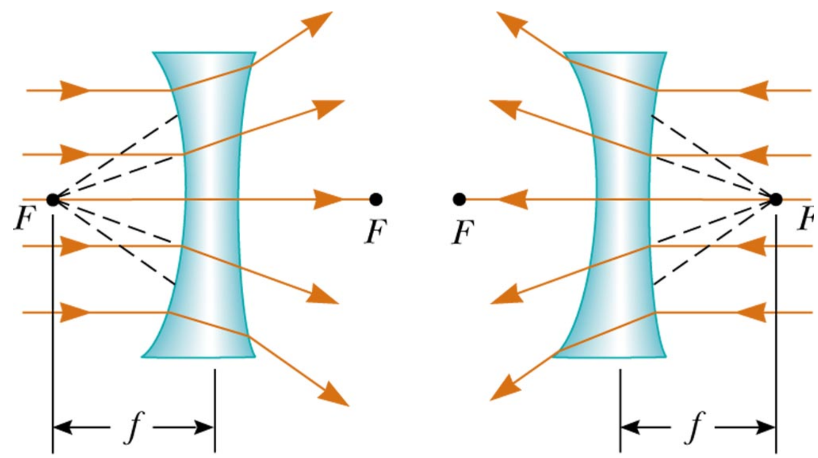


TABLE 23.3 Sign Conventions for Thin Lenses

Quantity	Positive When	Negative When
Object location (p)	Object is in front of lens	Object is in back of lens
Image location (q)	Image is in back of lens	Image is in front of lens
Image height (h')	Image is upright	Image is inverted
R_1 and R_2	Center of curvature is in back of lens	Center of curvature is in front of lens
Focal length (f)	Converging lens	Diverging lens



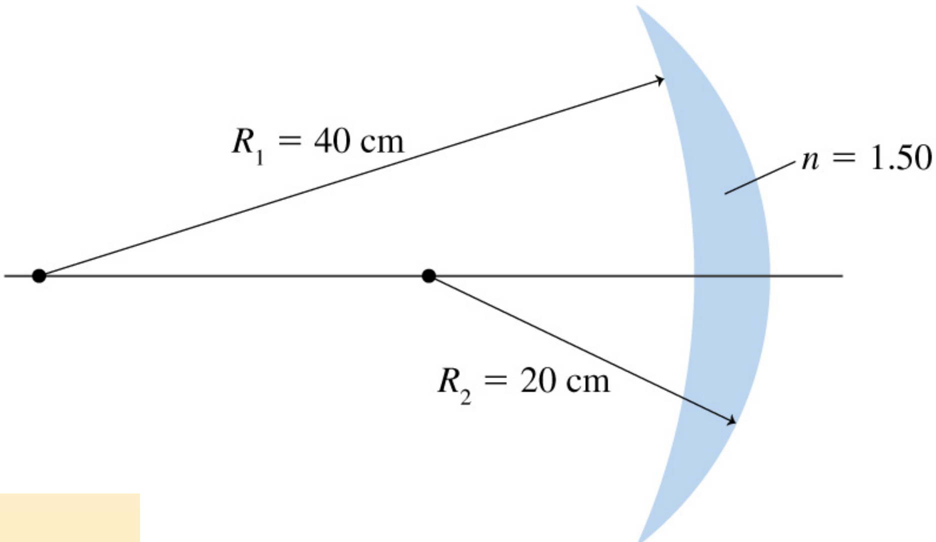
(a)



(b)

Example

- What is the focal length of the lens shown to the right? Is it a converging or diverging lens?



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You can use the sun's rays and a lens to start a fire. To do so, you should use

A. A converging lens.
B. A diverging lens.
C. Either a converging or a diverging lens will work if you use it correctly.

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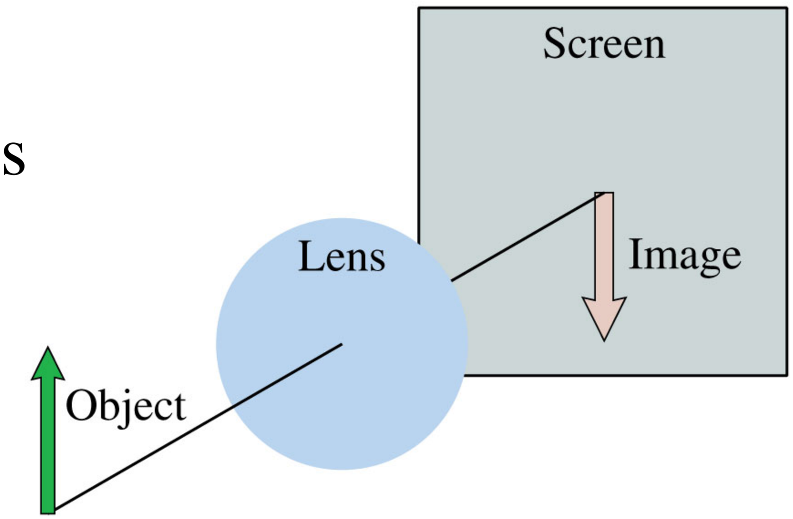
✔ **A. A converging lens.**

B. A diverging lens.

C. Either a converging or a diverging lens will work if you use it correctly.

A lens produces a sharply focused, inverted image on a screen. What will you see on the screen if the lens is removed?



A. An inverted but blurry image.
B. An image that is dimmer but otherwise unchanged.
C. A sharp, upright image.
D. A blurry, upright image.
E. No image at all.

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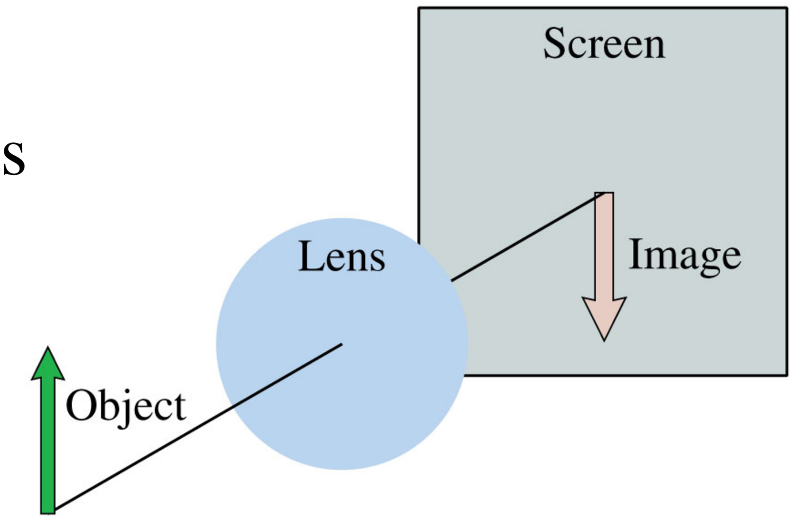


A. An inverted but blurry image.

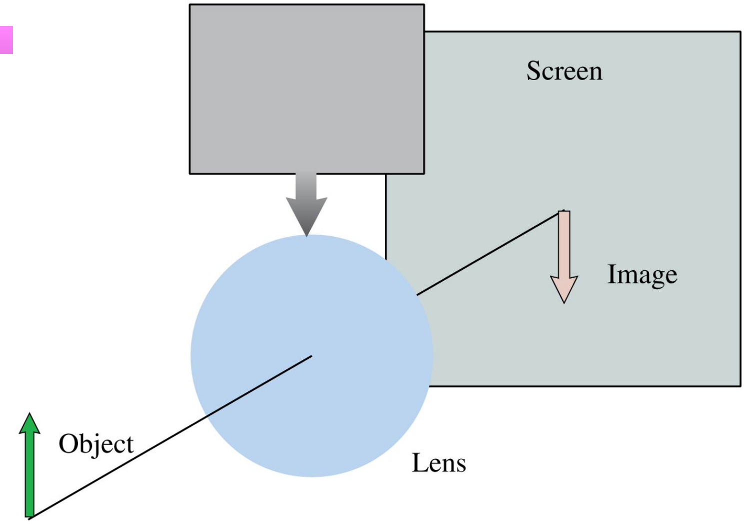
B. An image that is dimmer but otherwise unchanged.

C. A sharp, upright image.

D. A blurry, upright image.

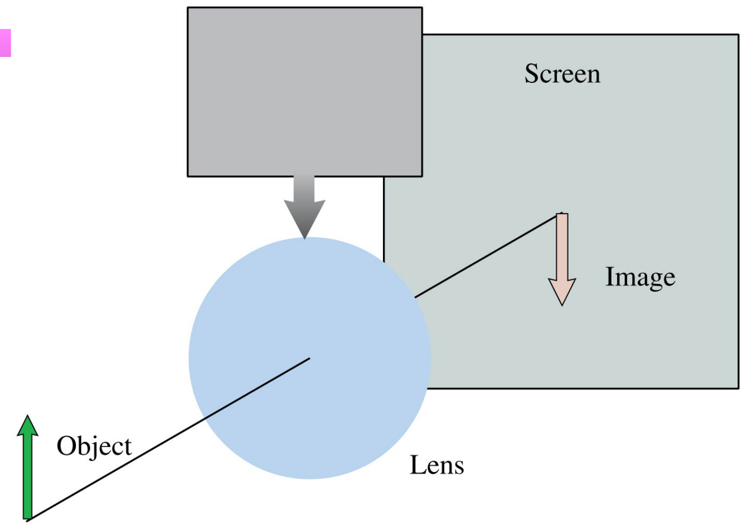
✔ **E. No image at all.**

A lens produces a sharply focused, inverted image on a screen. What will you see on the screen if a piece of dark paper is lowered to cover the top half of the lens?



A. An inverted but blurry image.
B. An image that is dimmer but otherwise unchanged.
C. Only the top half of the image.
D. Only the bottom half of the image.
E. No image at all.

A lens produces a sharply focused, inverted image on a screen. What will you see on the screen if a piece of dark paper is lowered to cover the top half of the lens?



A. An inverted but blurry image.

✔ **B. An image that is dimmer but otherwise unchanged.**

C. Only the top half of the image.

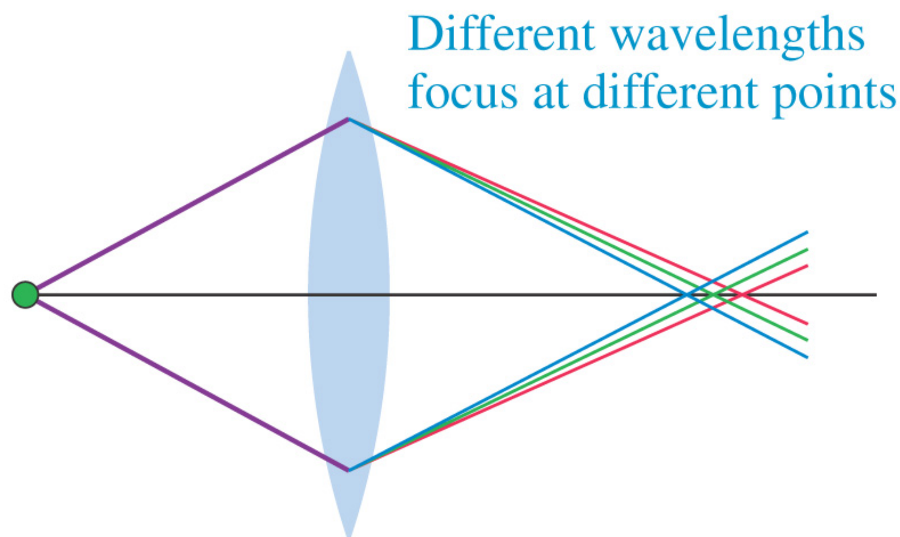
D. Only the bottom half of the image.

E. No image at all.

Lens aberrations

- Any lens has dispersion, that is its index of refraction varies slightly with wavelength
- Consequently different colors come into focus at slightly different distances from the lens
  - chromatic aberration
- Our analysis of image formation was based on rays of light travelling nearly parallel to the optical axis, so that we could use the small-angle approximation
- Actually rays incident on the outer edge of a spherical surface are not focussed in exactly the same point as rays incident near the center
  - spherical aberration
- Aberrations of converging and diverging lenses are in opposite directions and tend to cancel

(a) Chromatic aberration



(b) Spherical aberration