Lecture 34

Chapter 35

Images

Review

- Intensity of unpolarized light after hitting a polarizing sheet

$$I = \frac{1}{2} I_0$$

- Intensity of polarized light after hitting a polarizing sheet

$$I = I_0 \cos^2 \theta$$

- Peak intensity is twice the average intensity

$$I_{peak} = 2 I_{avg}$$

$$I_{peak} = \frac{1}{c\mu_0} E_m{}^2 = \frac{1}{c\mu_0} \left(\sqrt{2} E_{rms} \right)^2 = 2 \frac{1}{c\mu_0} E_{rms}^2 = 2 I_{avg}$$

Review

- Law of reflection: $\theta_1' = \theta_1$
- Law of refraction: Snell's law

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

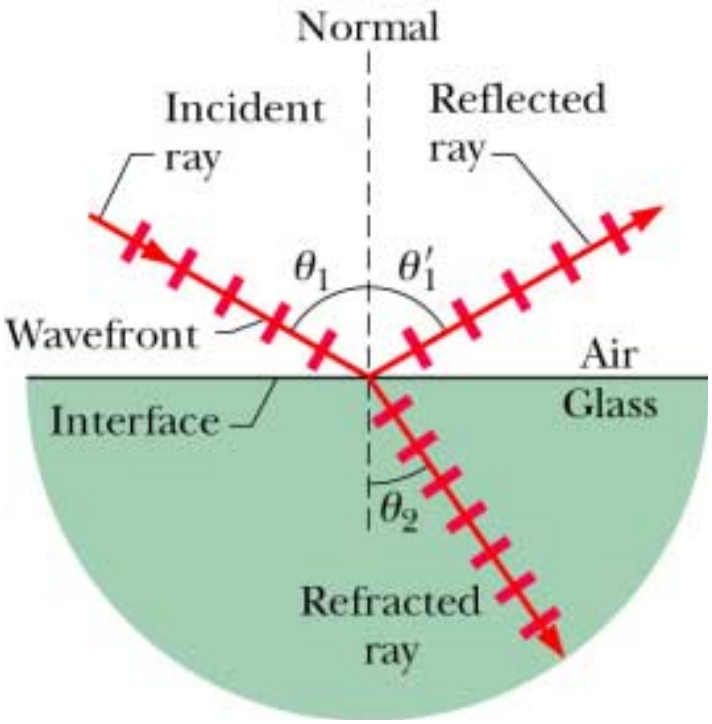
- Index of refraction
  - Nothing has *n* <1, is always < c

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

- If $n_2 = n_1$ hen $\theta_2 = \theta_1$

  $n_2 > n_1$ $\theta_2 < \theta_1$

  $n_2 < n_1$ $\theta_2 > \theta_1$



- Frequency of wave does not change but

$$\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

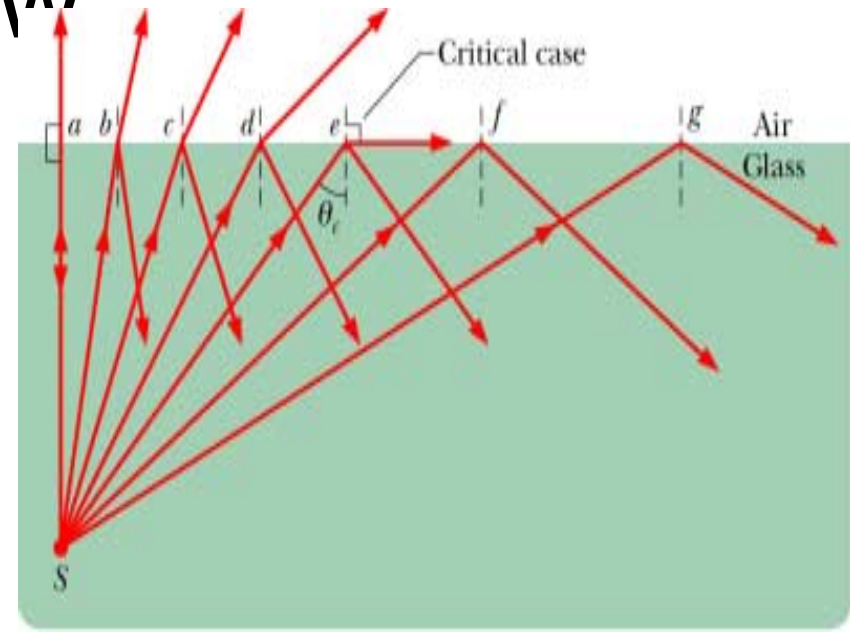
Review

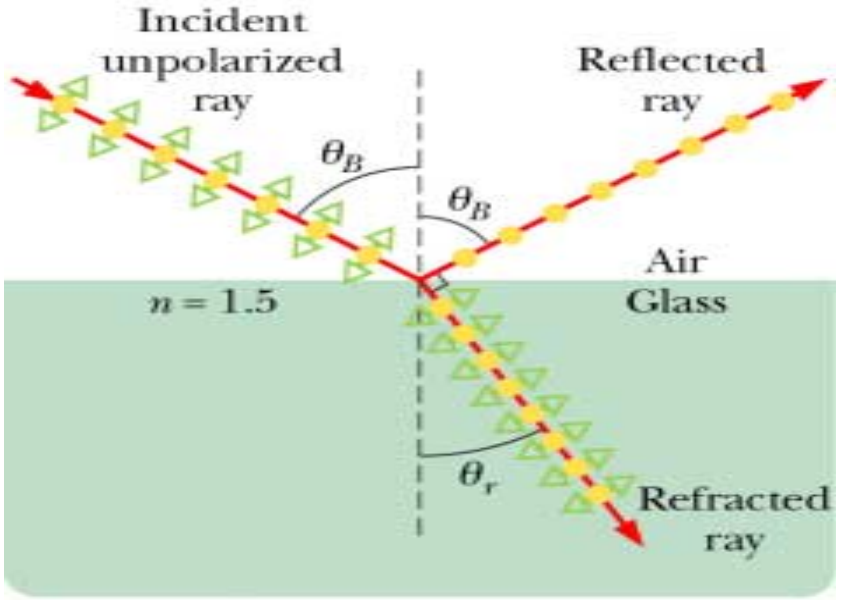
- Critical angle, θ_c – refracted ray along surface

$$\theta_C = \sin^{-1}\frac{n_2}{n_1}$$

- Total internal reflection – no refracted ray
  - Only occurs if $n_2 < n_1$
- Brewster angle - reflected light is fully polarized

$$\theta_B = \tan^{-1}\frac{n_2}{n_1}$$



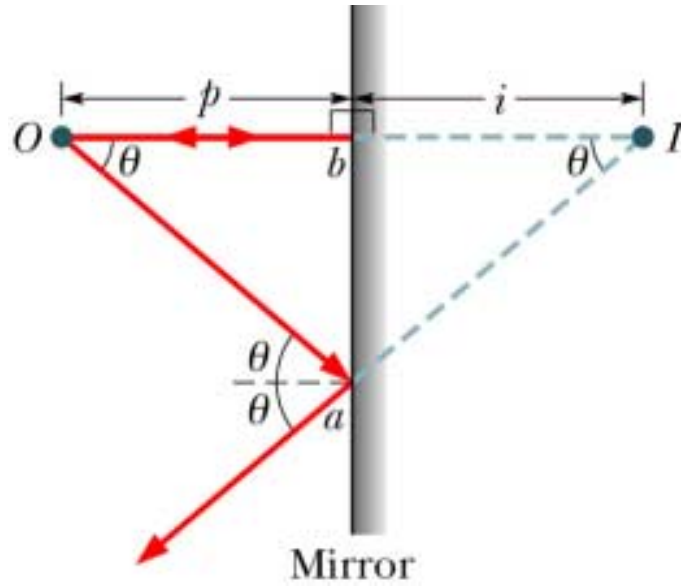


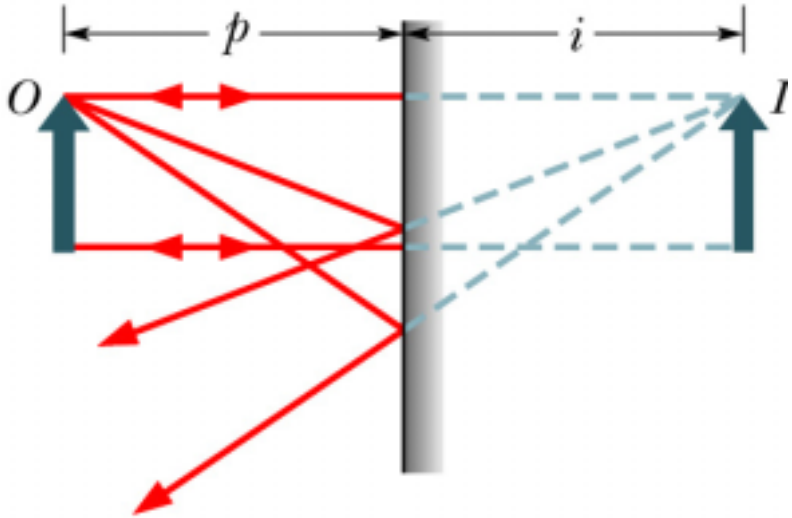
Review

- Plane mirror
  - Image I is virtual
  - I is as far behind the mirror as object O is in front of it
  - I has same orientation and height as O

$$i = -p$$

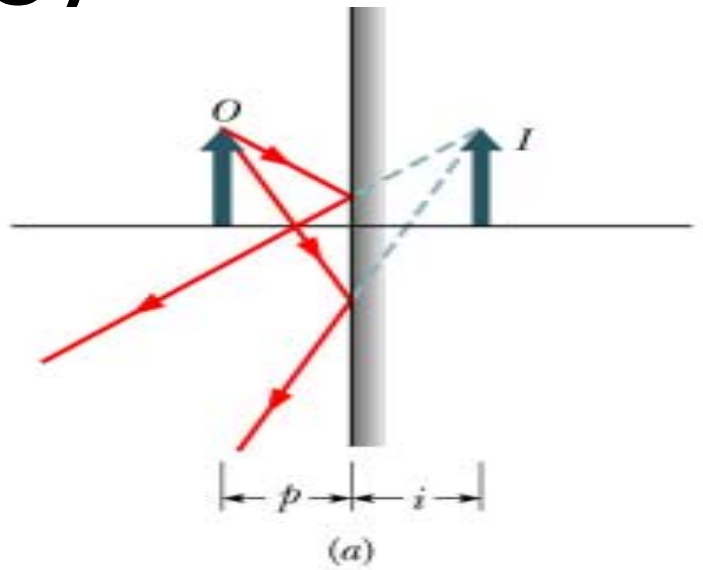
- Object distances p are positive, image distances i are positive for real, negative for virtual images

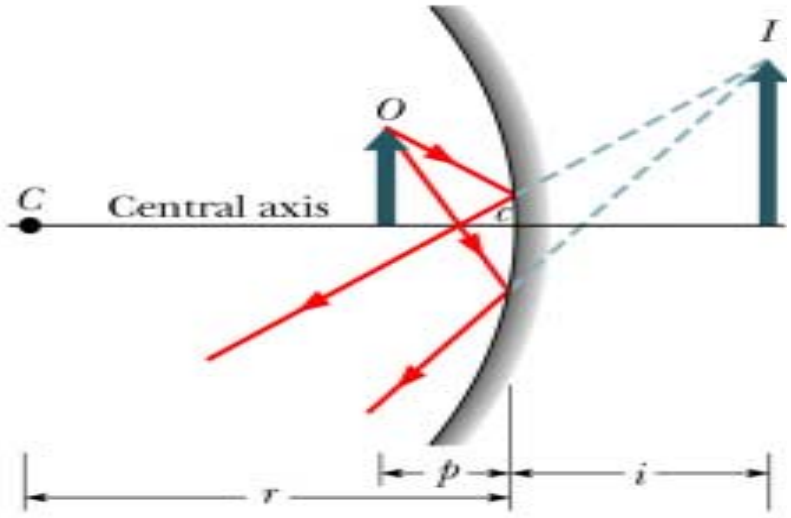




Images (5)

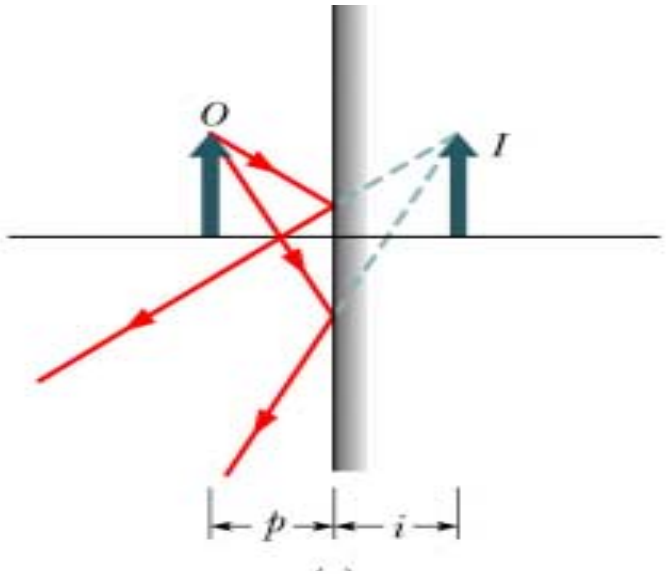
- Spherical mirror – small section of the surface of a sphere
- Concave mirror – plane mirror caved in
- Center of curvature is in front of mirror
- Field of view is smaller
- Image is farther behind mirror and taller

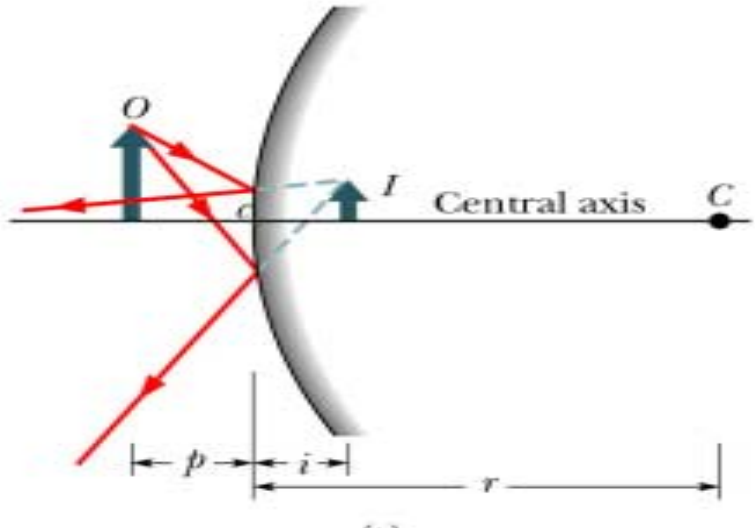




Images (6)

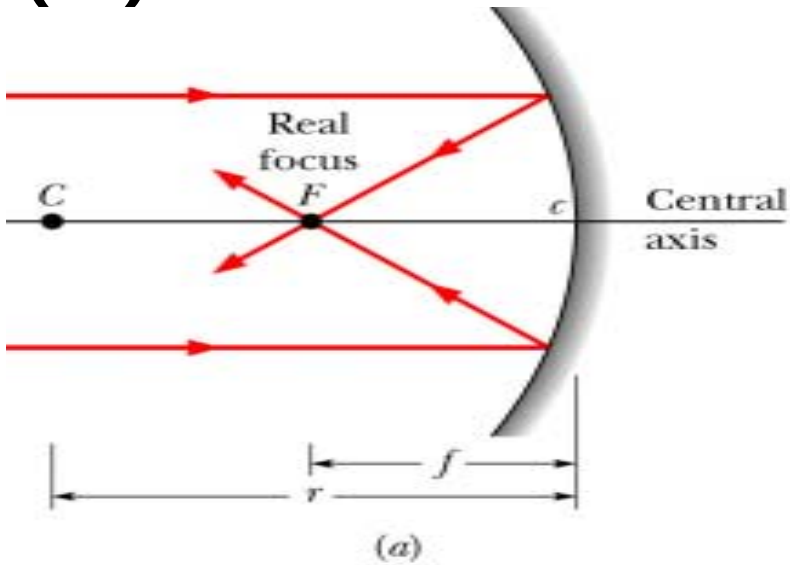
- Convex mirror – plane mirror is flexed out
- Center of curvature is behind the mirror
- Field of view is larger
- Image is closer to the mirror and smaller

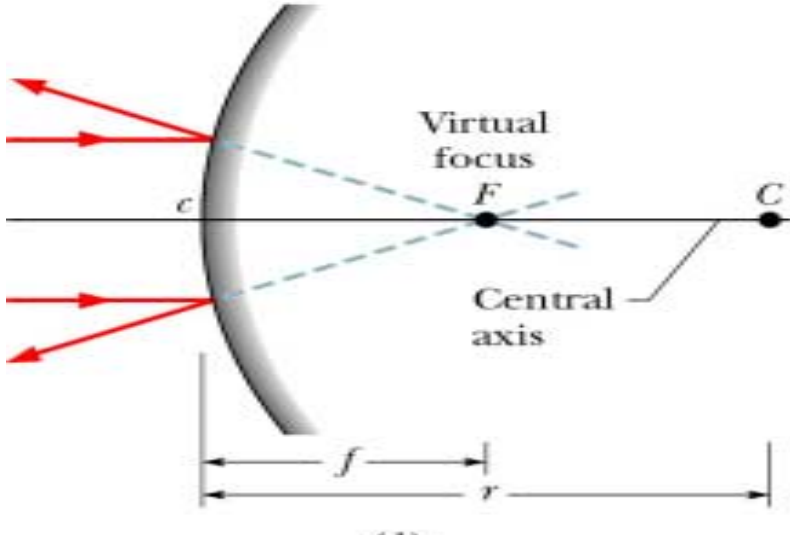




Images (7)

- Object O infinite distance from mirror on central axis
  - Concave mirror – focuses real image at a focal point in front of the mirror
  - Convex mirror – focuses a virtual image at a focal point behind the mirror
- Distance from center of mirror to image is called focal length, *f*

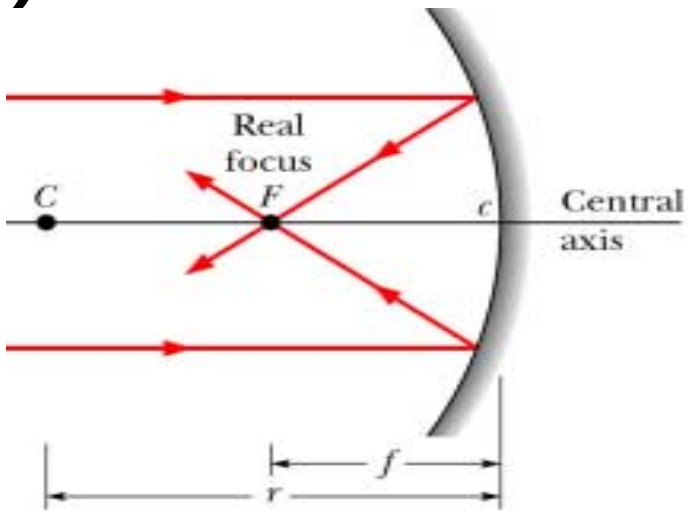




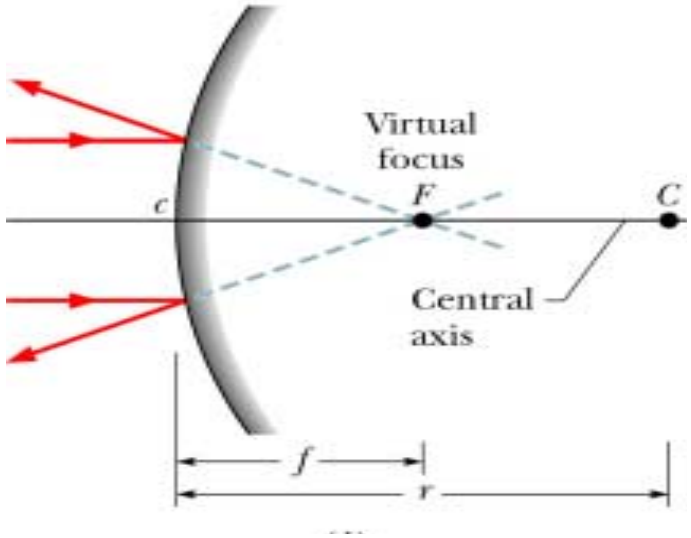
Images (8)

- Concave mirror has a real focal point
- Convex mirror has a virtual focal point indicated by a negative focal length
- Focal length, *f* is related to radius of curvature, *r* of mirror
  - *r* is + for concave, - for convex

$$f = \frac{1}{2} r$$

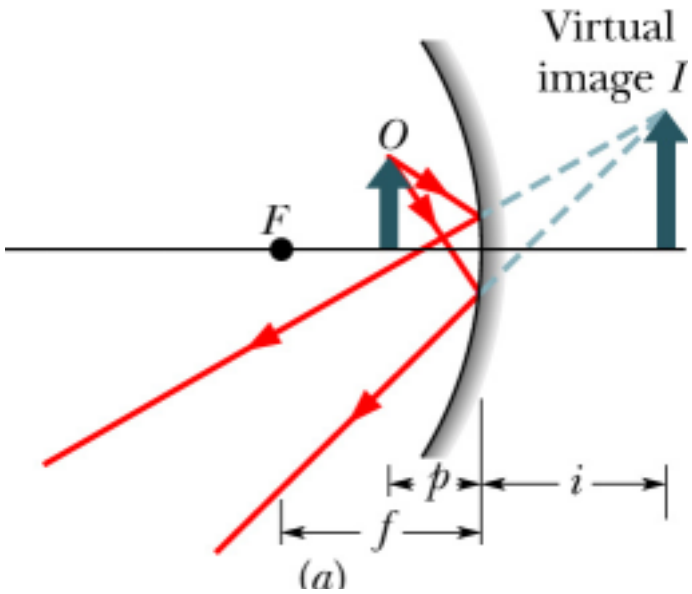


(a)



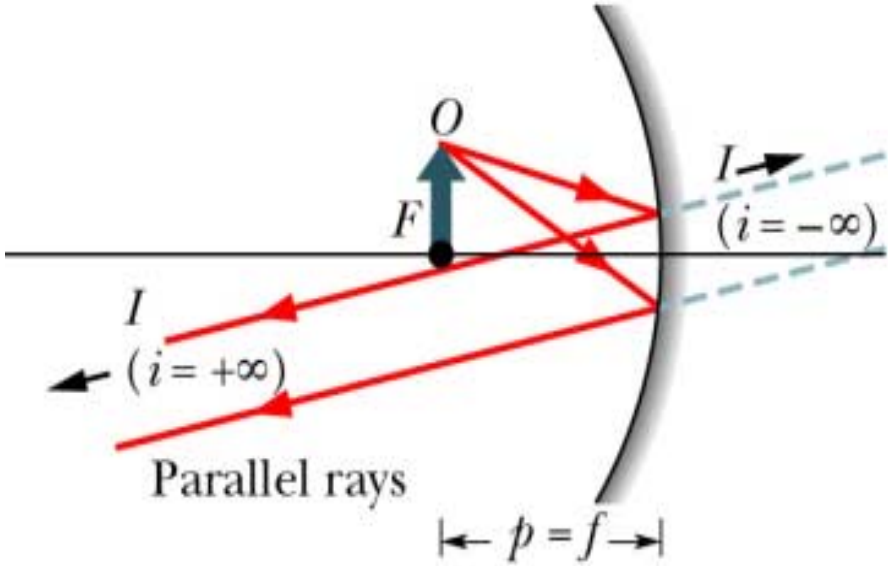
Images (9)

- Concave mirror –
- If object O inside focal point, $p<f$
- Extend rays behind mirror to find image I
- Image I is
  - Virtual
  - Bigger than O
  - Same orientation as O



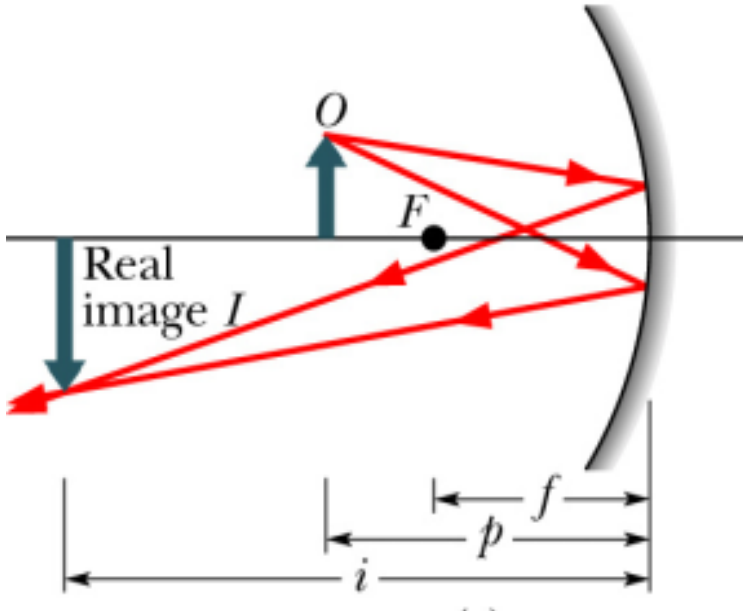
Images (10)

- Concave mirror –
- If object O at focal point, *p=f*
- Neither reflected or extended rays cross to form image
- Image is moved to infinity



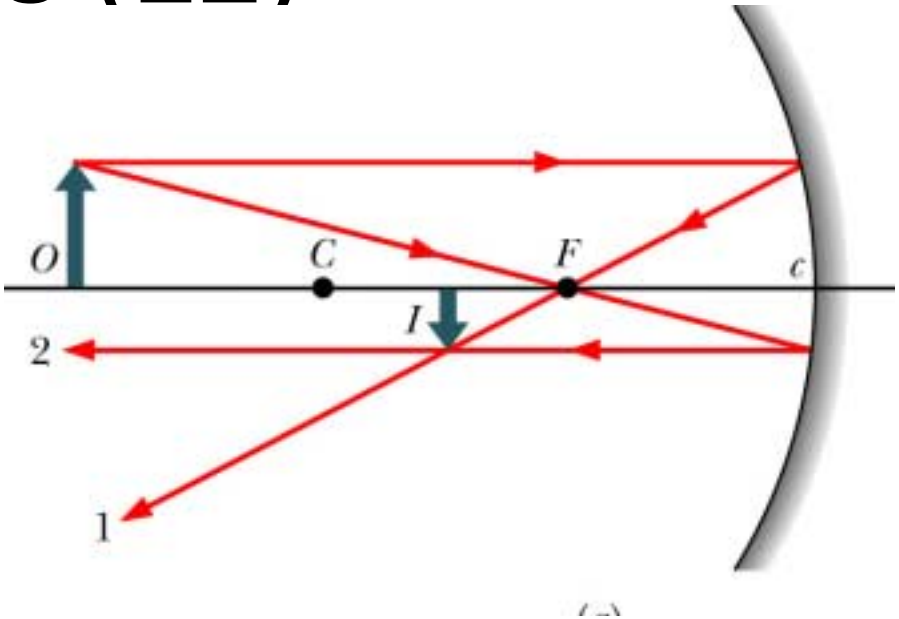
Images (11)

- Concave mirror –
- If object O between focal point *f* and twice the focal length, *f<p<2f*
- Image I is
  - Real
  - Bigger than O
  - Inverted
  - At distance, *i>2f*



Images (12)

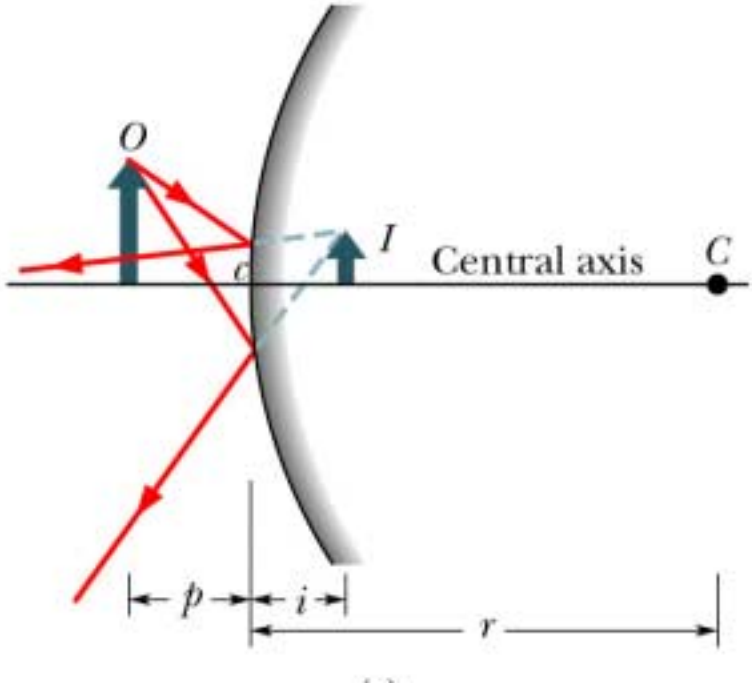
- Concave mirror –
- If object O outside two focal lengths, O>2f
- Image I is
  - Real
  - Smaller than O
  - Inverted
  - At a distance *f<i<2f*



- If object O is at *2f*
- Image I is
  - Real
  - Equal in size to O
  - Inverted
  - At distance *i=2f*

Images (13)

- Convex mirror –
- If object O placed anywhere on central axis
- Image I is
  - Virtual
  - Smaller than O
  - Same orientation
  - At distance, *i*<*f*

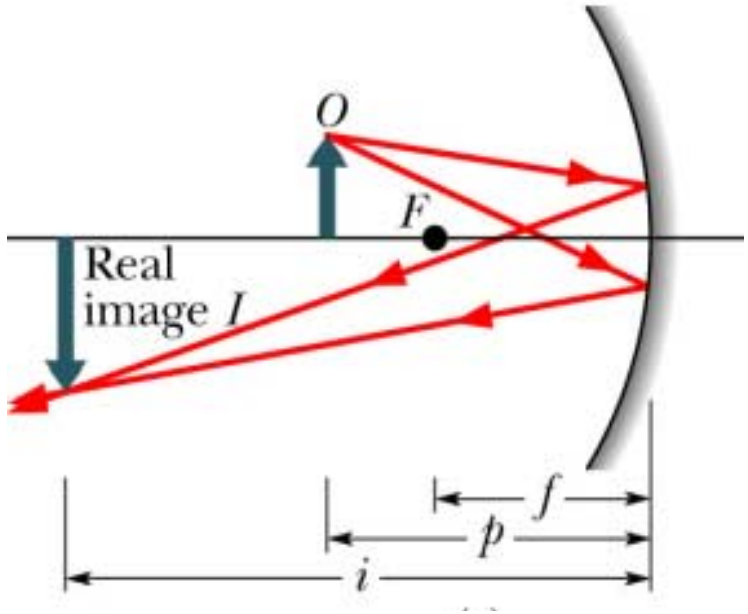


- For mirrors – real images on side where object is, virtual images on opposite side
- Convex and plane mirrors only form virtual images, have same orientation as object

Images (14)

- Formula for focal length, *f*

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



- Object distance *p* is +
- Image distance *i* is + for real images, - for virtual images
- Focal length *f* is + for concave mirror, - for convex mirror

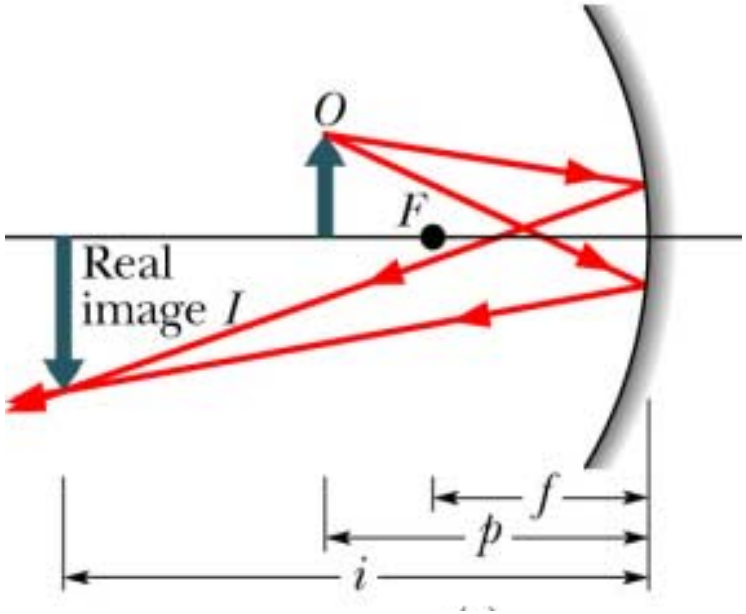
Images (15)

- Size of object or image measured ⊥ to central axis is defined to be height h
- Ratio of image's height *h´* to object's height *h* is called lateral magnification

$$|m| = \frac{h'}{h}$$

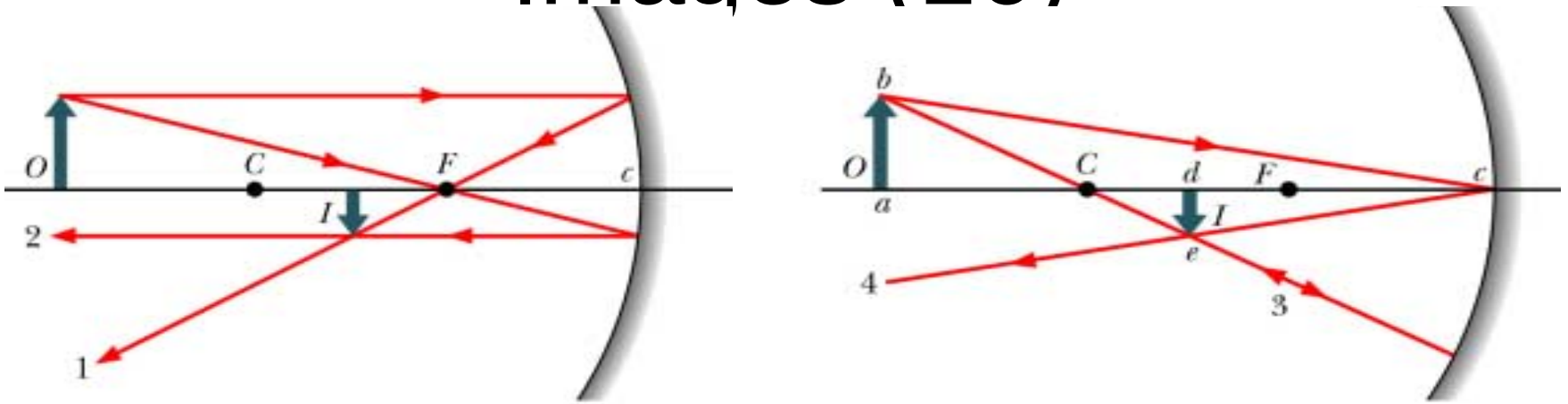
- Also written

$$m = -\frac{i}{p}$$



- *m* is + for same orientation
- *m* is – for inverted image
- Plane mirror *m* =+1

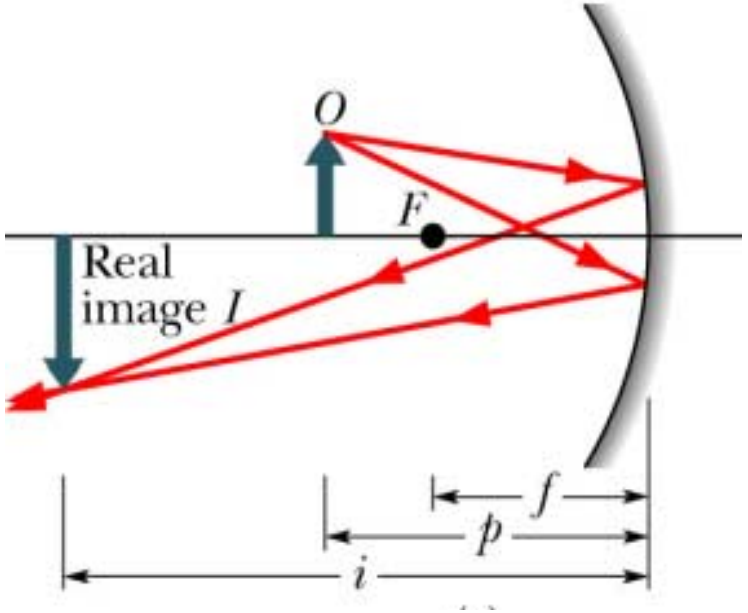
Images (16)



- Locate images by drawing rays
  - Ray parallel to central axis, reflects through focal point (Ray 1)
  - Ray passing through focal point, reflects parallel to central axis (Ray 2)
  - Ray passing through center of curvature returns along itself (Ray 3)
  - Ray hits mirror at intersection with central axis, reflects symmetrically about central axis (Ray 4)

Images (17)

- Checkpoint #2 – Vampire bat is dozing on central axis of spherical mirror. It is magnified by m=-4. Is this image a) real or virtual, b) inverted or same orientation as bat, c) on the same or opposite side of mirror as bat?
- m=-4 tells us image is and inverted
- Convex mirror only makes virtual images so concave
- Image must be real and same side

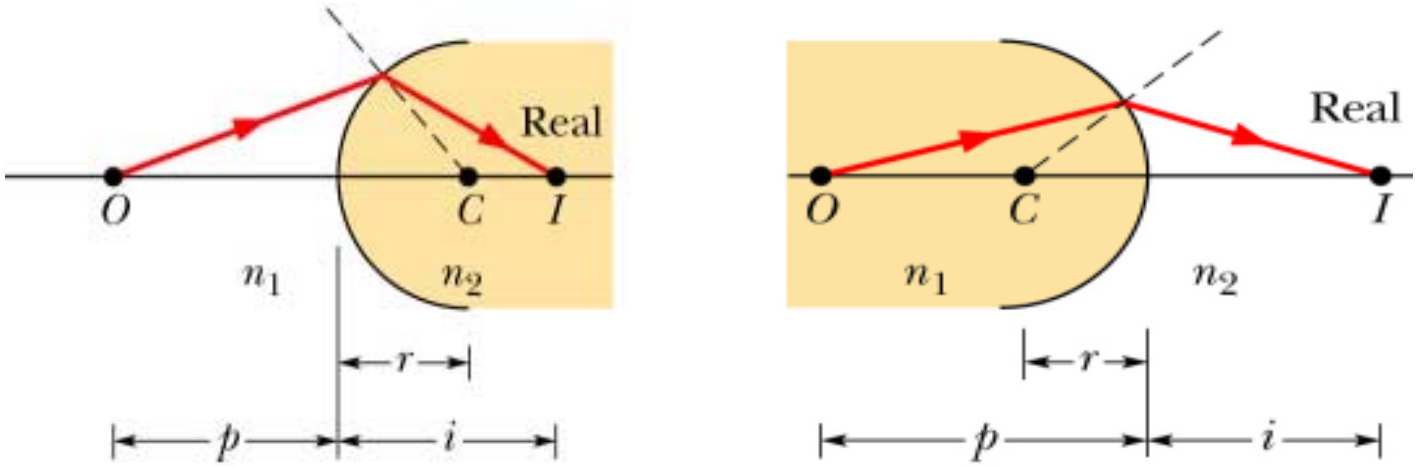


Images (18)

Mirror Type	Object Location	Image Location	Image Size	Image Type	Image Orient-ation	Sign of *f*	Sign of *i*	Sign of *m*
Plane	Any-where	i=-p	Equal	Virtual	Same	∞	-	+1
Concave	p<f	Any-where	Bigger	Virtual	Same	+	-	+
Concave	f<p<2f	i>2f	Bigger	Real	Invert	+	+	-
Concave	p=2f	i=2f	Equal	Real	Invert	+	+	-
Concave	p>2f	2f>i>f	Smaller	Real	Invert	+	+	-
Convex	Any-where	|i|<|f|	Smaller	Virtual	Same	-	-	+

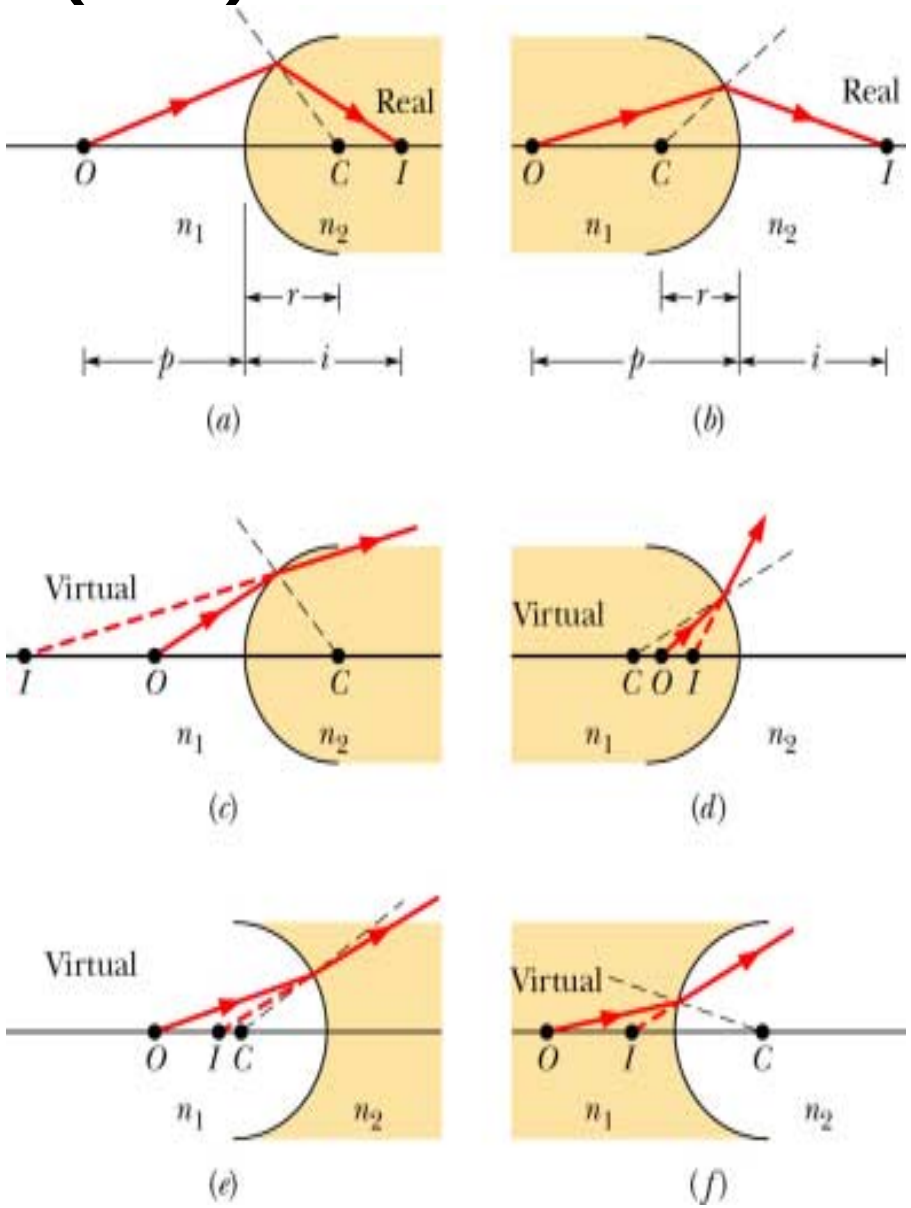
Images (19)

- Images can be formed by refraction through transparent material
- Object O on left in medium with n_1
- Normal to refracting surface is radial line through center of curvature C
  - Ray bends toward normal if $n_2 > n_1$
  - Ray bends away from normal if $n_2 < n_1$



Images (20)

- Real images – when refraction directs ray towards central axis
- Virtual images – when refraction directs ray away from central axis
- Real images on side of refracting surface that is opposite the object, virtual images on same side as object



Images (21)

- Relation for radius of curvature of refracting surface
- Object is in medium of n_1
- Object distance p is +
- Image distance i is + for real image, - for virtual image
- If object faces convex refracting surface radius r is +, faces concave surface r is –
  - Reverse of sign convention for mirrors

$$\frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r}$$