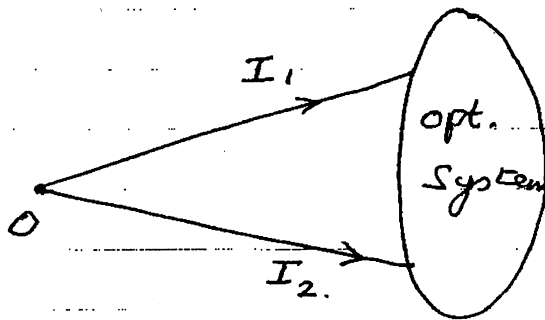


## FORMATION OF IMAGES - MIRRORS.

General Construct to locate image of a point Object  $O$  using the laws of reflection and refraction to locate the path of light

Step 1 Take two incident rays  $I_1$  and  $I_2$  starting from  $O$ .



Step 2 Follow them through the optical system using

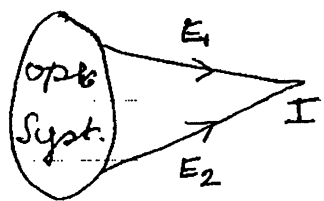
$$r = i \text{ for Reflection}$$

and

$$n_2 \sin R = n_1 \sin i \text{ for Refraction.}$$

Step 3: Locate the two rays  $E_1$  and  $E_2$  that emerge from the optical system. Two cases arise:

Case I



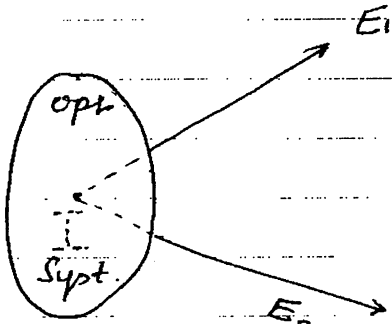
Point of intersection of  $E_1$  and  $E_2$  defines position of image  $I$ .

Here, light actually goes through the point  $I$  so it is called a

**REAL IMAGE**

Note: A real image can be projected on a screen.

Case II



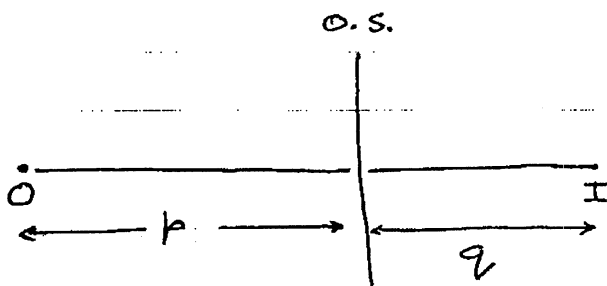
$E_1, E_2$  are diverging so they will not intersect. You will have to extrapolate the  $E_1, E_2$  lines to locate

the image  $I$  as the point from which  $E_1, E_2$  "appear" to be coming. No light actually goes through  $I$  so it is called  
VIRTUAL IMAGE

Note A virtual image cannot be projected on a screen (your eye can see it)!

SOME DEFINITIONS

$p$  = Distance of object from opt. Syst. (O.S.)



$q$  = Distance of image from opt. system.

Magnification  $m = \frac{\text{Size of image}}{\text{Size of object}} = -\frac{q}{p}$

The minus sign on the right side ensures

that for a single element o.s. all real images ( $q$  +ive) are inverted ( $m$  -ive) while all virtual images ( $q$  -ive) are upright ( $m$  +ive).

### MIRROR

A mirror is an optical system in which only reflections occur; so there is a light side and a dark side. We use the "Sign" convention that distances are "+ive" on light side and "-ive" on dark side.

#### 1. PLANE MIRROR: PLANE, SILVERED SHEET OF GLASS

TWO RAYS:

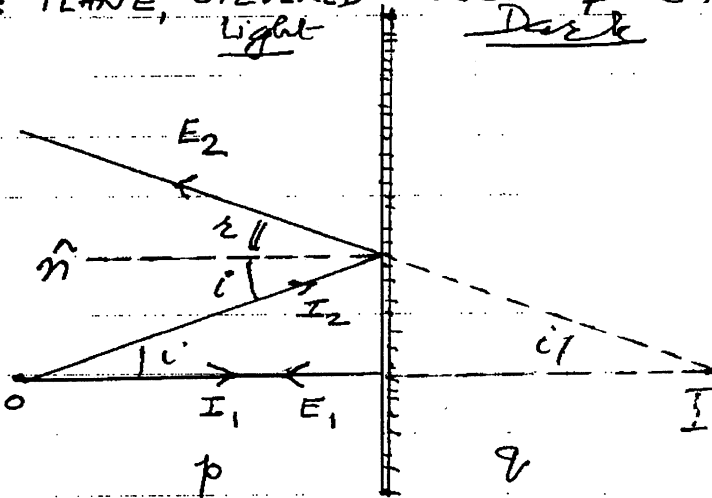
$$\vec{I}_1 \parallel \hat{n}$$

$$\vec{i} = 0, r = 0$$

$$\vec{E}_1 \parallel \hat{n}$$

$$I_2: r = i$$

localizes  $E_2$ .



$E_1$  and  $E_2$  diverge.

Localize image by extrapolation at  $I$ .

$q$  is -ive.

Image is virtual, clearly  $|q| = p$ .

$$m = \frac{-q}{p} = +1.$$

upright, virtual image is as far behind the

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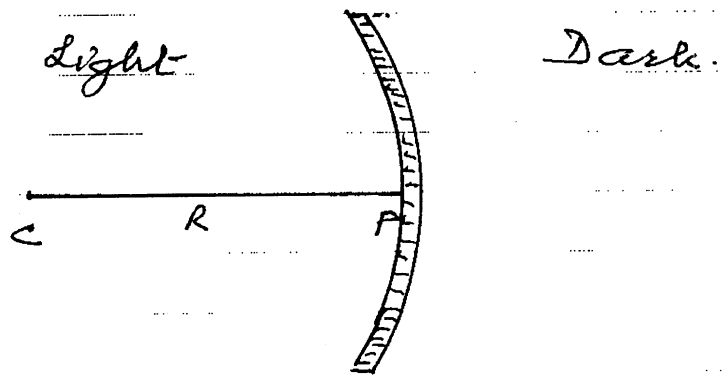
mirror as the object is in front of it

2 SPHERICAL MIRRORS: Mirror cut from a spherical shell of radius  $R$ .

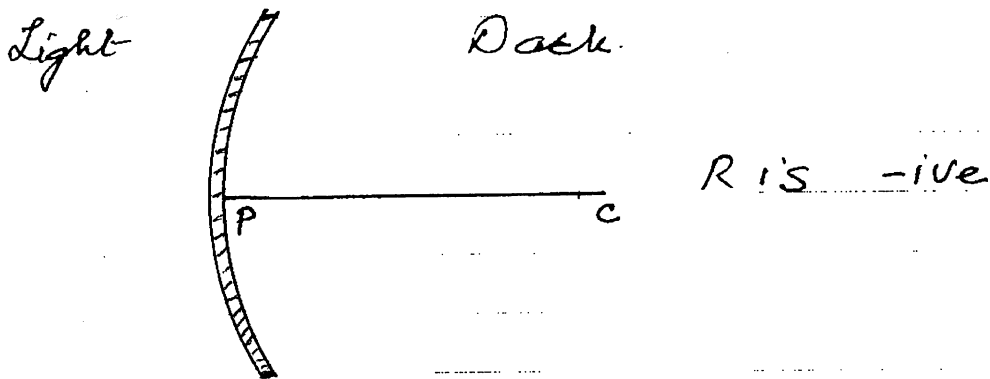
Two Cases arise

A CONCAVE. CENTER OF SPHERE IN FRONT OF MIRROR.

$R$  is +ive



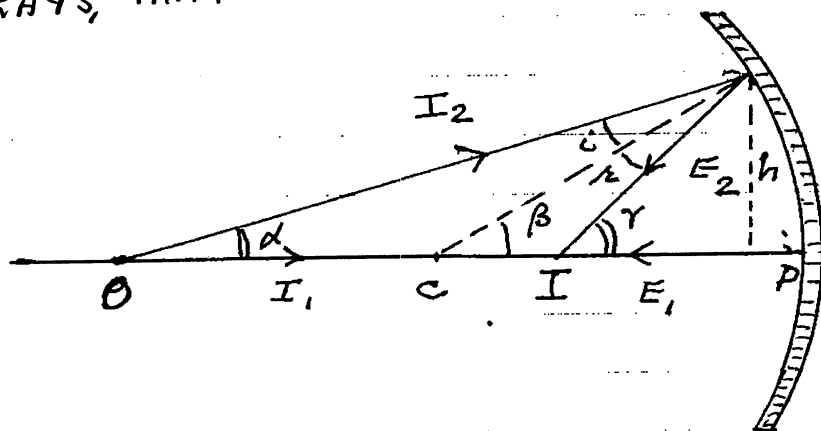
B CONVEX CENTER OF SPHERE BEHIND MIRROR.



A Images in Concave Mirrors

We will consider only paraxial rays, that is all angles are taken to be very small so  $\sin \theta \approx \tan \theta \approx \theta$ .

ALL OF OUR DISCUSSION ASSUMES "PARAXIAL" RAYS, THAT IS ALL ANGLES, ( $\alpha, \beta, \gamma$ ) are very small.



$$\beta \approx \tan \beta$$

$$\alpha \approx \tan \alpha$$

$$\gamma \approx \tan \gamma$$

Some construct.  $I_1, I_2$  start from O, after reflection we get  $E_1, E_2$ , intersection locates I.

Equations

$$\beta = \alpha + i$$

$$\gamma = \beta + i$$

$$i = r$$

Hence

$$\gamma = \beta + i = 2\beta - \alpha$$

or

$$\gamma + \alpha = 2\beta$$

Angles are small, hence

$$\tan \gamma + \tan \alpha = 2 \tan \beta$$

$$\frac{h}{IP} + \frac{h}{OP} = \frac{2h}{CP}$$

or

$$\frac{1}{p} + \frac{1}{q} = \frac{2}{R} \quad (1)$$

and combined with

$$m = \frac{-q}{p} \quad (2)$$

these two equations describe all possible images, and their sizes, formed by a concave mirror.

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SPECIAL CASES  
OBJECT SIZE.

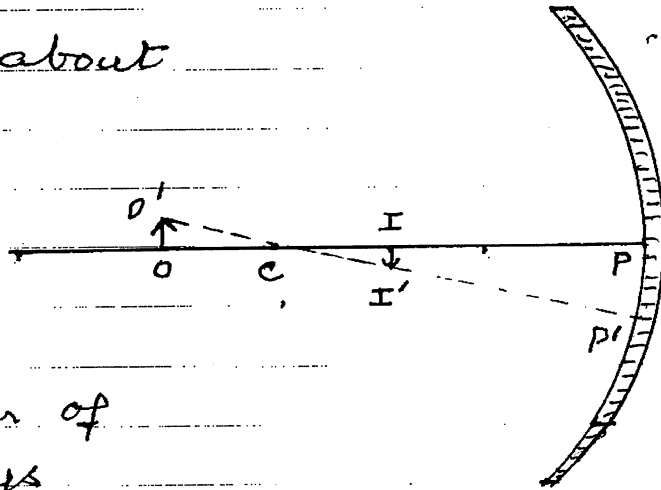
a) Small object

Rotational picture about  
the center (of  
curvature) C

The above  
calculations

apply.

Our assumption of  
paraxial rays  
requires that all  
objects are small.



SPECIAL CASES [Eqs (1) and (2)].

I  $p \rightarrow \infty, q = \frac{R}{2}$

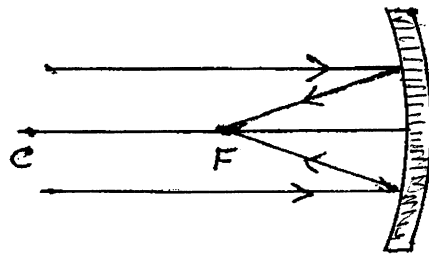
$p \rightarrow \infty$  implies that  
incident ~~light~~ <sup>light</sup> is a  
parallel beam,

and we learn that

when a parallel beam falls on the  
mirror, after reflection it converges to  
a point. This defines the focus and  
the focal length

$$f = R/2$$

So  $p \rightarrow \infty, q \rightarrow f, m \rightarrow 0$  Real Image



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Concave Mirror makes parallel light converge to a point hence  
 Concave Mirror  $\Rightarrow$  CONVERGENT MIRROR.

NOTE NO REAL IMAGE CAN COME CLOSER THAN  $f$ !

II  $p > R$  object lies beyond C.

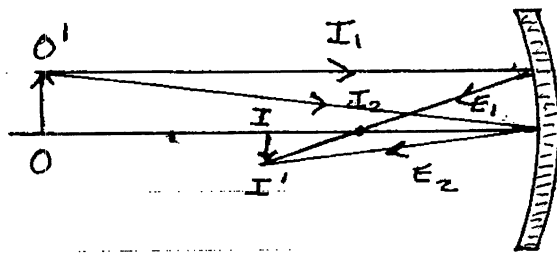
$$\frac{1}{q} = \frac{2}{R} - \frac{1}{p} = \frac{2p - R}{pR}$$

$$\frac{p}{q} = \frac{2p - R}{R} = > \frac{2R - R}{R} = > 2 - 1 = > 1$$

so  $q < R$ .

$$m = -\frac{q}{p}, \quad |m| < 1$$

Inverted, Real, Reduced Image.



III  $p = R, q = R, m = -1$ . [Lamp Expt.]

Object lies at C.

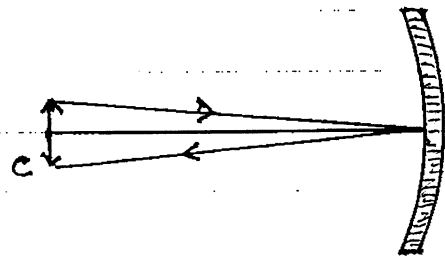
All light falls on

mirror at  $i=0$ , so

it leaves at  $r=0$

and goes right

back to C.



REAL, INVERTED IMAGE SAME SIZE AS OBJECT.

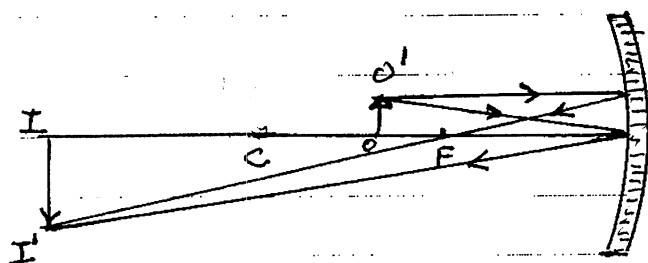
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IV  $p < R$ , object ~~also~~ lies between C and F

$$\frac{p}{q} = \frac{2p - R}{R} = \frac{2R - R}{R} = < 1$$

$$q > R, \quad m = -\frac{q}{p}, \quad |m| > 1$$

Inverted, Real, Enlarged Image



V  $p = f$ , object at F,  $q \rightarrow \infty$ ,  $m \rightarrow \infty$

Point Source

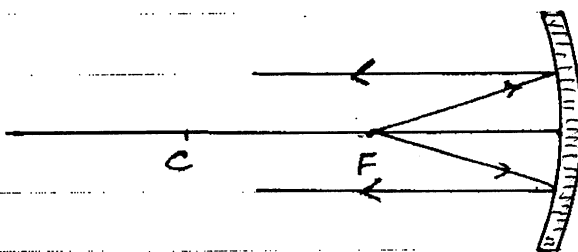
at F on

reflection

produces

a parallel

beam.



VI:  $p < f$ , object closer to mirror than F,

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

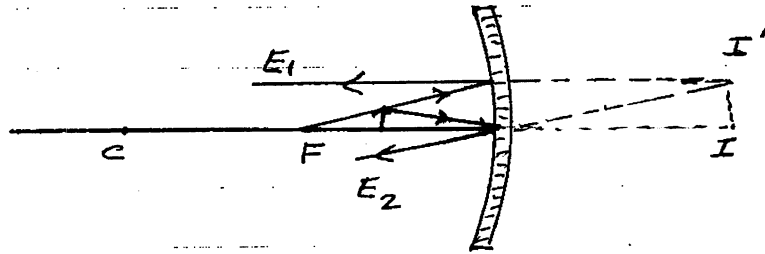
This equation cannot be satisfied unless  $q$  becomes -ive; IMAGE IS BEHIND MIRROR, ON THE DARK SIDE.

We get a VIRTUAL, ENLARGED IMAGE

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LIGHT

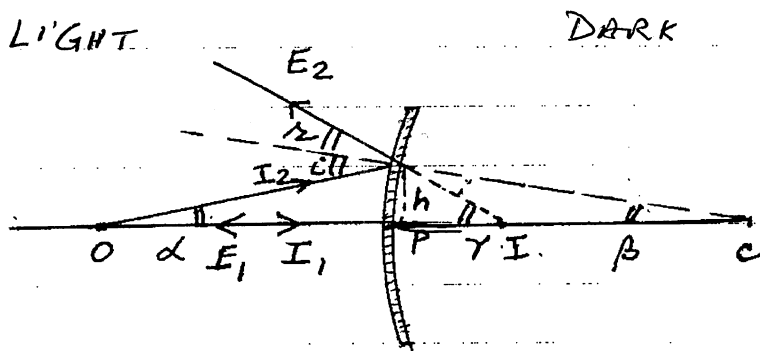
DARK



To Summarize: Start O far away, I at  $f$  (closest to mirror), bring O closer I moves away from mirror, gets bigger but remains inverted real, O at C, I at C,  $m = -1$ , O between C and F, I beyond C, enlarged, inverted, real, O at F,  $I \rightarrow \infty$ , parallel light; O closer than F, I goes BEHIND mirror becomes virtual and upright.

B Images in Convex Mirror

R is -ive



$OP = p$   
 $IP = q$  [ $q$  is -ive]

Eqns

$$\gamma = \alpha + \beta = i + \beta$$

$$i = \alpha + \beta$$

$$\gamma = \alpha + 2\beta$$

$$\alpha - \gamma = -2\beta$$

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$$\tan \alpha - \tan \gamma = -2 \tan \beta$$

$$\frac{h}{p} - \frac{h}{q} = -\frac{2h}{R}$$

or

$$\frac{1}{p} - \frac{1}{q} = -\frac{2}{R}$$

However, both  $q$  and  $R$  are -ive so one should write

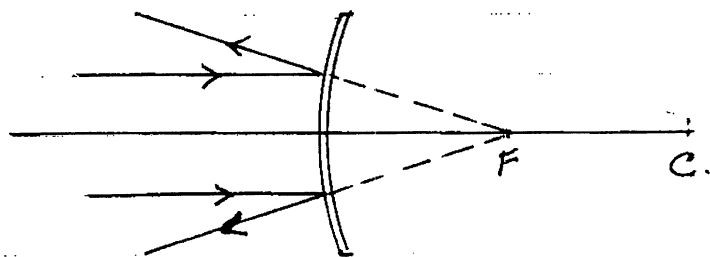
$$\frac{1}{p} + \frac{1}{q} = \frac{2}{R} \left[ \begin{array}{l} R \text{ -ive} \\ q \text{ -ive} \end{array} \right] \quad (3)$$

and supplement it with

$$m = -\frac{q}{p} \quad (4)$$

### SPECIAL CASES

I  $p \rightarrow \infty$ , Parallel light falls on mirror  
 $q = R/2 = f$  but  $f$  is -ive,  $f$  is behind  
 mirror on dark side.



A parallel beam of light incident on a convex mirror, on reflection appears to start from  $F$  and becomes divergent.

Hence

CONVEX MIRROR  $\Rightarrow$  DIVERGENT MIRROR.

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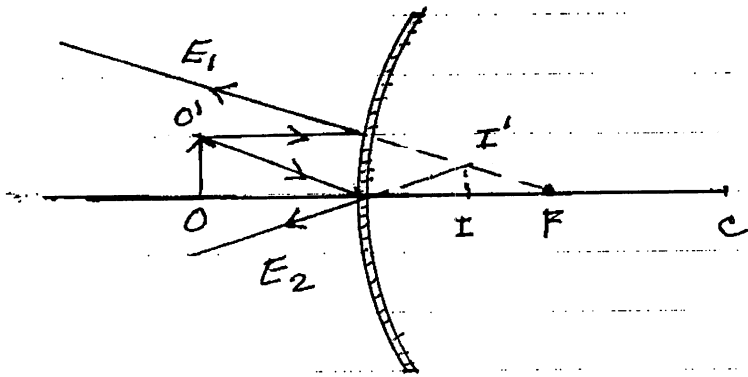
II Since  $q$  is -ive all Images are VIRTUAL and upright.

Also 
$$\frac{1}{p} - \frac{1}{q} = -\frac{2}{R}$$

or 
$$\frac{1}{q} = \frac{1}{p} + \frac{2}{R} \quad \left[ \frac{1}{q} > \frac{1}{p} \right]$$

So  $q$  is always less than  $p$ .  
and always less than  $f$ .

All Images are virtual, upright and reduced.



Right rear view mirror of automobiles!!

That is why cars appear small and we have a warning "objects in mirror are closer than they appear".