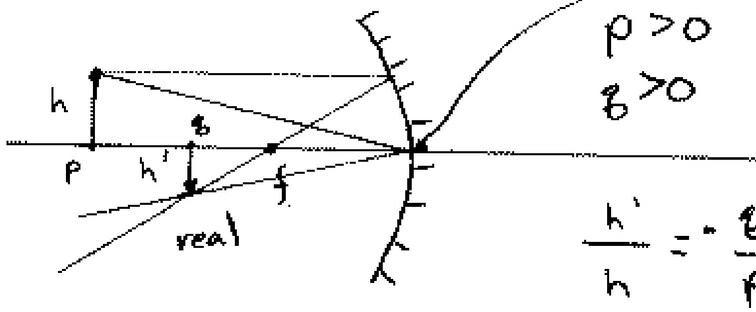
1st case

O (zero) is here

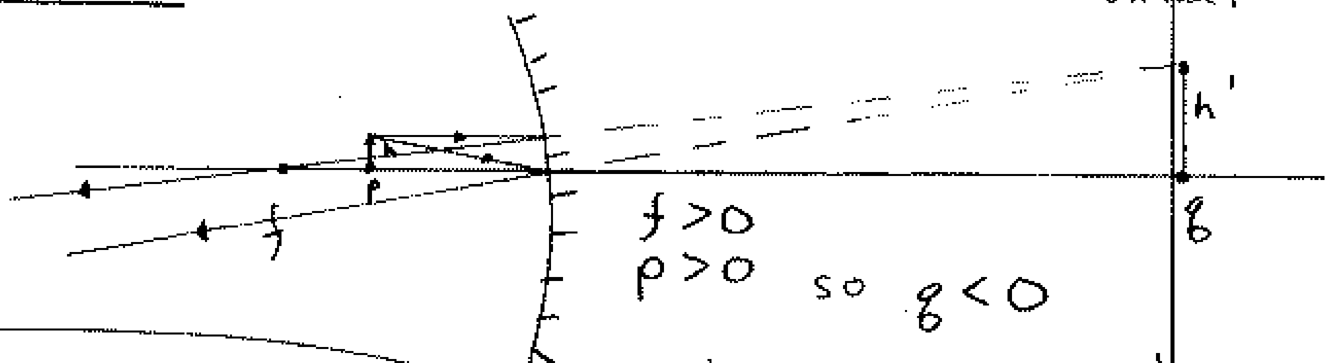


$p > 0$

$q > 0$ so $f > 0$

$$\frac{h'}{h} = -\frac{q}{p}$$

2nd case

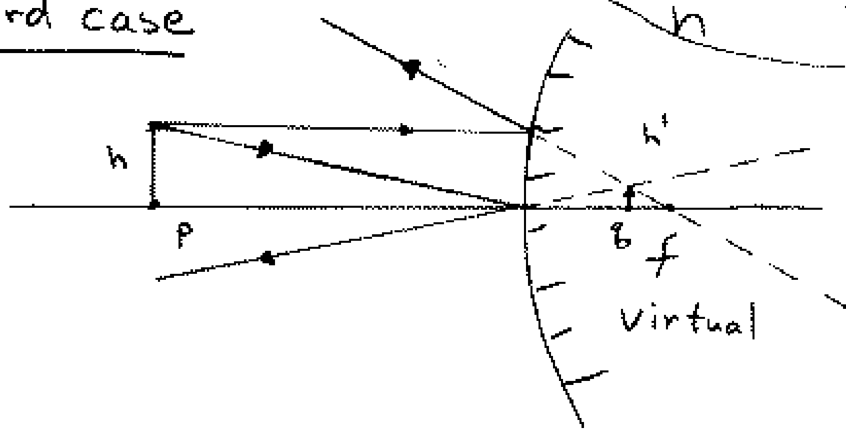


$f > 0$

$p > 0$ so $q < 0$

$$\frac{h'}{h} = -\frac{q}{p} \quad \text{(still!)}$$

3rd case



$q < 0$

$p > 0$

$h' > 0$

$h > 0$

$|q| < |f|$

$f < 0$

like on page 763 in your book

how, you can also have a virtual object (or h) if $p < 0$,

now, you can compute what happens if $p < 0$

<u>example</u> if $f = 10\text{cm}$ (con<u>cave</u>)
and $p = -1.0\text{cm}$, where is q?

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

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p} = \frac{p}{pf} - \frac{f}{pf} = \frac{p-f}{pf}$$

$$q = \frac{pf}{p-f} = \frac{(-1.0\text{cm})(10\text{cm})}{-1.0\text{cm} - 10\text{cm}} = \frac{-10\text{cm}^2}{-11\text{cm}^2}$$

$$= 0.91\text{cm}$$

$q > 0$ real image

$$\frac{h'}{h} = -\frac{q}{p} = -\frac{0.91\text{cm}}{(-1.0\text{cm})} = 0.91$$

in our example, a virtual object in a concave mirror produces a real image that is slightly smaller but not inverted

(Notice I didn't have to draw a picture to reason this out)

if you think of "<u>real</u>" being the <u>shiny side</u>

real objects $p>0$ here

real images $q>0$ here

shiny side

" $f>0$ "

mirror

$f<0$

dark side

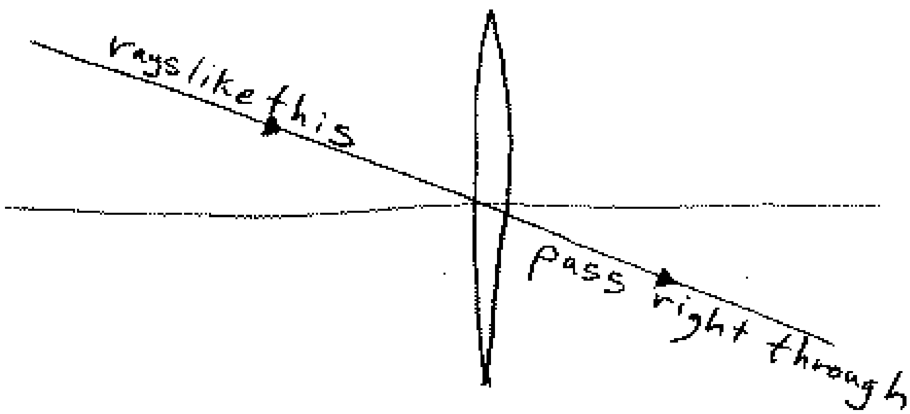
virtual objects $p<0$ here

virtual images $q<0$ here

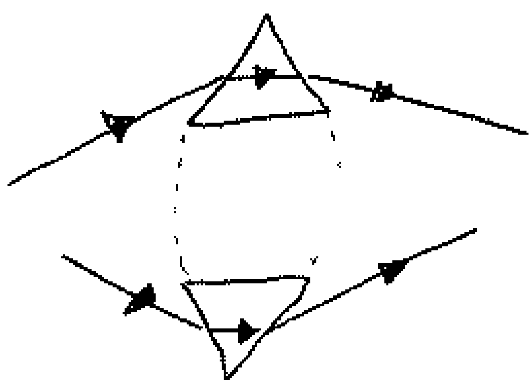
now, consider a lens

now light passes through, and more or less the same rules apply

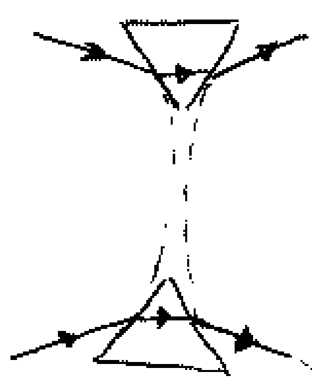
rays like this → pass through the focal point



You can imagine which way lenses work by considering a prism



rays focus

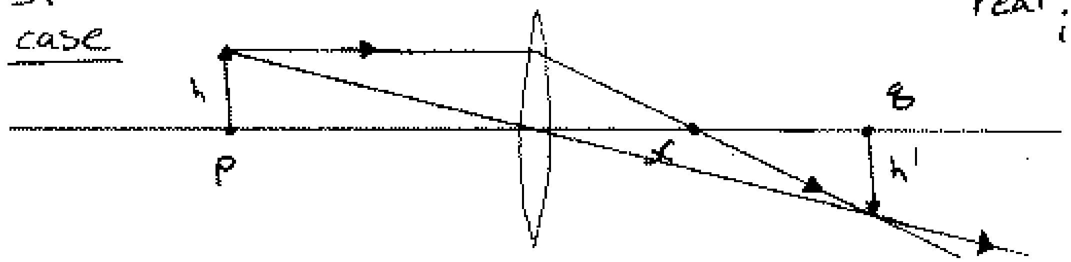


rays diverge

look at cases

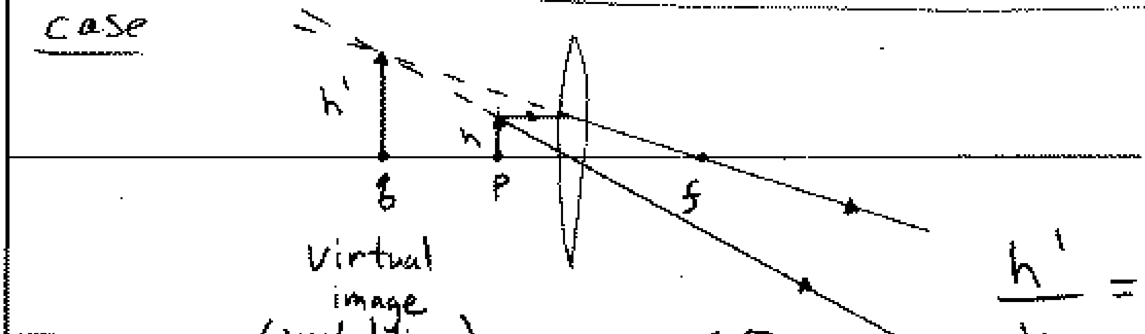
<u>1st case</u>

real image



$$\frac{h'}{h} = -\frac{q}{p} \quad \text{if} \quad \left.\begin{matrix} q>0 \\ p>0 \end{matrix}\right\} \text{makes } f>0$$

<u>2nd case</u>



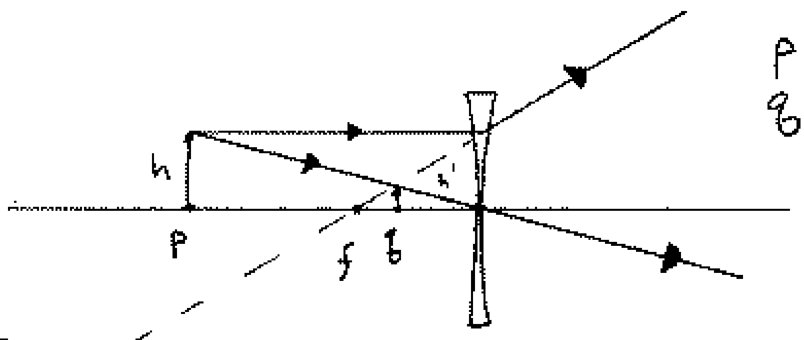
Virtual image (dashed lines)

$q<0$

$p>0$ $\quad f>0$

$$\frac{h'}{h} = -\frac{q}{p}$$

<u>3rd case</u>



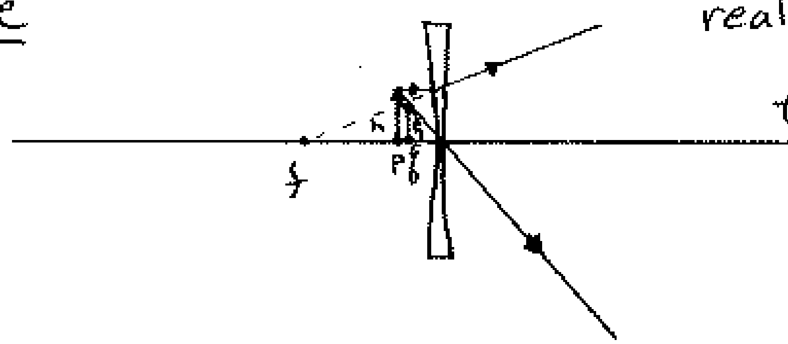
$p>0$ $\quad |q|<|f|$

$q<0$ $\quad |p|>|f|$

$f<0$

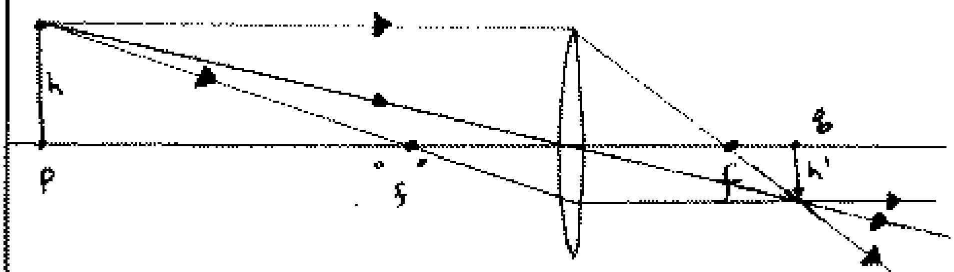
$$\frac{h'}{h} = -\frac{q}{p}$$

<u>4th case</u>

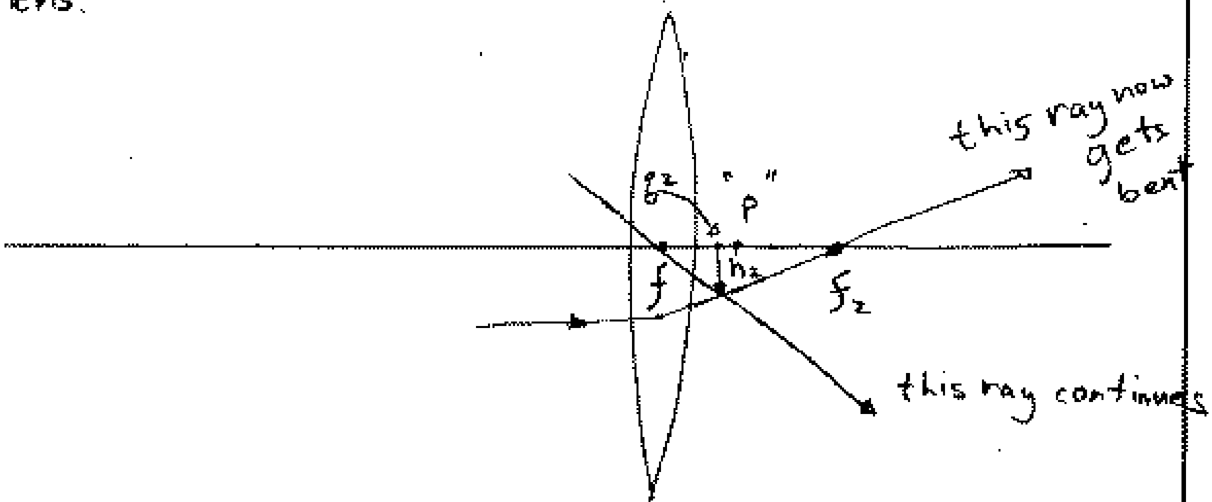


really, about the same as 3rd case

For a lens, you also get a bonus ray



this can be extremely useful for systems with more than one lens. The best example to draw, is when one lens is placed at the focal point of the other lens:



"p" <u>was</u> the position of the 1st image (h'), but now is the position of a <u>virtual</u> object of height h', at a distance of "p" from the center of a second lens. Let's work an example for the 1st lens:

$$p = 30\,cm$$
$$f = 10\,cm$$
$$\text{so, } \frac{1}{q} = \frac{1}{f} - \frac{1}{p}$$
$$q = \frac{fp}{p-f} = \frac{300}{20}\,cm$$
$$= 15\,cm$$

$$h' = -\frac{q}{p}h = -\frac{15}{30}h = -\frac{1}{2}h$$

The second lens in placed at the focal point of the 1st lens so "p" = - 5cm

and if $f_2 = 12\,cm$

$$q_2 = \frac{f_2\,\text{"}p\text{"}}{\text{"}p\text{"} - f_2} = \frac{(12\,cm)(-5\,cm)}{(-5\,cm) - 12\,cm}$$

$$= \frac{-60}{-17}\,cm \sim 3.5\,cm$$

$$h_2 = -\frac{q_2}{\text{"}p\text{"}}h' = -\frac{3.5}{-5}h'$$

$$= .7h' = .7\left(-\frac{1}{2}h\right) = -.35h$$

this is about what we saw

Now, as you change the position of the second lens, you get different results. At the point when

$$"p" = -q = -15\text{ cm} \quad \left(\begin{array}{c}\text{or when the 2nd,}\\ \text{is inside the 1st}\end{array}\right)$$

$$q_2 = \frac{f_2 \, "p"}{"p" - f_2} = \frac{(12\text{ cm})(-15\text{ cm})}{(-15\text{cm} \;\; -12\text{ cm})}$$

$$= \frac{-180}{-27}\text{ cm} = \frac{20}{3}\text{ cm}$$

This is the same as if we had a single lens with focal length

$$\frac{1}{p} + \frac{1}{q_2} = \frac{1}{f_{new}}$$

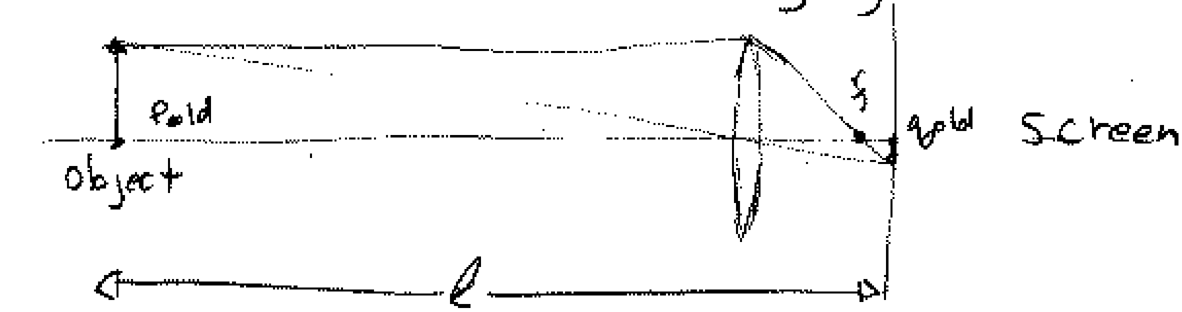
$$f_{new} = \frac{p\,q_2}{p+q_2} = \frac{(30\text{cm})(\frac{20}{3}\text{cm})}{30\text{cm} + \frac{20}{3}\text{cm}}$$

$$= \frac{\left(\frac{600}{3}\right)}{\left(\frac{110}{3}\right)}\text{ cm} = 5.46\text{cm}$$

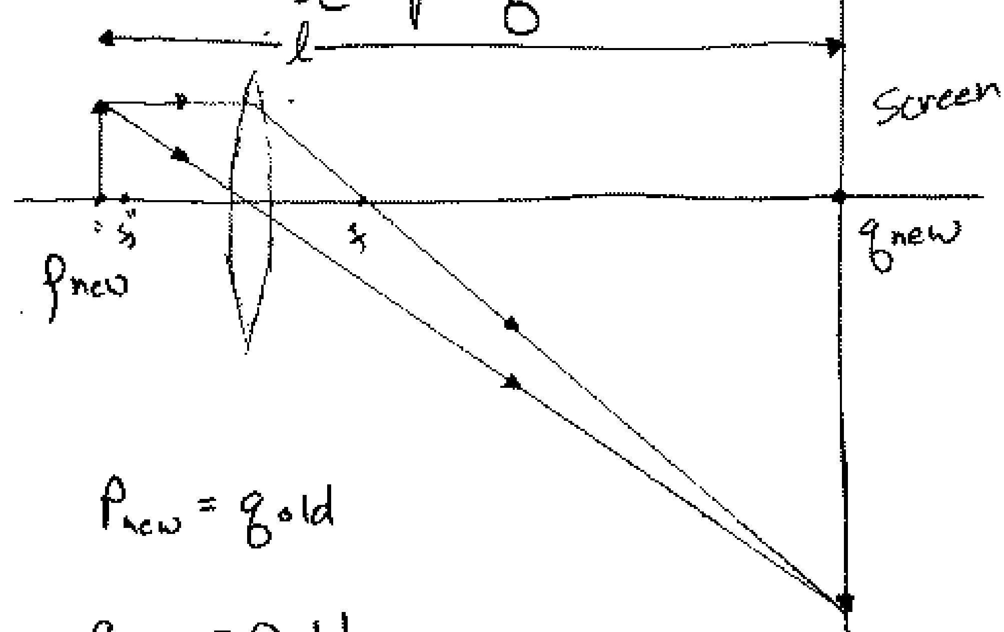
and if we use the equation in your lab manual $\frac{1}{f_{new}} = \frac{1}{f_1} + \frac{1}{f_2}$ $\quad f_{new} = \frac{f_1 f_2}{f_1 + f_2} = \frac{(10\text{cm})(12\text{cm})}{(10\text{cm} + 12\text{cm})}$

$= 5.46\text{ cm}$ same

Also, curiously, you can get an image to form twice with an object, a screen and a converging lens.



if the image focus is at the screen $\ell = p + q$



$p_{new} = q_{old}$

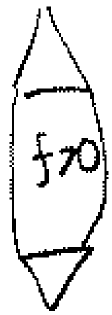
$q_{new} = p_{old}$

If you measure the difference between the 2 lens positions d

$$2(q_{old}) = \ell - d \qquad q_{old} = \frac{\ell - d}{2}$$

$$p_{old} = \ell - q_{old} = \ell - \frac{(\ell - d)}{2} = \left(\frac{\ell + d}{2}\right)$$

Almost Forgot { for real objects on the left ...) (18)

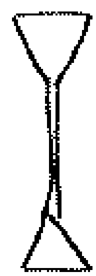


$q>0$
images real

$p>0$
Objects real

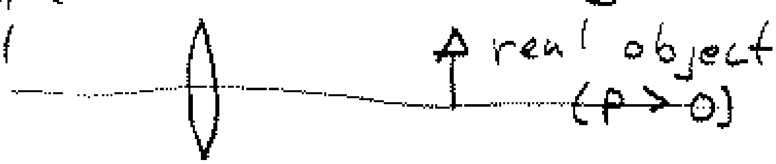
objects virtual
$p<0$

images virtual
$q<0$



$f<0$

Nasty profs will put a real object on this side

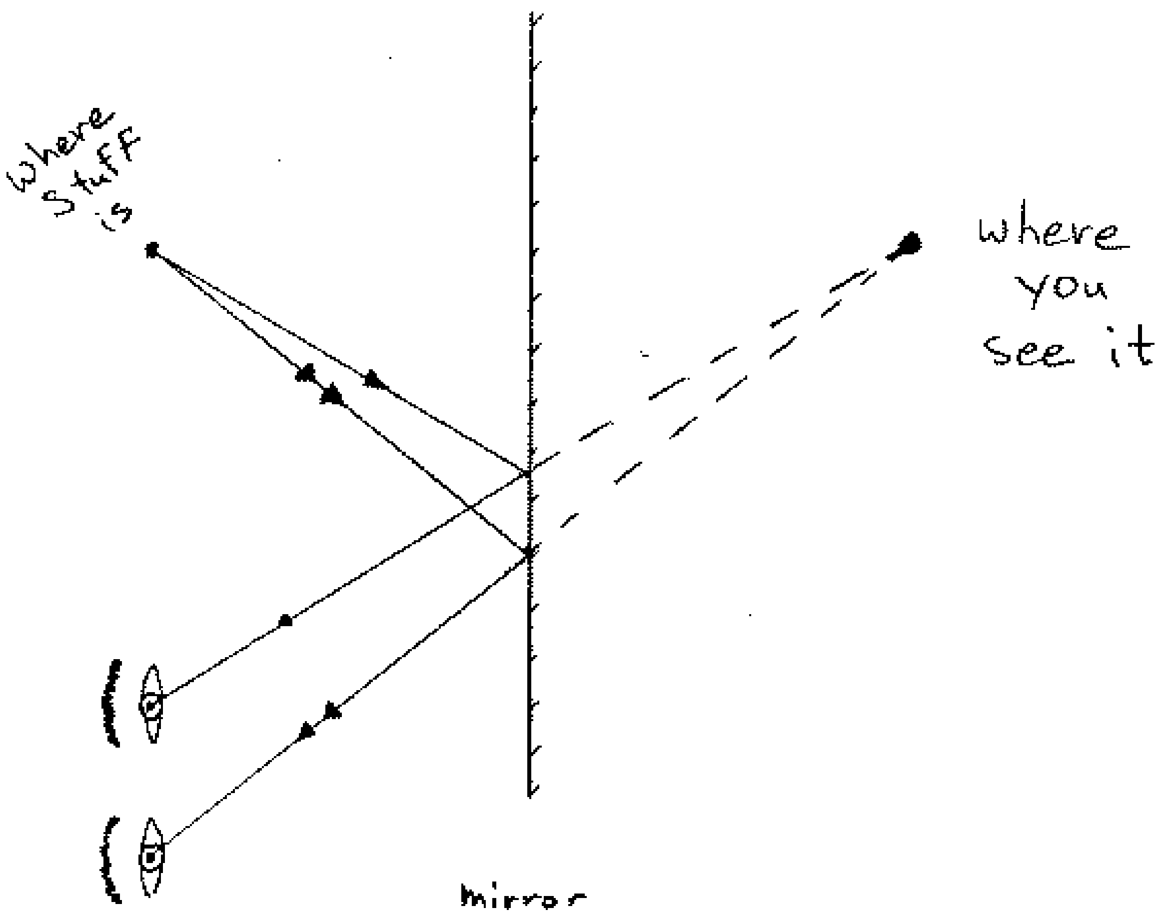


have to redefine!
Sometimes

as a question

We know that the angle of incidence = angle of reflection for a good mirror, but how do you really see stuff in a mirror?

Try this on



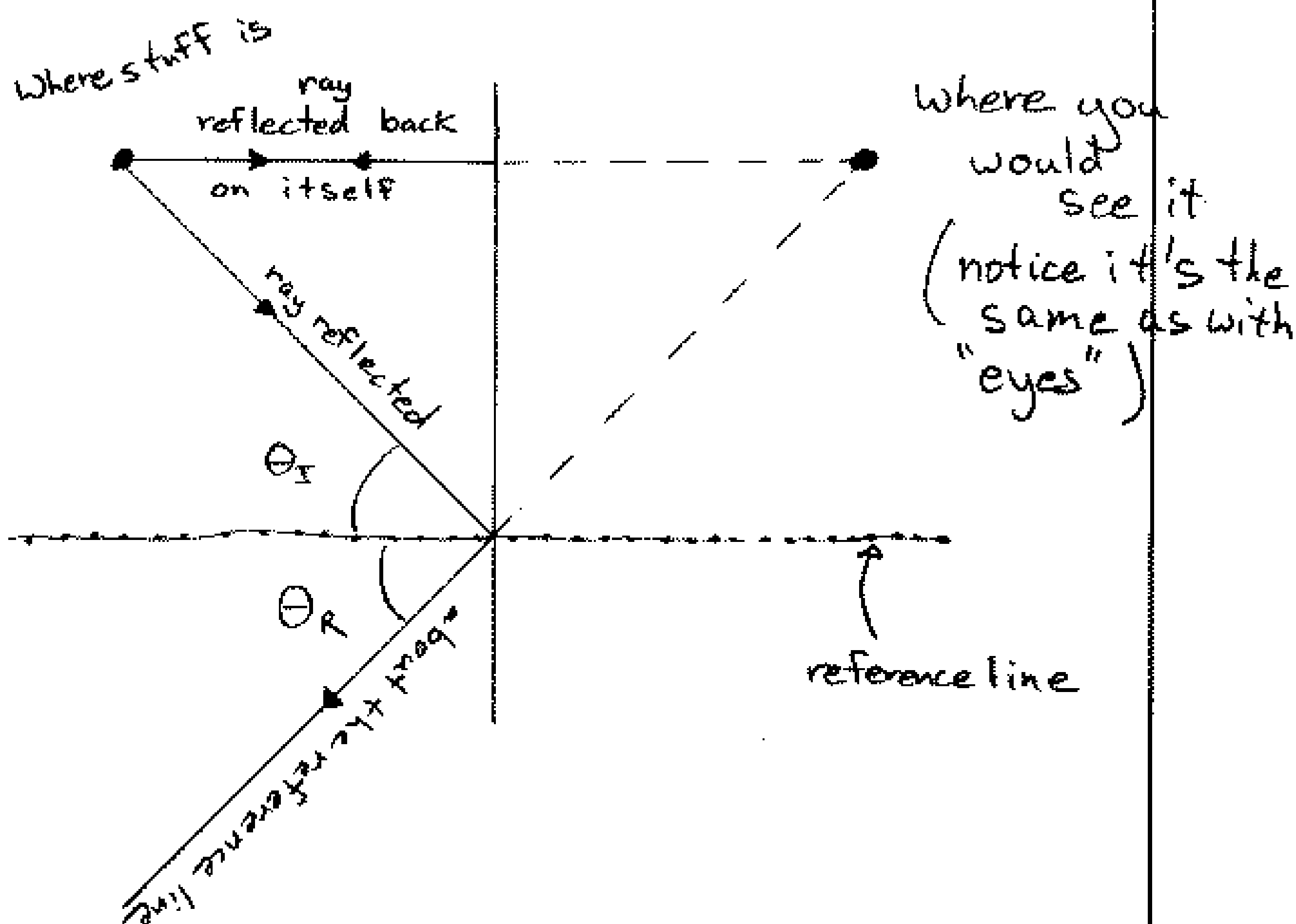
usually, in books, you don't get this convenience. They skip steps and just draw a picture like Figure 26.1 (They seem to forget that you can have trouble with one eye & distances) now, lets curve this mirror and use

1) $\measuredangle$ incidence = $\measuredangle$ reflection

2) Keep in mind we may need one or more lines or rays to determine what happens.

1st, lets make a more automatic way for determining a position of an image in a mirror if we were to look. (or, more convenient)

Here's the trick, draw a reference line

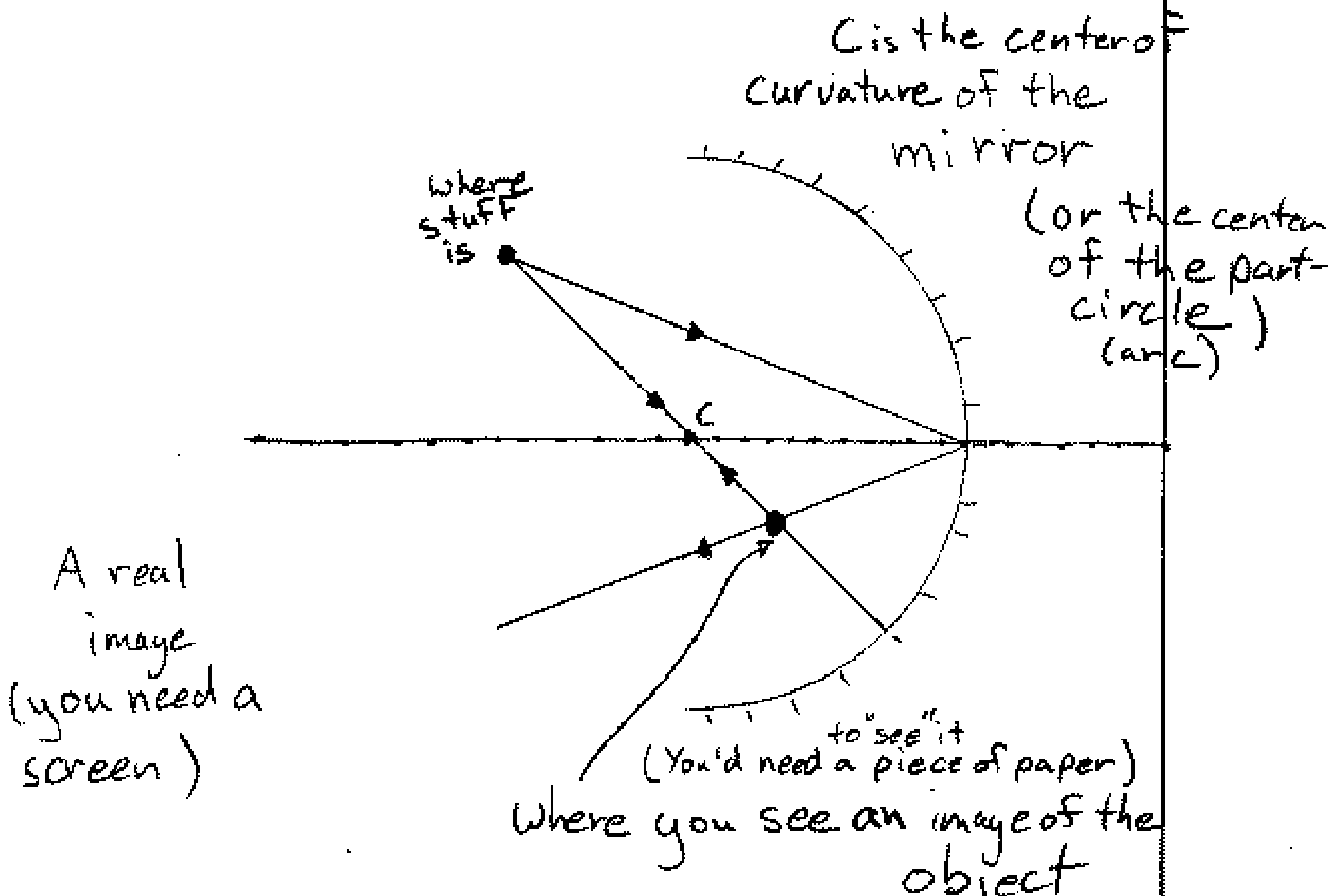


we can get a lot of mileage out of these 2 rays

1) Ray reflected back

2) Ray reflected about the reference line

curve that mirror!

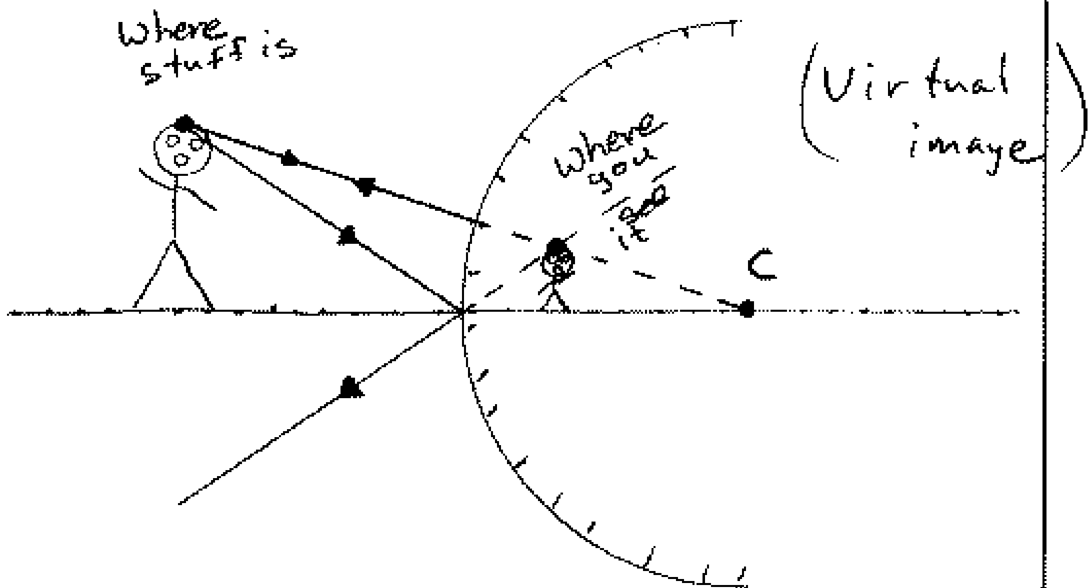


the ray that is reflected back on itself will, or will try to go through the center of curvature.

(incidentally, a flat mirror has $C = \infty$ which is why the reflected back upon itself ray went ⟷)

Lets curve the ray the other way

Here it is the other way.



The figure suggests that we can magnify images too. In fact, the figure above is what happens in the curved mirror of a convenience store.

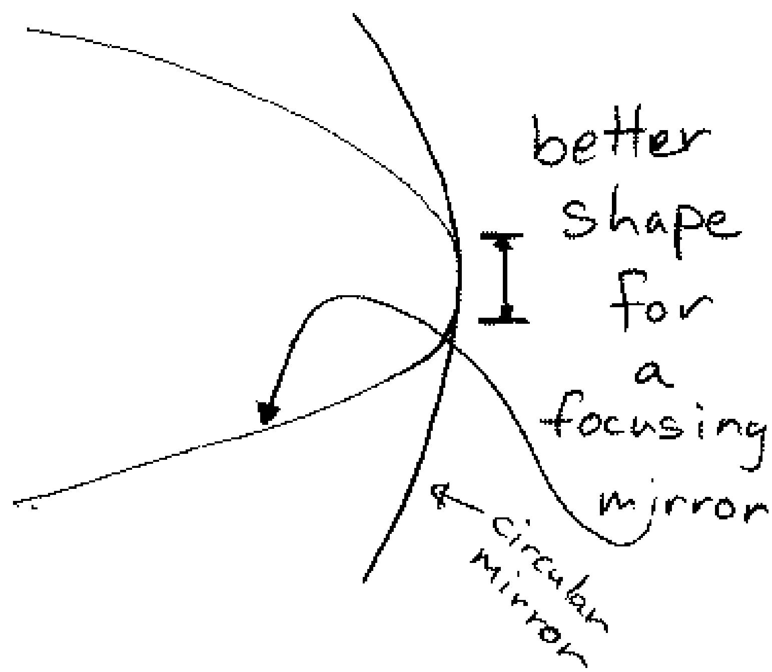
With all these rays running around, there should be a way to calculate

1) where the image is

2) how big & whether an object is upside down.

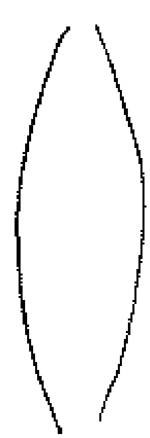
(The skeptics among you are correct, this doesn't exactly work since the paths that each ray takes is different. (over))

This circular mirror business is just a convenience for the real surface you'd have to draw, more like a parabola

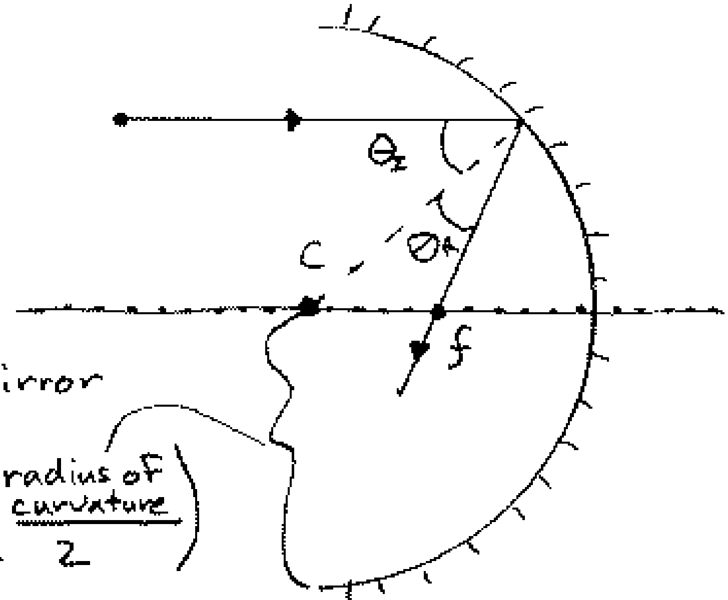


We usually just <u>make</u> a spherical mirror (or lens) and use the part that is very much like a parabola (the part)

which is why most lenses look like:



we can still use our tricks though, but lets introduce a new concept. A focal point.
If we draw a ray ⟶ (As if it came from very faraway)
how does it intersect our reference line?

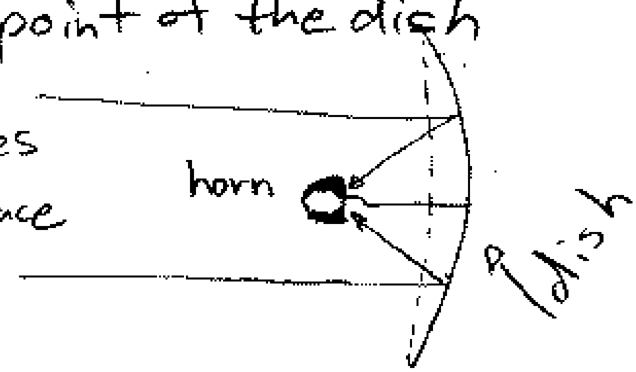


For a spherical mirror you guessed it
$$f = \left(\frac{\text{radius of curvature}}{2}\right)$$

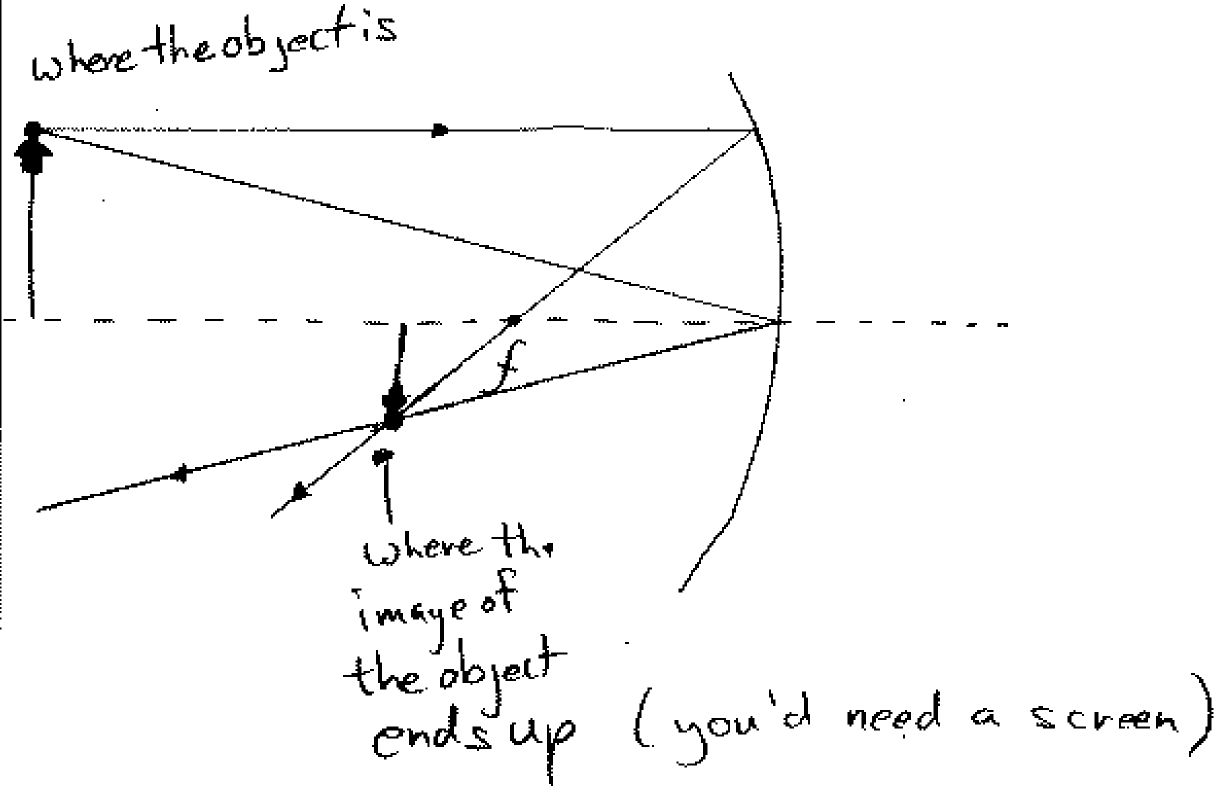
notice that about
the line from the center of curvature to the surface of the mirror (The ⊥ to the surface of the mirror)
the $\measuredangle$ Incidence = $\measuredangle$ Reflected

The point where the infinite ray crosses the reference line is the Focal point

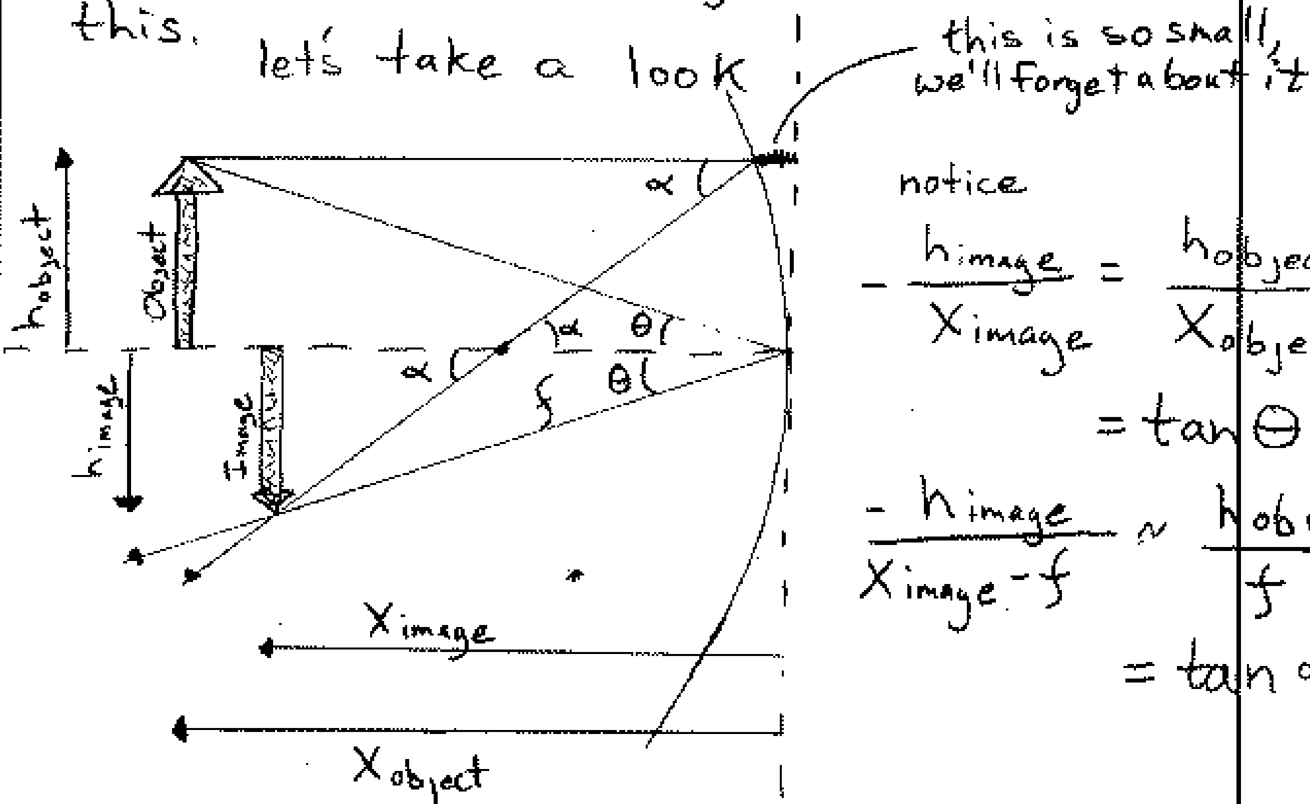
That horn you see in a satellite dish is at the focal point of the dish



And we can add a new way to draw the rays



now, we promised a way to calculate all this. let's take a look



notice

$$-\frac{h_{image}}{X_{image}} = \frac{h_{object}}{X_{object}}$$

$$= \tan\theta$$

$$\frac{-h_{image}}{X_{image}-f} \approx \frac{h_{object}}{f}$$

$$= \tan\alpha$$

or $\quad -h_{image} = \frac{x_{image}}{x_{object}} h_{object}$

so that

$$\frac{-h_{image}}{x_{image} - f} = \frac{\frac{x_{image}}{x_{object}} \cancel{h_{object}}}{x_{image} - f} = \frac{\cancel{h_{object}}}{f}$$

$$\frac{\frac{x_{image}}{x_{object}}}{x_{image} - f} = \frac{1}{f} \Rightarrow \frac{x_{image}}{x_{object}} = \frac{x_{image} - f}{f} = \frac{x_{image}}{f} - 1$$

$$\left(\frac{1}{x_{image}}\right) \frac{x_{image}}{x_{object}} = \left(\frac{x_{image}}{f} - 1\right)\left(\frac{1}{x_{image}}\right)$$

$$\frac{1}{x_{object}} = \frac{1}{f} - \frac{1}{x_{image}}$$

$$\frac{1}{x_{object}} + \frac{1}{x_{image}} = \frac{1}{f}$$

(your book does this a
different & complimentary way)

In your book $X_{image} \equiv q$

$X_{object} \equiv p$

<u>mirror equation</u>

$$\frac{1}{p} + \frac{1}{q} = \frac{2}{R} = \frac{1}{f}$$

radius of curvature

lenses are <u>very</u> similar, you deal with the equation

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \quad \text{(hmmm)}$$

---

lets examine this equation a little

$$\left.\begin{array}{l} \text{if } p = f,\ q = \infty \\ p = \infty,\ q = f \end{array}\right\} f > 0$$

now, apparenty, we're going to have to figure out where minus signs go since f is not the same for) and (mirrors, lets examine cases