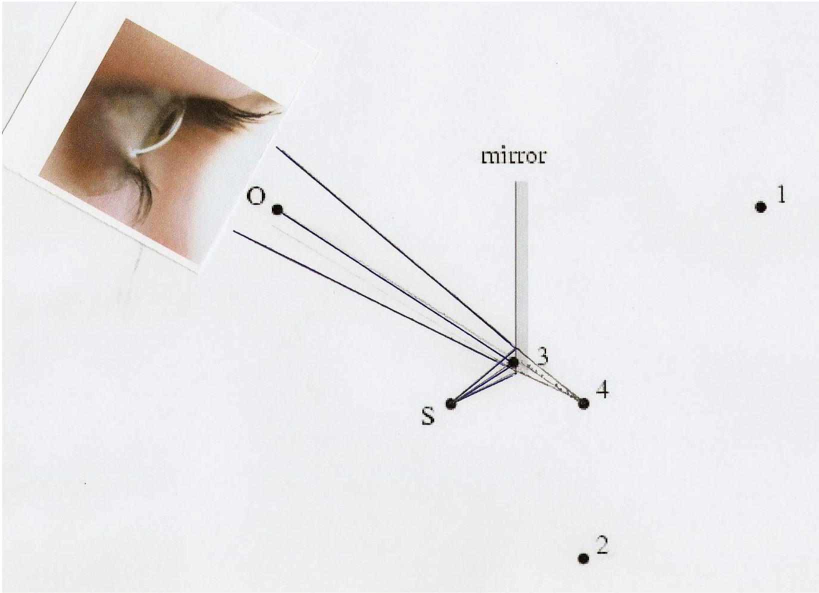
Physics 9 — Monday, October 1, 2018

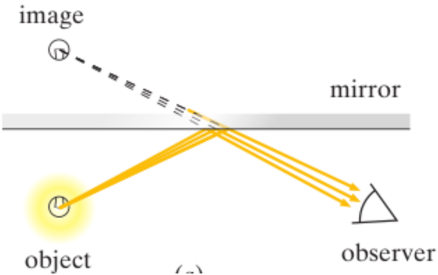
- Pick up handout for HW#4 (due Oct 12), in back-right corner of room.
- I found a way to run both Odeon and CATT-Acoustic on MacOS without a virtual machine! Stay tuned.
- For today, you read Giancoli ch24 (wave nature of light)
- For Wednesday, read Giancoli ch25 (optical instruments)

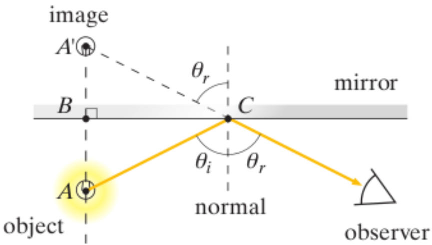
Mirror: $\theta_r = \theta_i$.



Object is at point **S**. Eye sees rays that appear to come from point **4** (where they meet), so brain perceives image located at point **4**.

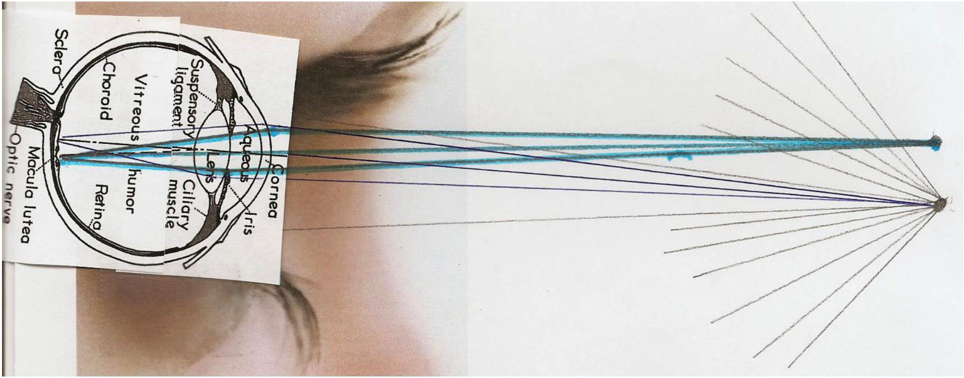
Mirror: $\theta_r = \theta_i$. Angles measured w.r.t. surface normal.





Question: is this a "real" or a "virtual" image?

(A) real
(B) virtual

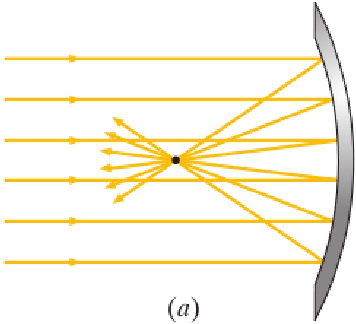


Again: the eye detects (and focuses onto the retina) rays of light that diverge from a point. That point from which the rays diverge is where the eye/brain perceives the image to be.

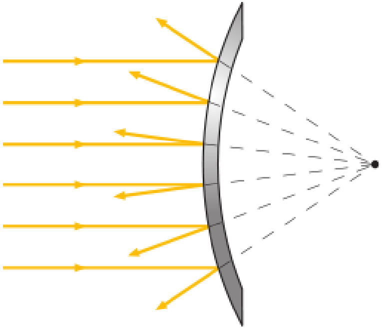
Mirror: angle of reflection = angle of incidence.

$$\theta_r = \theta_i$$

works for curved mirrors as well as flat ones. The farther away you are from the middle of the mirror, the bigger the slope, and thus the larger the change in angle. So parallel rays are focused to a point by a "concave" ("converging") mirror. The "focal length" is $f = R/2$, where R is radius of curvature.

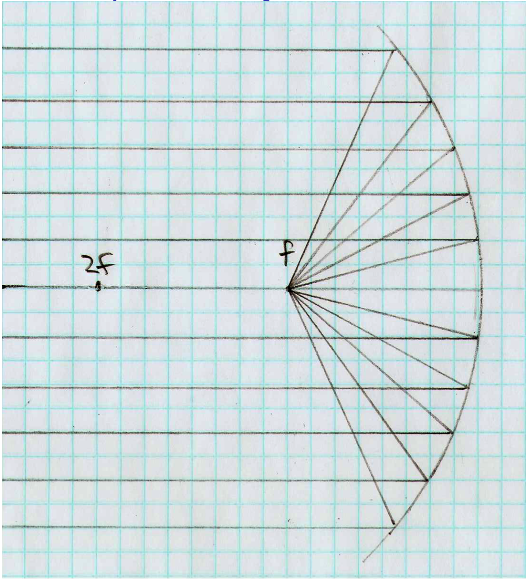


concave/converging mirror



convex/diverging mirror

Converging mirror: parallel rays focus on LHS

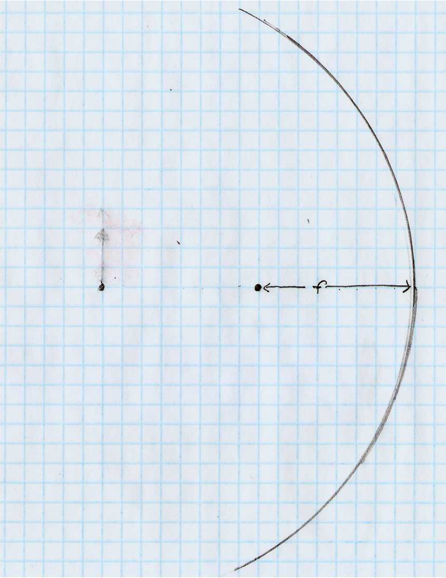


Strictly speaking, this is true of a parabolic mirrors, not spherical, but it's a useful approximation, and spheres are easier to fabricate.

Demo: light bulb with converging mirror

We put a light bulb ("object") of height h a distance d_o from converging mirror, with $d_o = 2f$, and we saw a real, upside- down image of the bulb at $d_i = 2f$. Let's see how this works.

First we draw the mirror and the focal point, which is a distance $f = R/2$ away from the mirror surface, along the x axis.



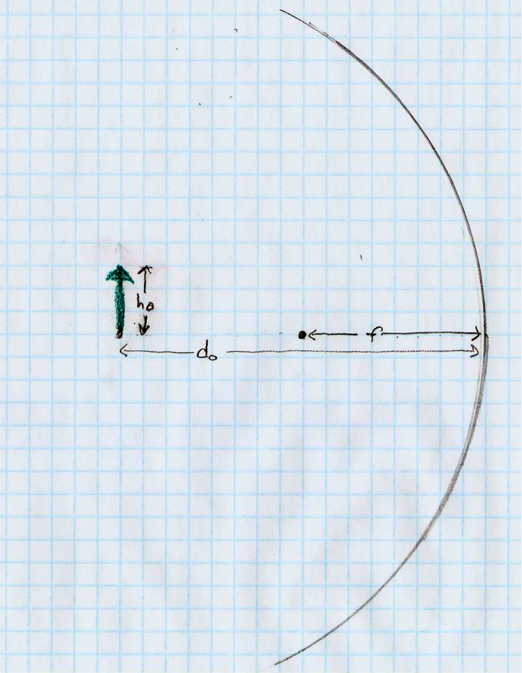
Next, we draw the "object" (in this case, the actual light bulb), as a vertical arrow.

By convention, the base of the arrow is on the x axis at distance d_o from the mirror.

In this special case, we're trying $d_o = 2f$.

The arrow's tip is a height $h_o > 0$ above its base.

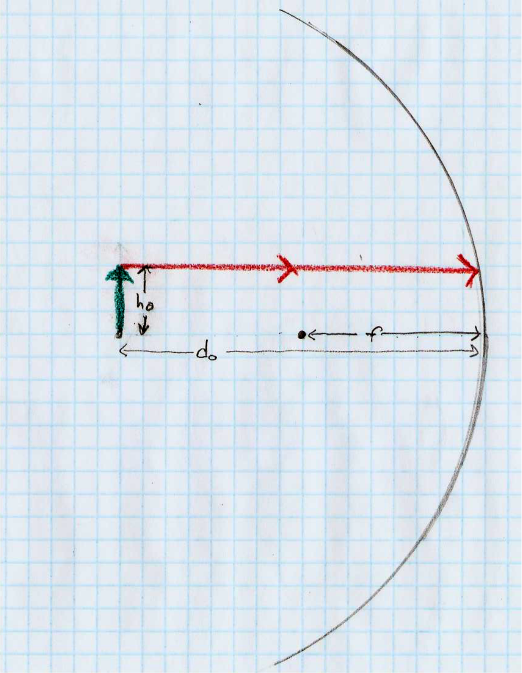
The goal is to figure out where (if anywhere) the mirror forms an image of the point $x = d_o$, $y = h_o$.



The goal is to figure out where (if anywhere) the mirror forms an image of the point $x = d_o$, $y = h_o$.

Starting from the **tip** of the object, we draw the three easy-to-draw rays.

I've started one ray here: how do I continue it after it strikes the mirror?



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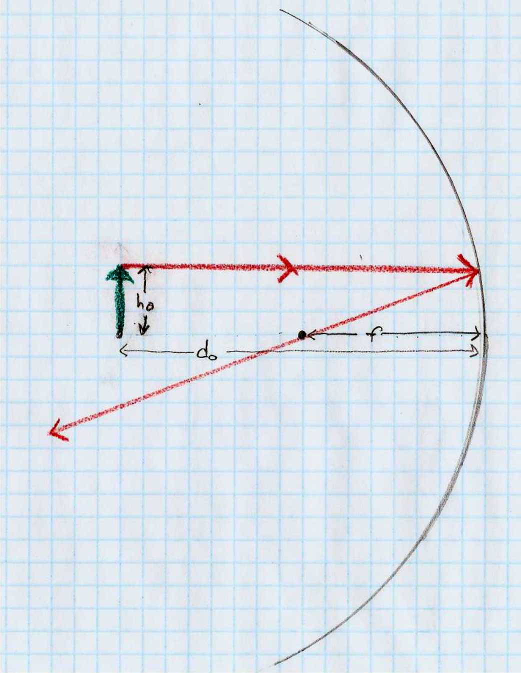
Starting from the **tip** of the object, we draw the three easy-to-draw rays.

An incident horizontal ray is reflected through the focus.



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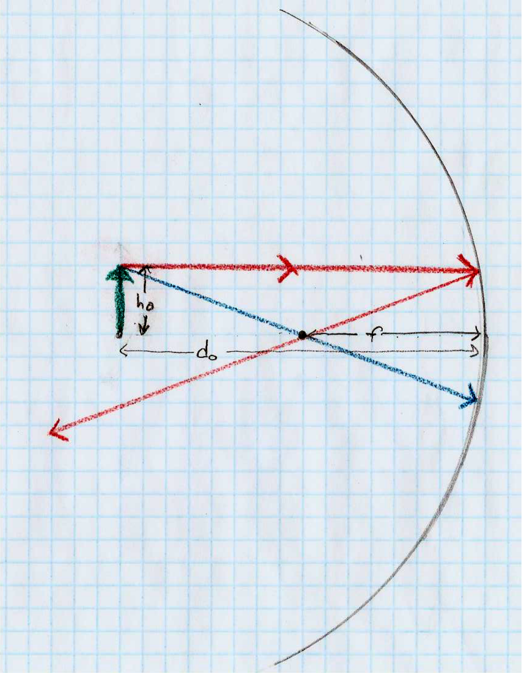
Starting from the **tip** of the object, we draw the three easy-to-draw rays.

An incident horizontal ray is reflected through the focus.

What happens to an incident ray that passes through the focus?



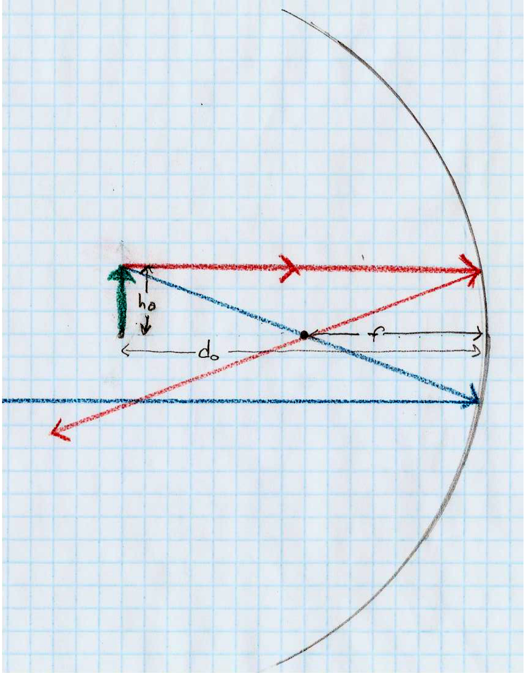
The goal is to figure out where (if anywhere) the mirror forms an image of the point $x = d_o$, $y = h_o$.

Starting from the **tip** of the object, we draw the three easy-to-draw rays.

An incident horizontal ray is reflected through the focus.

An incident ray that passes through the focus is reflected as a horizontal ray.

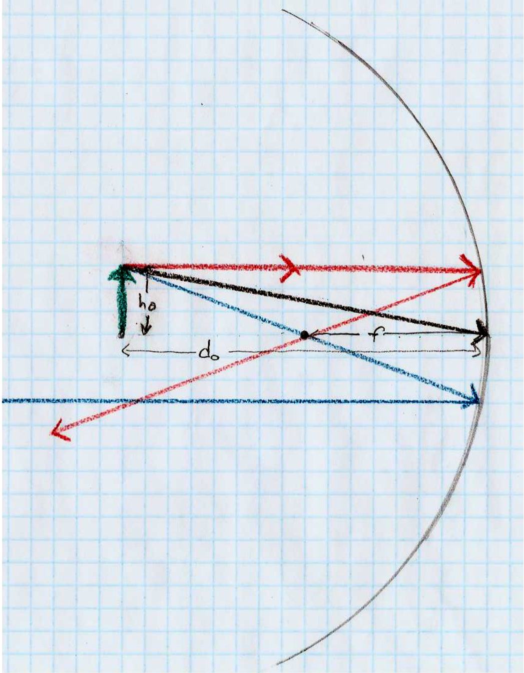
Two lines suffice to determine a point, but we'll do one more ray as a check.



The goal is to figure out where (if anywhere) the mirror forms an image of the point $x = d_o$, $y = h_o$.

Starting from the **tip** of the object, we draw the three easy-to-draw rays.

What happens to an incident ray that hits the mirror on the x axis, where the surface normal is horizontal?

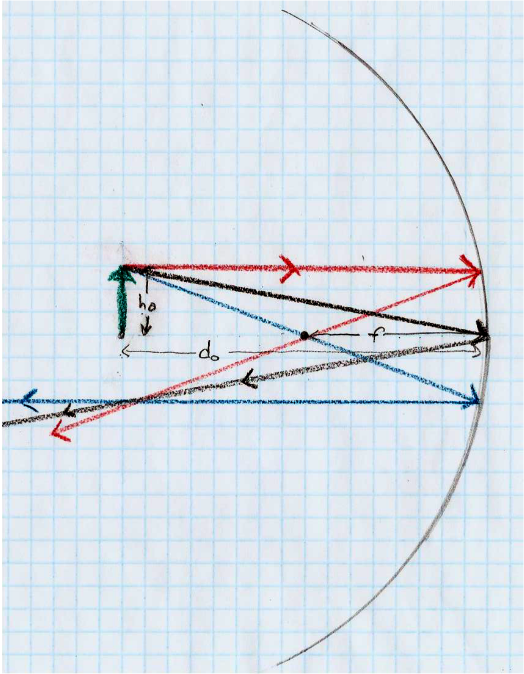


The goal is to figure out where (if anywhere) the mirror forms an image of the point $x = d_o$, $y = h_o$.

Starting from the **tip** of the object, we draw the three easy-to-draw rays.

An incident ray that hits the mirror on the x axis is just mirrored across the x axis.

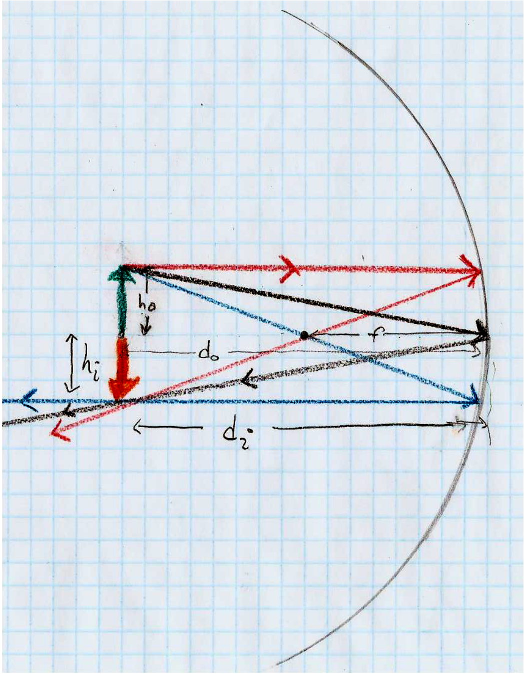
(Alternative: a ray passing through the center of curvature comes right back on itself. That ray is harder to draw in this case. **Where would it be?**)



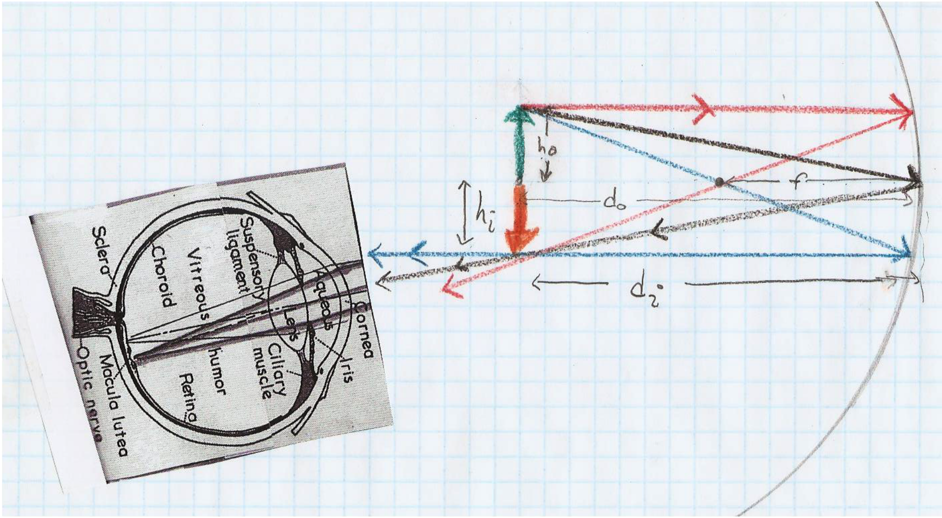
The goal is to figure out where (if anywhere) the mirror forms an image of the point $x = d_o$, $y = h_o$.

In this case, the image is the same height as the object, but it is "inverted." So $h_i = -h_o$.

We'll see from the math in a minute that if I had drawn more carefully, the rays would meet (in this example) at $d_o = d_i$. Imprecision is a limitation of the graphing method.



Your eye perceives the rays diverging from (d_i, h_i) as an image of the object that is at (d_o, h_o). Is this a real or a virtual image?



Let's try the same thing with equations.

- You relate f, d_o, and d_i, for both mirrors and lenses, with the memorable phrase, "**If I do, I di**e."

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

- The hardest part is remembering the sign conventions.
- For a converging mirror, $f = +R/2$.
- We almost always draw the object on the left side (which is the reflective side of the mirror), so $d_o > 0$ means left side.
- We take $d_i > 0$ for a "real" image. For a mirror, $d_i > 0$ means left side.
- One more equation: works for both mirrors and lenses.

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Magnification $m < 0$ means image is upside-down ("inverted").

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Let's try solving for d_i and h_i. This result is useful for plugging in numbers, but too hard to remember:

$$d_i = \frac{d_o f}{d_o - f} \qquad h_i = \frac{h_o f}{f - d_o}$$

Now plug in the present situation: $\boxed{d_o = 2f}$. We get

$$d_i = d_o \qquad h_i = -h_o$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

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Notice that image "blows up" if $d_o = f$. See what happens if $d_o = 1.5f$. Then $d_i = 3f$, $h_i = -2h_o$. Light bulb gets bigger, but image appears farther away from mirror (closer to you). You can't see a clear image of yourself in a make-up mirror if $f < d_o < 2f$, because the image of your face is behind you.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Solve for d_i and h_i:

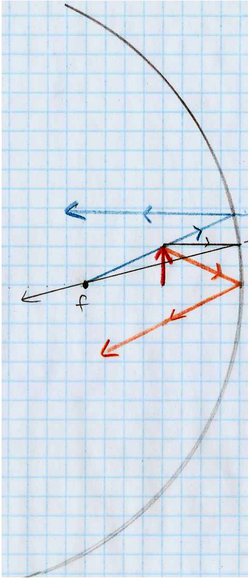
$$d_i = \frac{d_o f}{d_o - f} \qquad h_i = \frac{h_o f}{f - d_o}$$

Now plug in $d_o = \frac{1}{2}f$. This is how you normally use a make-up/shaving mirror.

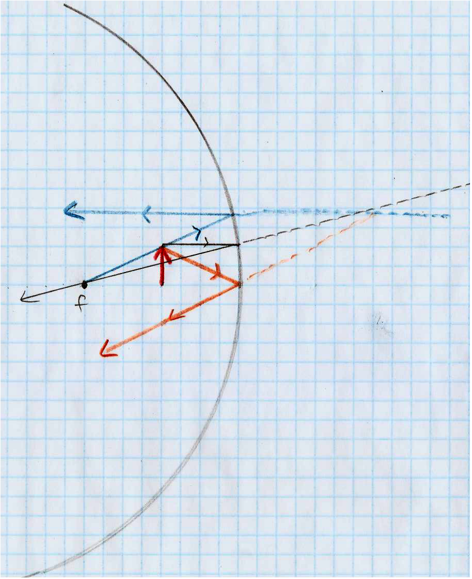
$$d_i = -f \qquad h_i = 2h_o$$

You get an upright (not inverted) image of yourself that is $2x$ taller than the object. But where is the image? Is it real or virtual? Let's try drawing the rays!

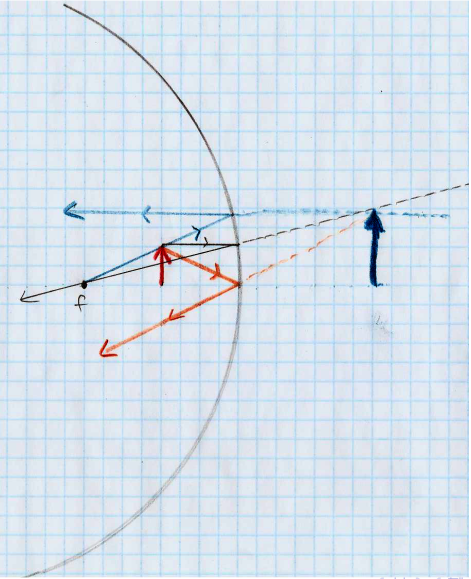
$d_o = \frac{1}{2}f \quad d_i = -f \quad h_i = 2h_o$. Where do these rays converge?

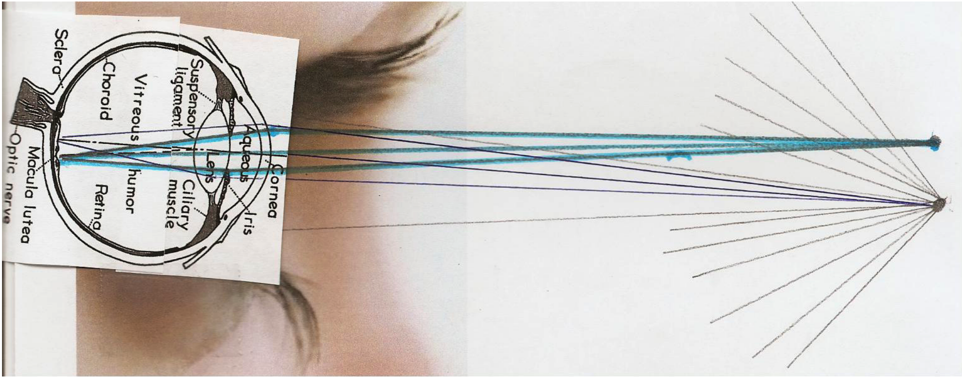


$d_o = \frac{1}{2}f \quad d_i = -f \quad h_i = 2h_o$. Is this image real or virtual?!



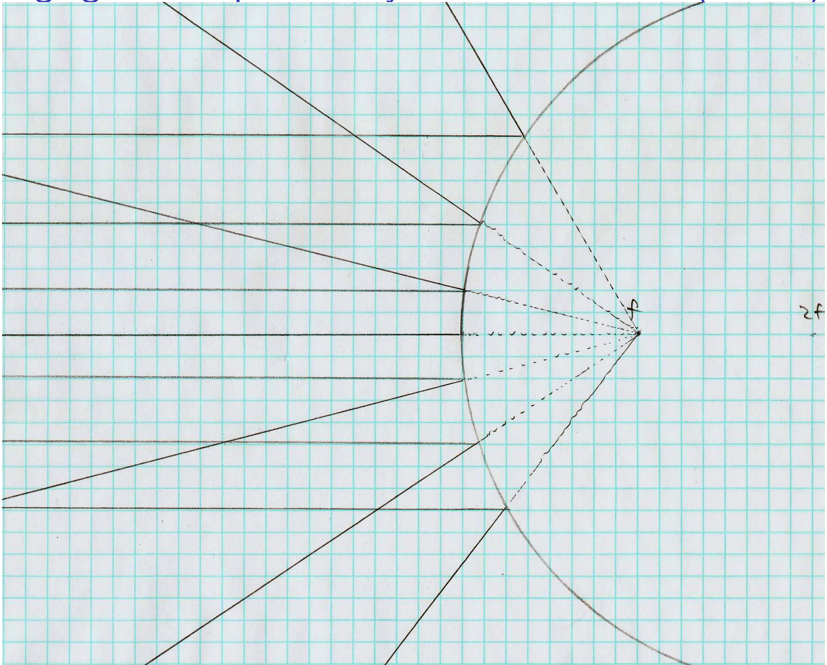
$d_o = \frac{1}{2} f$ $\boxed{d_i = -f}$ $h_i = 2h_o$. Is this image real or virtual?! Do the light rays really go where the image is? (Notice that I drew the rays back there as dashed/dotted lines.) $\boxed{d_i < 0 \quad \Rightarrow \text{virtual}}$



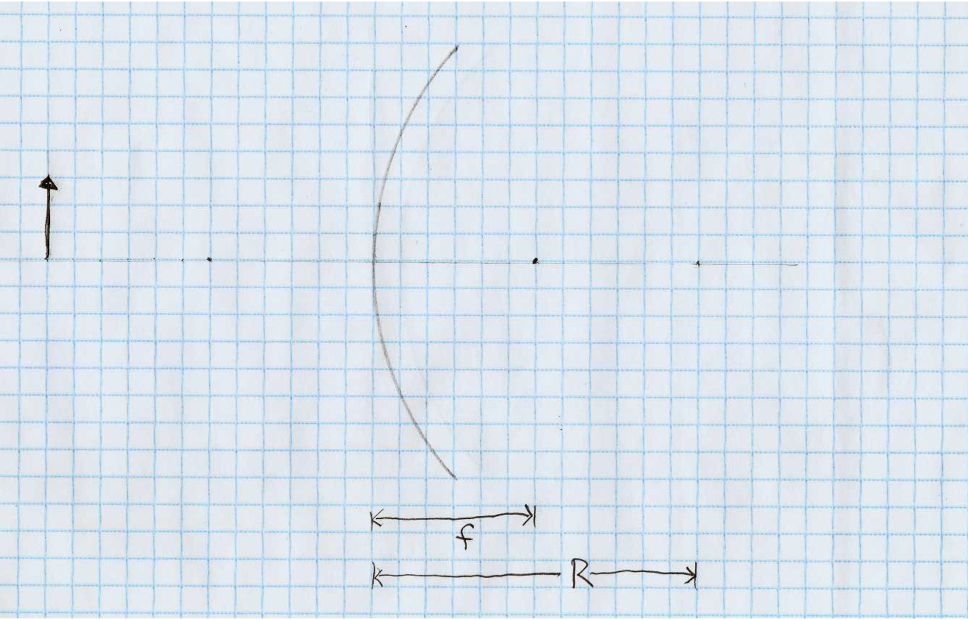


Again: the eye detects (and focuses onto the retina) rays of light that diverge from a point. That point from which the rays diverge is where the eye/brain perceives the image to be. Rays seem to be diverging from there $\Rightarrow$ eye is fooled into seeing the image there.

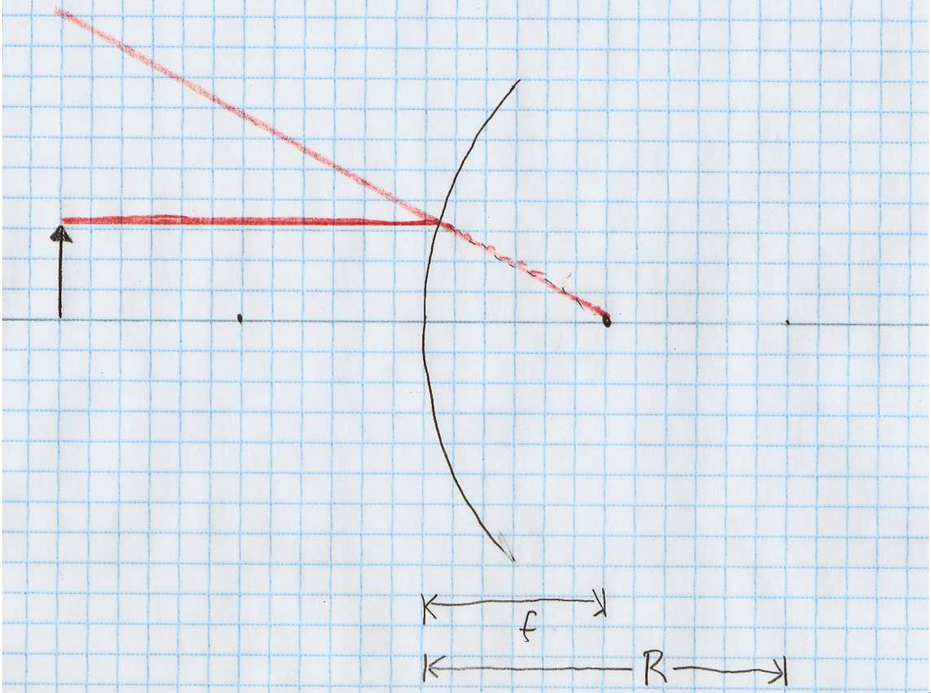
Diverging mirror: parallel rays "focus" on RHS (virtual)

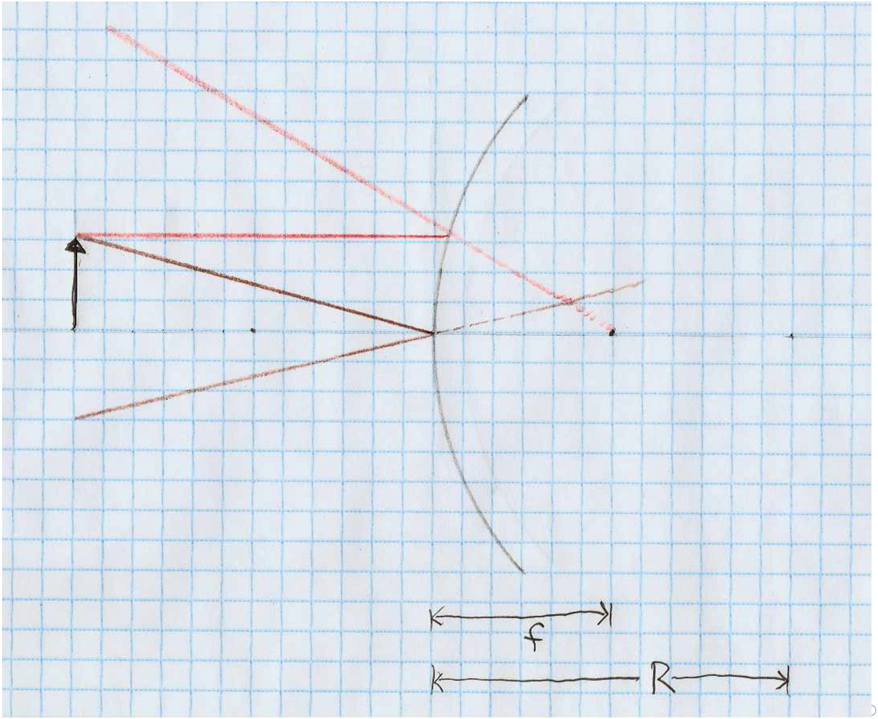


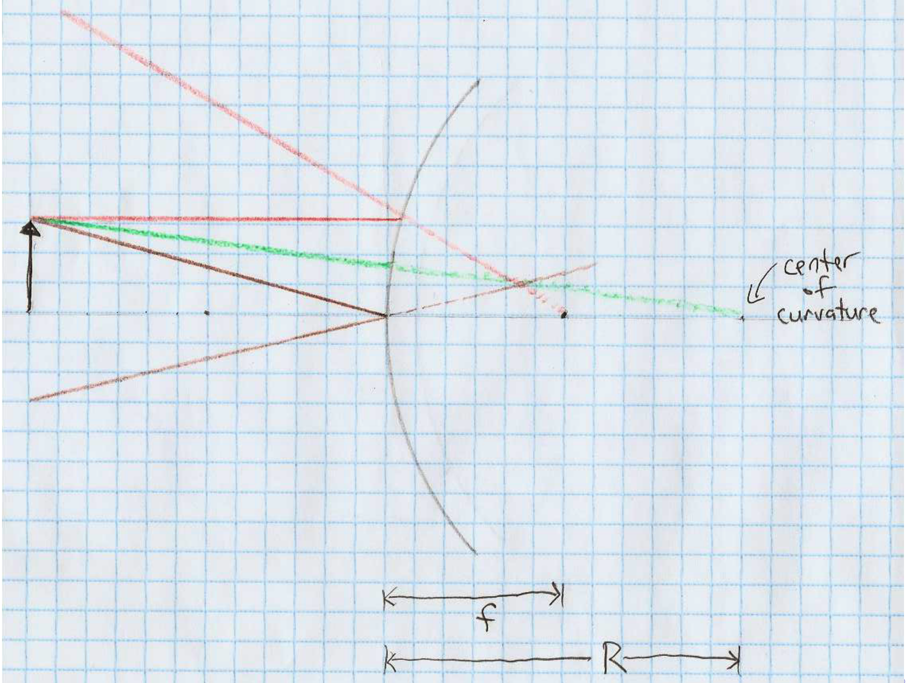
RHS car mirror: “objects in mirror are closer than they appear”

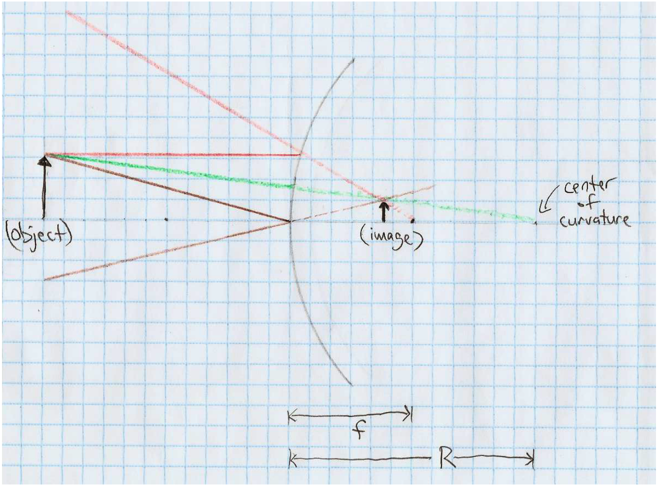


How do we draw the “principal rays” to find the image here?


f
R


f
R


center
of
curvature
f
R



RHS car mirror: diverging mirror, with object typically far away. Image is upright but smaller than object (smaller $\Longrightarrow$ appears farther away). [Also used as wide-angle security mirror.]

Let's analyze same situation using equations.

Lens & mirror summary (light always enters from LHS):

converging lens	$f > 0$	$d_i > 0$ is RHS	$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$
diverging lens	$f < 0$	$d_i > 0$ is RHS	$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$
converging mirror	$f > 0$	$d_i > 0$ is LHS	$f = R/2$
diverging mirror	$f < 0$	$d_i > 0$ is LHS	$f = -R/2$

Horizontal locations of object, image (beware of sign conventions!):

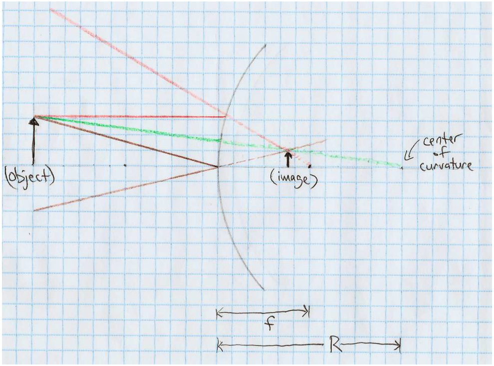
$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

Magnification (image height / object height):

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Lenses: $R_{1,2} > 0$ for "outie" (convex), < 0 for "innie" (concave).

Real image: $d_i > 0$. Virtual image: $d_i < 0$. Real image means light really goes there. Virtual: rays converge where light doesn't go.



Diverging mirror:
$f = -R/2$.

Distant object: $d_o = 2|f|$ in our example.

Object and image distances: d_o and d_i.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

Magnification:

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Easier if we first solve for d_i and h_i ...

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