Lesson 26: Reflection & Mirror Diagrams

The Law of Reflection

There is nothing really mysterious about reflection, but some people try to make it more difficult than it really is.

- All EMR will reflect off of appropriate surfaces, but for the purposes of this lesson we will only care about visible light reflecting off of mirrors.

Drawings that show reflection always include a special line that must be drawn first... the **normal**.

- You might remember this word from when we studied forces. We say that a line drawn at 90° to the surface is a **normal line**.
- When you want to figure out how something will reflect from a surface, draw a **normal line** to that boundary at that point.

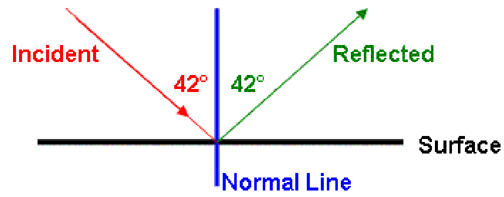

Illustration 1: Reflection diagram.

The Law of Reflection says "**the angle of incidence equals the angle of reflection**."

- These angles are always measured from the **normal line** so that we have a common reference.
- In *Illustration 1* we see that the angle is 42° coming in and 42° reflecting off.
- This is an example of **regular** (*specular*) reflection.

The only time you need to be really careful with the law of reflection is when the surface is somehow irregular.

- We still draw normal lines, but we can end up with millions of them if the surface is really random.
  - For example a lake on a windy day will show a really blurred image because the surface reflects the light in so many directions.
- We won't worry too much about this irregular (diffuse) reflection.

Plane Mirror Diagrams

We can use the Law of Reflection to draw diagrams to predict the way an observer will see an image in a plane mirror.

- "Plane" in this case refers to boring, old fashioned, *flat* mirrors.

Doing problems involving plane mirrors is actually pretty easy since we only have to remember a few things:

1. **The image will be the same size as the original object.**
2. **The image will appear as far behind the mirror as the object is in front of the mirror.**
3. **The Law of Reflection**. Any light beam that hits the mirror will bounce off at exactly the same angle. We assume the mirror is perfectly flat in these situations. We will have to make sure that the light rays reflected off the mirror do so at an angle that makes them hit the observer's eye.

Let's look at a simple example to illustrate how we have to draw these diagrams.

Example 1: **Sketch** a ray diagram that shows how light will travel from the object to the eye by reflecting from the mirror in *Illustration 2*. **Identify** the position of the image.

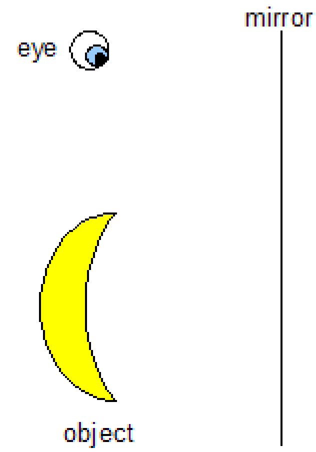

Illustration 2: An object in front of a mirror. This diagram is edge-on.

First, measure how far the object is in front of the mirror. Draw a quick sketch (*Illustration 3*) of the image behind the mirror at the same distance (just make sure it's flipped around, and ***must*** be drawn with a dashed line).

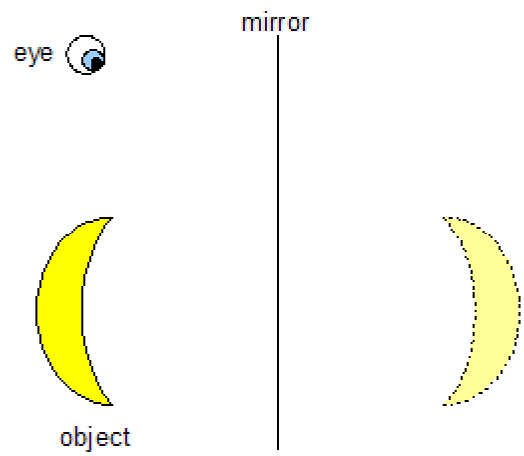

Illustration 3: Showing the image behind the mirror

Illustration 4 shows how we draw a light ray (a line) from the observer's eye to an important part of the image (like the top). The light ray should be dashed when it is behind the mirror to show that the light ray isn't really there.

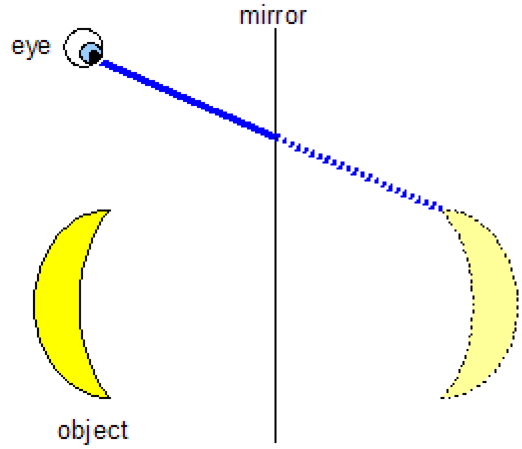

Illustration 4: The first ray showing how the person sees the image.

At the point where that light ray hit the mirror, bounce it back at the same angle (**law of reflection**) so that it hits the same spot on the original object as shown in *Illustration 5*.

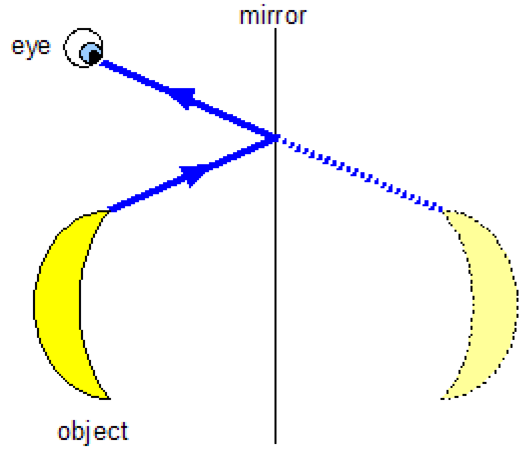

Illustration 5: The light ray actually bounces off the mirror.

Now we draw another separate light ray that shows the path the light takes to get from the bottom of the object to the eye. It should look like *Illustration 6*. This shows how the light rays from the object converge on the eye.

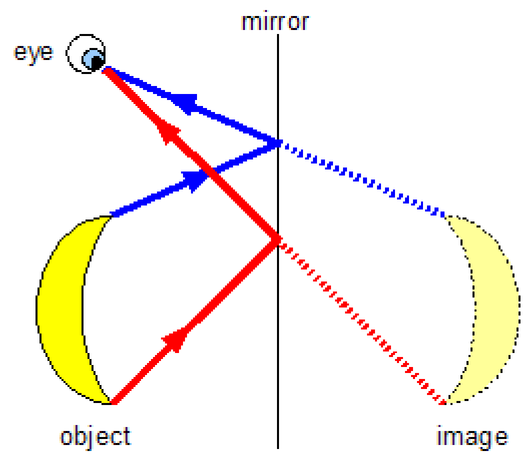

Illustration 6: A second, separate ray drawn on the diagram.

This gives you an idea of how the light rays are traveling from the object to you eye, and also why the image appears to be behind the mirror.

- Because the image isn't really behind the mirror (meaning that there are no true light rays that are back there), we refer to it as a "**virtual image**."
  - That's why we drew everything behind the mirror as dotted lines. It shows that there are no real rays of light back there.
- You can always do a test in your head to determine if you are dealing with a virtual image. Ask yourself "If I put a piece of paper where I think the image is (in the example above that would be behind the mirror), will I see the image on the paper like a film on a movie screen?" If the answer is "no", you have a virtual image.
  - Sometimes the answer can be "yes" when dealing with curved mirrors.

Curved Mirrors

Maybe you've gone into a mirror fun house that has all those weird mirrors that make you look 10 feet tall, skinny in the middle and wide at the top.

- Obviously these are not regular, plane mirrors. Instead, they're all curved and bumpy and misshaped.
  - Don't worry, we're not going to be analyzing mirrors that are that weird, but we will be looking at curved mirrors.
- Imagine taking a giant metal ball and cutting a section out of it. You spray some shiny paint on the inside or outside and you have a curved mirror.
  - The first kind we will be looking at is a **concave converging** mirror, which would mean that you made the inside of the ball shiny.
  - Later we will look at **convex diverging** mirrors, where the outside of the ball was made shiny.

Concave Converging Mirrors

To be able to figure out how an image will be formed in one of these converging mirrors, you need to be aware of a few basic "parts". Check out *Illustration 7* and the description of each part that follows.

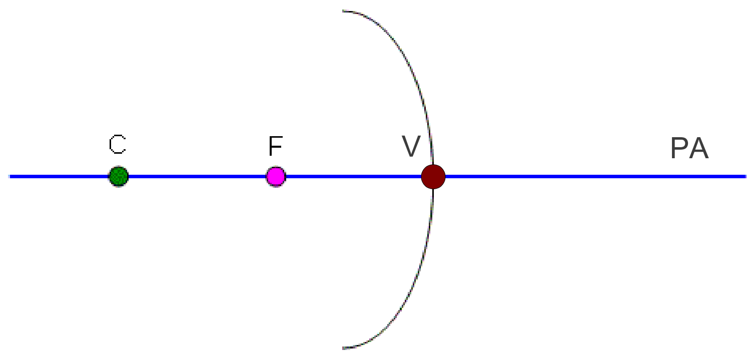

Illustration 7: Parts of a curved mirror.

Centre (C)

The centre shown in the diagram is where the centre of the sphere would be. The diagram exaggerates the shape of the mirror a bit to be able to use it in some of the diagrams later on, but you should be able to get the basic idea. Like a regular circle, the distance from the centre to the surface of the mirror is the ***radius***.

Focus or Focal Point (F)

If an object was infinitely far away from the mirror, the light from it would converge on this one point. In the diagrams we are doing we will mostly be looking at how some light rays pass through (or appear to pass through) this focal point. The focal point is exactly in between the mirror and the centre. Since the distance between the centre and the mirror is the radius, the distance from the focal point to the mirror is *half* of the radius. This distance is referred to as the **focal length**.

Principle Axis (PA)

The blue line is the principle axis, a line that we will use as a reference point in our diagrams. It passes through the centre and is perpendicular to the surface of the mirror.

Vertex (V)

Where the principle axis meets the mirror surface.

There are three rules you need to use to figure out where the image of the object will appear. You only need to use **two** of the three to actually locate the image.

- All of the rules involve what a ray will do when it leaves the object.
- You will need to have a ruler to draw the lines when you figure out these problems.
- When you sketch the curved mirror itself, you'll find you don't have to be too careful about making its shape perfect… close enough will give you decent results.
- The object we will be using in these examples is an arrow pointing up... that way we will have an easy time seeing if the image is flipped upside down or not.
  - The image will appear where any two ***reflected*** rays cross.

Warning!
If you use all three rules, you'll sometimes see that the don't all intersect at the same point and it might seem you did something wrong. Don't worry, it's just because our mirror diagrams are not perfect.

Rule #1: Any ray through the focal point will reflect parallel to the principle axis (*Illustration 8*).

Don't start worrying about how that ray of light came off the object and went straight through the focus… it just did. Light reflects off objects at all sorts of angles, and if it will help us to find where an image is, we might as well assume one ray goes right through the focus.

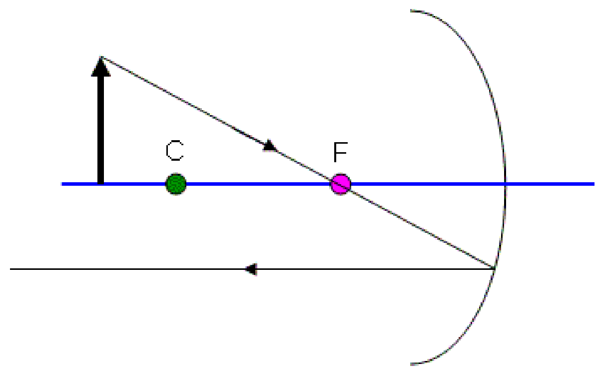

Illustration 8: Light Ray through the focus.

Rule #2: Any ray parallel to the principle axis will reflect so that it passes through the focal point (*Illustration 9*).

I know this sounds exactly the same as the first rule, but look at it carefully and you'll see that it is the opposite.

Notice the spot where the reflected red ray is crossing the reflected black ray from rule one… this shows me where the image will appear.

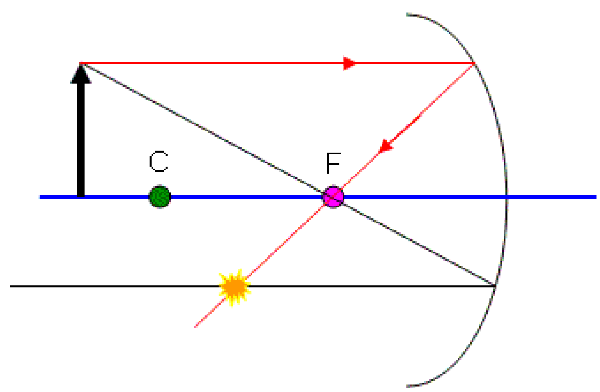

Illustration 9: Light Ray parallel to the principle axis.

So how do we draw in the image?

- Since all the rays were drawn from the tip of the object, this shows where the tip of the image will be.
- We know that since the base of the object is on the principle axis, the base of the image will also appear on the principle axis.

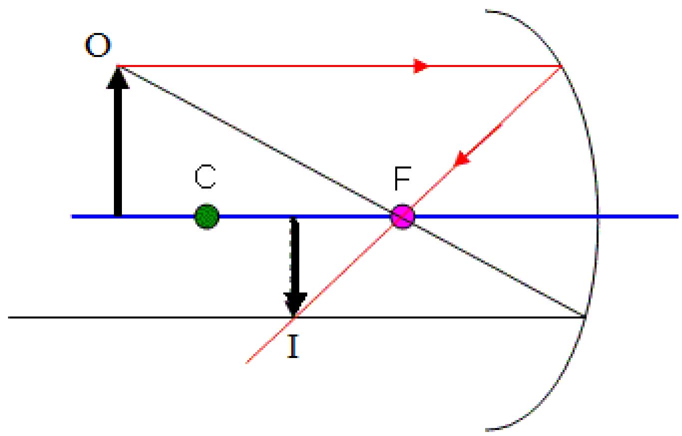

Illustration 10: Image drawn in diagram.

Converging mirrors are so named because the light rays that are reflected off the mirror come together (converge) on the real side. It's ok to call these mirrors either converging or concave.

We label the object as "O" and the image as "I", as shown in *Illustration 10*.

- We draw the image as a solid line because the rays of light that make the image are actually traveling through that point… if I was to hold a piece of paper right there, I would see the image appear there! It is a ***real*** image.
- Also notice that the image is upside down (***inverted***) and slightly smaller (***diminished***) compared to the original.
  - This is not always the case with curved mirrors. You might even find that your rays need to be extended to behind the mirror to be able to be able to cross each other… then the image would be a ***virtual*** image behind the mirror.

For any image, you will need to classify it as:

Characteristic	Description
Magnification	Same / Enlarged / Diminished
Attitude	Erect / Inverted
Type	Real / Virtual

Warning!
Real light rays and images are drawn as solid lines, but virtual rays and images are drawn as dotted lines.

Although we know where the image is, and that it is a real, inverted, smaller image, we can still confirm it using our last method…

Rule #3: Any ray that passes through the centre will reflect back through the centre.

Unfortunately, this is the least reliable way to draw a ray, since we had to assume that if the mirror was big enough it would have bounced the ray back. Notice that it hits just about where the other two rays meet up. We're probably doing ok.

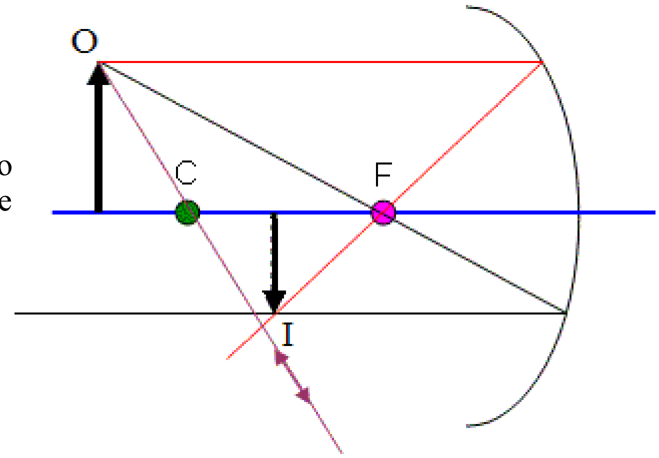

Illustration 11: Showing the ray through the centre.

Convex Diverging Mirrors

The same set of rules shown above apply to diverging mirrors, it's just that things will look a bit different since convex mirrors have their focal point and centre behind the mirror.

- Diverging mirrors typically make a diminished, virtual image of the original object.

Let's look at an example using the three rules covered above for converging mirrors.

- The only difference is that I will extend the rays behind the mirror as dotted lines to be able to show how they "pass through the focal point" or "through the centre".

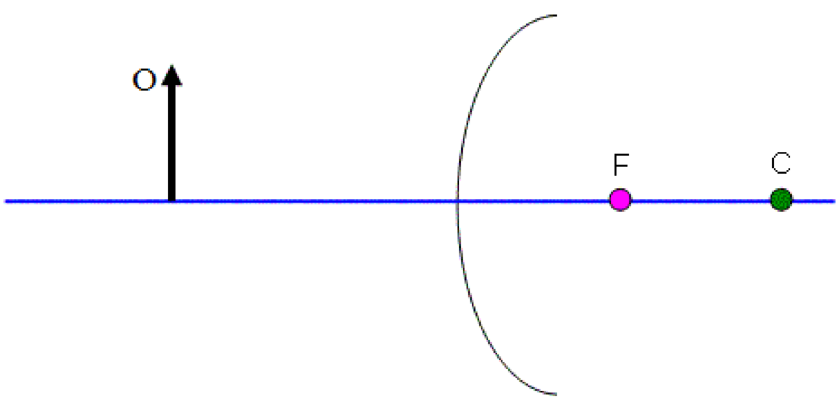

Illustration 12: Diverging mirror.

Diverging mirrors are so named because the light rays that are reflected off the mirror go apart (diverge) on the real side.

Use **Rule #2** (because it works well for this mirror) to draw the ray coming off of the tip of the object parallel to the principle axis as shown in illustration 13. When it hits the mirror, it bounces off so that a dotted line drawn behind the mirror will pass through the focal point .

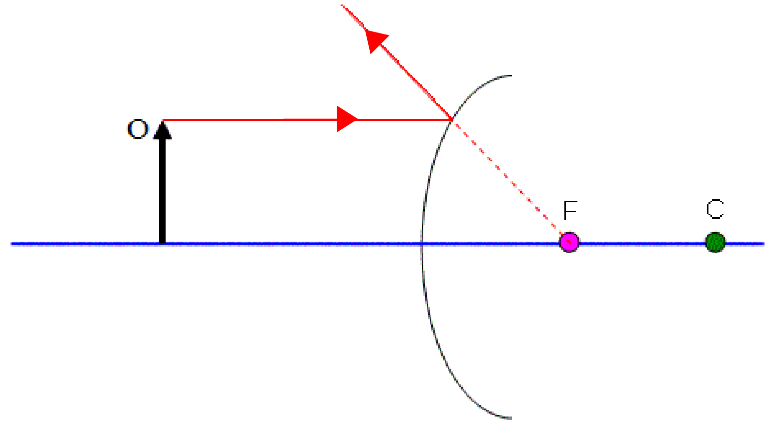

Illustration 13: A ray parallel reflects as though it came from the focus.

Rule #3 (again, just because it works well for this mirror) is used in *Illustration 14*. This ray comes off of the tip of the object aiming straight for the centre. Where it hits the mirror it will bounce back, but I draw a dotted line behind the mirror to show where the ray *would* have gone.

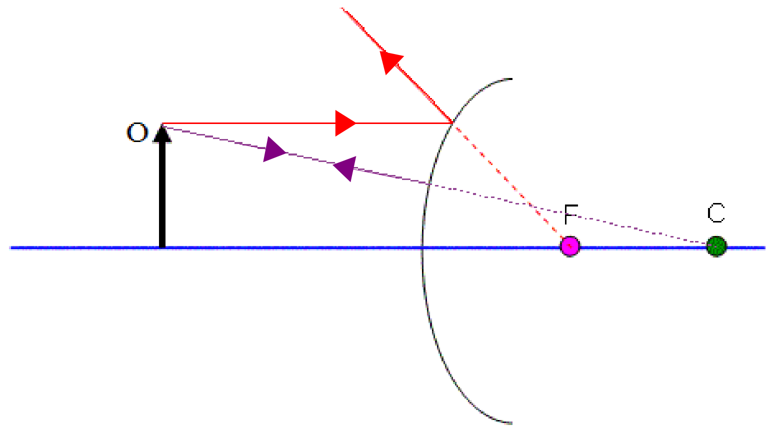

Illustration 14: Light ray through the centre.

Notice that there is now a place where the two dotted lines hit behind the diverging mirror. This is where the image will appear.

- The image is **virtual** (it's behind the mirror), it is **erect** (right side up), and **diminished** (smaller).

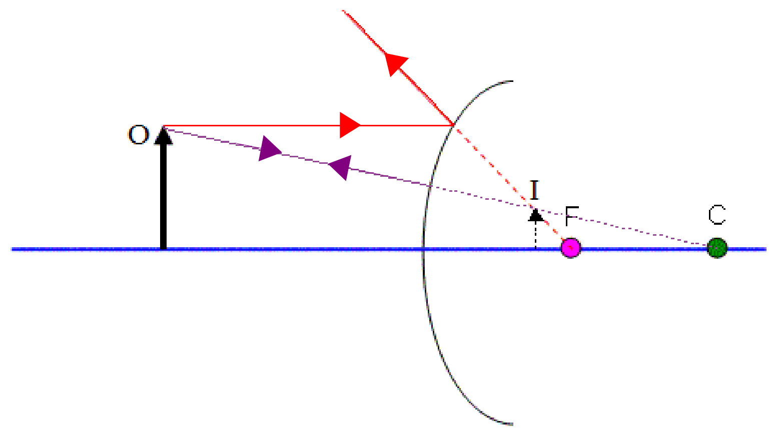

Illustration 15: Image shown behind the mirror.

The Formulas

There are a couple of formulas you can use to figure out its position, attitude (erect or inverted), and magnification.

Mirror Equation

The first is called the **mirror equation**...

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

f = focal length (m)
d_o = distance from mirror to object (m)
d_i= distance from mirror to image (m)

Ultra-Special Notes for Signs Using the Mirror Equation:

Anything in Front of the Mirror (Real) → Positive +

Anything Behind the Mirror (Virtual) → Negative -

This applies to the distances, and also applies to focal length...

- a **converging** mirror with its focus in front has a **positive focal length**
- a **diverging** mirror with its focus behind the mirror has a **negative focal length**.

Example 2: A diverging mirror has a radius of 20 cm. An object is placed 30 cm in front of the mirror. **Determine** where the image will appear.

Since the radius is 0.20 m (which is the distance from the mirror to the centre), the focal length is -0.10 m. This is because the focus is half ways between the vertex and the centre, and negative when the focus is behind the mirror of a diverging mirror.

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

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

$$\frac{1}{d_i}=\frac{1}{-0.10}-\frac{1}{0.30}$$

$$d_i=-0.075\,m=-7.5\,cm$$

The negative sign on the answer indicates that the image is virtual, behind the mirror.

Magnification Equation

The **magnification equation** is...

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

Same as **mirror equation** and...
h_i = height of the image (m)
h_o = height of object (m)
m = magnification (how many times bigger or smaller)

Ultra-Special Notes for Using the Magnification Equation:
Same rules as for the **mirror equation** and...

Anything **above** the Principle Axis → **Positive +**
Anything **below** the Principle Axis → **Negative -**

Magnification Quantities:

|m| < 1 Diminished
|m| = 1 Same
|m| > 1 Enlarged

Example 3: For the same situation from Example 2, **determine** how tall the image is if the object is 5.0cm tall. Also **determine** the magnification.

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

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

$$h_i=\frac{-(-0.075)(0.050)}{0.30}$$

$$h_i=0.0125=0.013\,m$$

The height is positive so the image is erect, above the principle axis.

To calculate the magnification either distances or heights could be used. Since the distances have been through less calculations, we trust them more.

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

$$m=\frac{-(-0.075)}{0.30}$$

$$m=0.25$$

The magnification is positive, verifying the image is erect. But, it less than one, so the image is smaller than the object... one quarter the size!

Homework

p664 #1-5
p665 #9-10