Shedding Light on Reflection

Program-Support Notes

Program Summary

Join presenter Spiro Liacos as he delves into every aspect of reflection and mirrors. What is reflection? How do mirrors reflect light differently to everything else? How are mirror images different to two-dimensional photos? How does our ability to see in 3D affect the way we see images in mirrors? Can animals see things in mirrors? How do periscopes work? These questions, and many more, are answered in this entertaining and informative program, which finishes with Spiro presenting a range of optical illusions which all incorporate mirrors. You'll never look into a mirror in the same way again.

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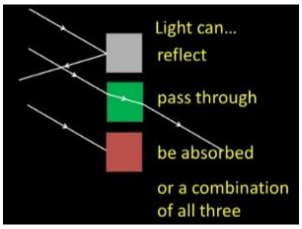
Download the worksheet.

Download the Law of Reflection practical exercise, and **watch the instructions.**

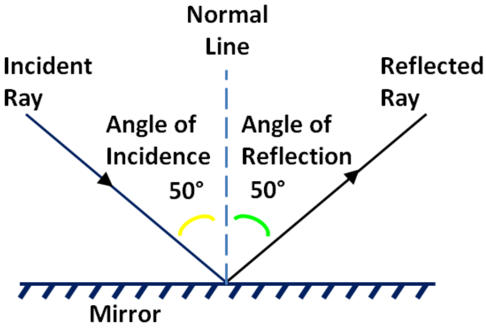
Part A: Light Reflection

Reflection. It's what light does when it strikes a mirror, but light also reflects off pretty much everything.

Some things, like the sun, light globes, fluorescent tubes, and fire produce their own light which shines into our eyes allowing us to see them. These things are said to be **luminous**. But the only reason we can see things that don't produce their own light is because they reflect the light from luminous objects into our eyes. The trillions of light rays which are produced by a luminous object don't travel instantaneously, but travel at an incredibly fast **300,000km/s**.



Of course light doesn't just reflect when it strikes an object. It can also pass through it, like it does when it strikes water or glass, or it can be absorbed, making the object hotter. Depending on the object, a combination of all three occurs at the same time. White paper reflects a lot of light, absorbs a little, and allows a little to pass through it. Black paper absorbs most of the light that hits it and reflects very little, while glass reflects a little, which is obvious when there's no light coming from behind it, but allows most of the light to pass through it. Objects which allow light to pass through them are said to **"transmit"** light, but this is different to a transmitter of a TV or radio station which also "transmits" light waves in the form of radio waves. The video does not use the word "transmit" or "transmission".



The angle of incidence = the angle of reflection

When light rays strike a reflecting surface at an angle, they always reflect in such a way that the angle of reflection equals the so-called angle of incidence.

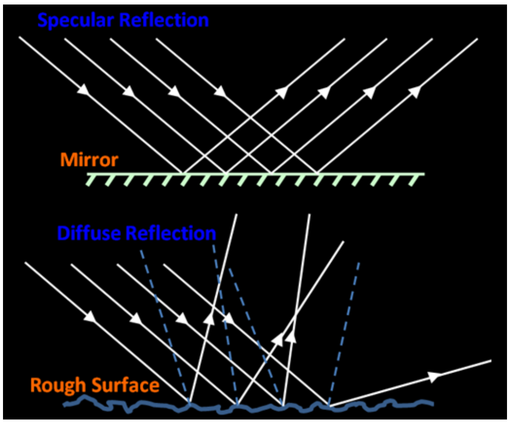
The light beam striking the mirror is called the incident ray. To measure the angle that it's striking the mirror, we draw in a so-called normal line at 90 degrees to the mirror. The angle of incidence is the angle between the incident light ray and the normal line. The angle of reflection, that is the angle between the normal and the reflected ray, is always the same as the angle of incidence.

Light rays always follow this Law of Reflection: the angle of incidence equals the angle of reflection.

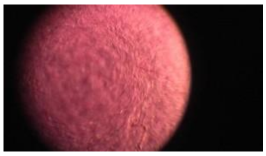
We don't use the angle between the incidence ray and the mirror as the angle of incidence because many reflecting surfaces are curved.

The Law of Reflection for every light beam holds true not just for mirrors, but for every surface.

In a flat mirror, four parallel light beams all reflect at the same angle. This is

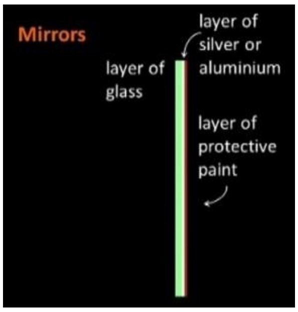


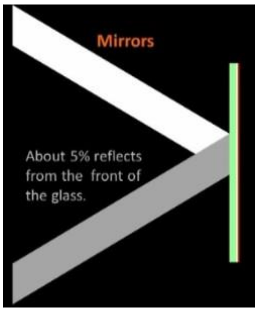
called **specular** reflection. Mirrors, smooth glass, still water and smooth polished metal all produce specular reflection.
But what about rough surfaces? Light still reflects off rough surfaces, but the reflected light rays scatter in every direction, not because the Law of Reflection doesn't hold, but because the surface is, at the microscopic level, really rough. You may think a table or a piece of paper are smooth, but they aren't if you zoom in. Four parallel light rays shining onto a rough surface all reflect off in different directions, but the angle of incidence for each one still equals the angle of reflection; it's just that the angle of the surface is constantly changing. This type of reflection is called **diffuse** reflection. Most surfaces reflect light diffusely, scattering the light in every direction. This allows us to see them no matter where the light is shining from.

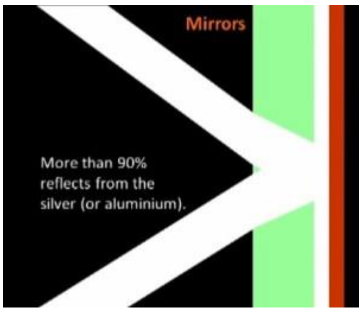


Part B: Images in Flat Mirrors (which are also called Plane Mirrors)

Flat mirrors are obviously very common. Bathroom mirrors, rear-vision and side-vision mirrors in cars, and dressing-table mirrors are all flat mirrors.



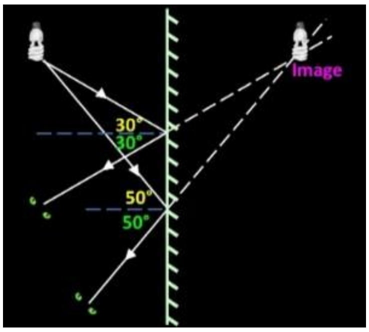


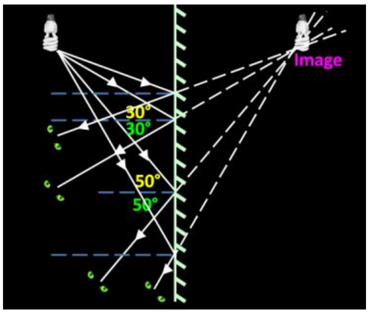


A mirror is made of a **layer of glass** onto which a reflective **layer of silver or aluminium** is applied with the help of certain chemicals. Over the top of this reflective layer, another **layer of paint** is applied to protect it from scratches. About 5% of the light striking the front surface of the glass reflects, but more than 90% of the light travels through the glass and reflects off the metal layer at the back, before re-emerging from the front. Some of the light is also absorbed.
When we draw ray diagrams we usually represent mirrors as single lines, but it's the back surface of the mirror's glass that does most of the reflecting.
The fact that mirrors are so smooth that they reflect light rays specularly is the reason that mirrors are able to produce images.
Now a quick clarification. We often use the word reflection to mean the thing we see in the mirror, as in, "Can you see my reflection in the mirror?", or "can you see the reflection of the trees in the water?" There's nothing wrong with using the word reflection, but when we're trying to explain how mirrors work, we often talk about the reflection of light, so instead of calling what we see in a mirror a reflection, scientists and engineers who work with optical instruments prefer to call it an **image**.

The light rays which hit a mirror and reflect into our eyes follow the Law of Reflection. But where are we looking when we look at something in the mirror? A lot of people believe that you have to look at and focus on the mirror itself to see the image. But that's not actually the case.

Whenever we see something, we can't really tell where the light originated from, we can only tell the last direction it was travelling in when it entered our eyes. The observer has to look in the direction the light is coming from to see the image.





The light rays entering the observer's eyes appear to be coming from somewhere behind the mirror along a specific line of sight, which we represent with a dotted line. The point where these lines of sight intercept is in fact where the image of the object is located. Every single one of the trillions of reflected rays appears to be coming from the image.

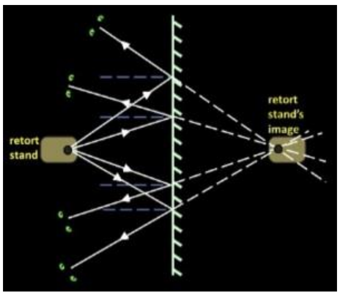
We don't usually think of the images we see in a mirror as having a location. But the image does have an actual location, even though there's nothing physically behind the mirror.

For flat mirrors, the image is the same distance behind the mirror as the object is in front of the mirror.

So if something is 5cm from a mirror, its image looks for all the world as if it's 5cm behind the mirror.

Part C: The Virtual 3D Mirror World

Now drawing ray diagrams is very useful, but we can also show the location of an image using what we call **parallax**. In the photos, we see a retort stand in front of a mirror and we can see the image of the stand behind the mirror. But we can also see a second retort stand exactly the same distance behind the mirror as the first retort stand is in front of the mirror, in this case 22cm.



Regardless of the angle from which we observe the image, the second stand appears to be in exactly the same location as the image of the first stand. Parallax refers to the way an object appears to change its position as the observer changes the angle from which he or she is viewing it. Here the parallax of the image and the parallax of the second retort stand is the same because they're both in the same location.

Though there's nothing wrong with the expression "looking in the mirror", it is a little misleading. When we look at something in a mirror, our eyes point towards a location that is somewhere behind the mirror.

We call the image in a flat mirror a "**virtual**" image: the light we see doesn't come from behind the mirror, but it looks as if it's coming from behind the mirror.

So, if you're standing 1 metre away from a mirror, your image is 1 metre behind the mirror, so you must be 2 metres away from your image. If you step back a metre, then you and your image are now 4 metres apart.

The image in a mirror is in fact 3D. However, the 3D image is a **virtual 3D image**. A **three-dimensional** (or "3D") object has **height, width and depth**. In a mirror, no object is actually there, and we can't of course enter the virtual 3D mirror world, but, because of the way the light reflects, everything we see in a mirror appears to have height, width and depth, and occupies a specific location somewhere behind the mirror. This is completely different to images in photos or on most televisions which are **2D**. **Two-dimensional** (or "2D") pictures and shapes only have height and width. Now you might think, because of 3D movies, that a 3D image has to jump out at you, but it doesn't really. The world we live in and observe is 3D, and the virtual image we see through the mirror is also 3D (but virtual 3D).

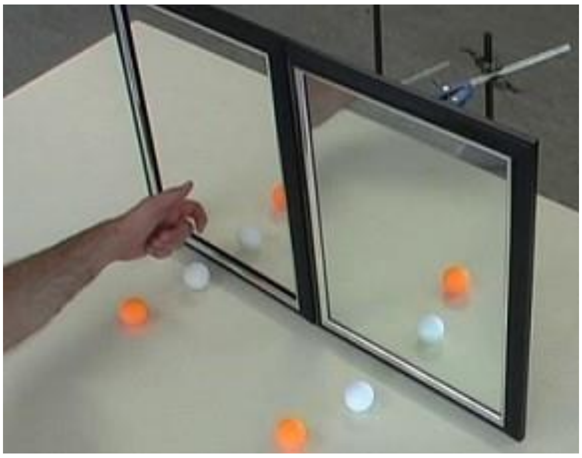
In two-dimensional photos we can only get an idea of size and distance based on comparisons with what we already know the size of. When we look at objects in a mirror though, it's a virtual three-dimensional world we're looking at, and we can judge distance and size pretty accurately in exactly the same way that we judge distance and size when we're not looking in the mirror. So to fully understand how we see images in mirrors, we need to delve a little more deeply into how we see things in real life…

Part D: Seeing Images in 3D

(i) SEEING 3D Two Eyes → 3D Vision

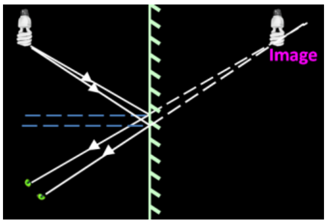
Firstly, the fact that **we have 2 eyes** gives us the ability to see 3D. When we're looking at an object, each eye points in a slightly different direction and sees the object from a slightly different angle. Our brain puts the information together, and we get an accurate perception of depth. Try closing one eye and putting your finger directly downwards onto a retort stand, or onto someone else's finger. With two eyes, we can judge the distance accurately, but with one eye, it's a lot harder, because with one eye, we see only in 2D.

Catching a table tennis ball with both eyes open is fairly easy because we have 3D vision when we use both eyes, but it becomes more difficult when you close one eye because, in 2D, you can only judge distance by the fact that it gets bigger as it comes closer to you.



When we look at table tennis balls with both eyes in mirrors though, we can accurately use our 3D depth perception to determine how far each one is and go to pick up one of them, because we're looking at a 3D virtual image, but of course, we can't actually touch them.

In our diagram earlier on, we showed four different observers to locate the image, but you don't really need that many. One observer will do as long as the observer has two eyes. In a ray diagram though, if you draw two eyes too close together, it's very hard to draw the light rays accurately enough to work out the image's location.



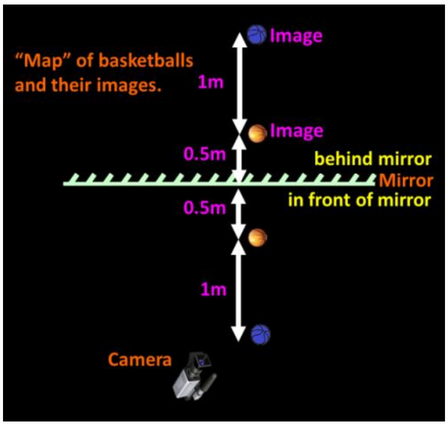
Part D (continued):

(ii) SEEING 3D: Nearby Objects Appear Bigger

How else can we judge distance? When something is up close, it looks big. If it's further away, it seems smaller.

The 4 basketballs in the photos are all the same size and have been placed in a line at 1 metre intervals. The blue and white ball appears much larger, and each basketball seems to get smaller the further away it is.

When a mirror is placed between the basketballs, we can see the image of the orange ball and the image of the blue and white ball. But the image of the blue and white ball is smaller than the image of the orange ball, so it must it must be further away from us in the virtual 3D world than the image of the orange ball. In fact, since the actual orange ball is half a metre from the mirror, it's image is half a metre behind the mirror, and since the actual blue and white ball is 1½ metres from the mirror, it's image is 1½ metres behind the mirror, or, from our point of view, the blue and white ball's image is 1 whole metre behind the image of the orange ball.



Part D continued:

(iii) SEEING 3D Closer Objects Obscure the Sight of Objects Further Away.

Now another way of determining depth is that something that's closer to us blocks our view of something that's further away.

In the photo on the left, the blue and white ball must be closer than the orange ball, because the orange ball is only partially visible. However, in the mirror, the image of the blue and white ball is further than the image of the orange ball, and we can tell because our view of it appears partially blocked by the image of the orange ball. Everything we see in a mirror has a definite location in the 3D virtual image that is formed.

In 3D movies, you can't move to another seat and see the scene from a different angle; the images you see on the screen depend on where the 3D cameras were when the movie was filmed. In a mirror though, it's a genuine 3D virtual image you can see. Moving around allows you to see the scene from a different angle.

Part D continued:

(iv) SEEING 3D Relative Movement.

Now when we do move our point of view, the relative movement of objects that are different distances away is also something we use to judge distance.

If you're moving in a car, the poles on the side of the road and the white lines seem to move past us more quickly than distant objects, which hardly seem to move at all. The same thing happens if we're looking at images in a mirror.

Now we constantly use all these techniques to see 3D as we go about our daily lives, and they all overlap. However, our 3D depth perception works best with nearby objects and gets less and less accurate as objects get further away especially when you can't see anything familiar that you know the size of.

The astronauts who went to the moon all had excellent 3D vision, but since there were no trees or houses or anything other than rocks, and bare hills and mountains, they had real difficulties in judging how far distant objects were. They could operate their equipment perfectly well because it was up close, but they sometimes set out to walk or to drive to something like a boulder or a crater that they thought wasn't too far away, and then discovered that it was actually much further away than they thought. When we see distant objects, both our eyes are pointing almost exactly in the same direction and the relative movement of the objects if we're moving is tiny, so our ability to see in 3D is reduced. If the objects are unfamiliar to us, as was the case on the moon, judging their size, or how far away they are, is surprisingly difficult, even though they might only be 50 or 100 metres away. But this problem doesn't just occur on the moon.

It can also happen on Earth, when we find ourselves in barren locations. In a desert, for example, you could be looking at a small dune only 200m away or a larger dune 400m away. Seeing a familiar object though, like a tree or a truck, helps enormously.

Part E: Other Attributes of Images in Mirrors.

As well as being the same distance behind the mirror as the object is in front of the mirror, **images in mirrors are always the same size as the actual objects**. If the mirror's upright, the image is upright as well. If the mirror is horizontal, the image is upside down.

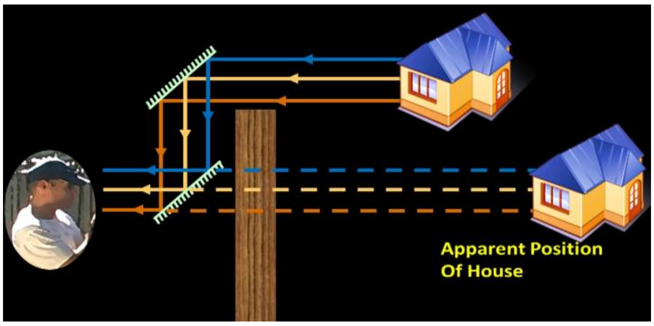
However, images in mirrors are **laterally inverted**; left becomes right and right becomes left. To put it another way, whatever you would call an object's left-hand side in the real world, becomes its right-hand side in the mirror world.

Ambulances usually have the word ambulance printed on the front in laterally inverted writing so that when drivers see one in their mirror, they can read the word more easily and then get out of the way quickly.

But mirrors don't just swap left and right, they also swap front and back. Whenever you face a mirror, your image is facing in the opposite direction to you. If you point towards a mirror, your image points back towards_you, that is, in the opposite direction to which you're pointing. So the image is **front-back inverted**, as well as laterally inverted.

With lateral inversion, if you see an image in a second mirror of an image in the first mirror, the image is laterally inverted twice, so it appears normal.

Periscopes make use of two mirrors to allow you to see over things. The light hits the top mirror, reflects down to the bottom mirror and then reflects into your eyes.



Since the light reflects twice, what you see doesn't appear laterally inverted: left is still left, and right is still right. And it isn't front-back inverted either. The image simply appears a little further back than the object, since the light has to travel the extra distance between the mirrors, and you have to look in a slightly different direction to what you would have had to look had the obstruction blocking your view not been there.

Apart from lateral inversion, what we see in a mirror looks very real and we can usually only tell that we're looking at a mirror when we see a frame around it, or if it's a little dirty, or when we know that what we're looking at couldn't possibly be there, like when we see ourselves for example.

Most animals can't tell that what they see in a mirror is just an image. They think it's real. They can sometimes get aggressive at what they think is an intruder in their territory, or they can get curious about their new virtual friend.

Sometimes the animal just ignores its image. Many animals quickly realize that they can't go through the glass, and so try to go around it to meet their friend. It must be a little confusing for them.

Only a handful of animals can recognise that they're looking at themselves in a mirror, among them, elephants, orang-utans, dolphins and magpies. To test their self-recognition, scientists introduce animals to a mirror and wait until they become accustomed to it. The scientists then place a small mark on the animals' face which they can't see directly. If the animal notices the mark in the mirror and goes to wipe it off or to examine it in some way, then it's obvious that it can recognise itself in the mirror. Most animals can't.

Ultimately it shouldn't be too surprising that the image in a mirror looks real. When we say that we can see something, all we can really see is the light reflecting from it, which tells us the object's colour, shape and texture, and its position. But the light reflecting from the object can also hit a mirror and then reflect into our eyes. This light is more or less the same as the light reflecting directly into our eyes. Since the light rays reflect specularly, it looks as if the light is coming from something that's actually there. But only the image is there. The object is in the real world.

Part F: Creating Illusions with Mirrors.

Because everything in a mirror looks real, mirrors allow us to create lots of illusions. But, these are best seen in the video.

The Lateral Inversion Controversy.

In a mirror, the image is laterally inverted. By definition, this means that whatever you would call an object's left side in the real world becomes its right side in the mirror world. But if you face the mirror and point towards your left, your mirror image points towards the left as well! So why does a mirror produce a laterally inverted image? And if left and right swap over, why don't up and down swap over, too?

The reason is that the mirror actually inverts front and back, and if you invert front and back, left and right invert, too, since left and right are really defined by whichever way front and back are. But up and down don't change when front and back change. It's a little complicated, but, if nothing else, it's good to bring to students' attention the role that definitions play in Science (and, in fact, everywhere).