Is the Moon really larger near the horizon?

The challenge

You're sitting on a beach, watching the Moon rise. It looks big — really big. A few hours later, when it's high in the sky, it looks a lot smaller. What's going on? You know the Moon itself hasn't shrunk. But is the image of the Moon on the horizon actually bigger? Or is your brain playing tricks on you?

Your challenge is to design and carry out an experiment, using the telescope and its camera, to answer the question, "Is the Moon really larger when it is near the horizon than when it is higher in the sky?"

There's more than meets the eye here. In fact, this question stumps the experts. See if you can set the record straight!

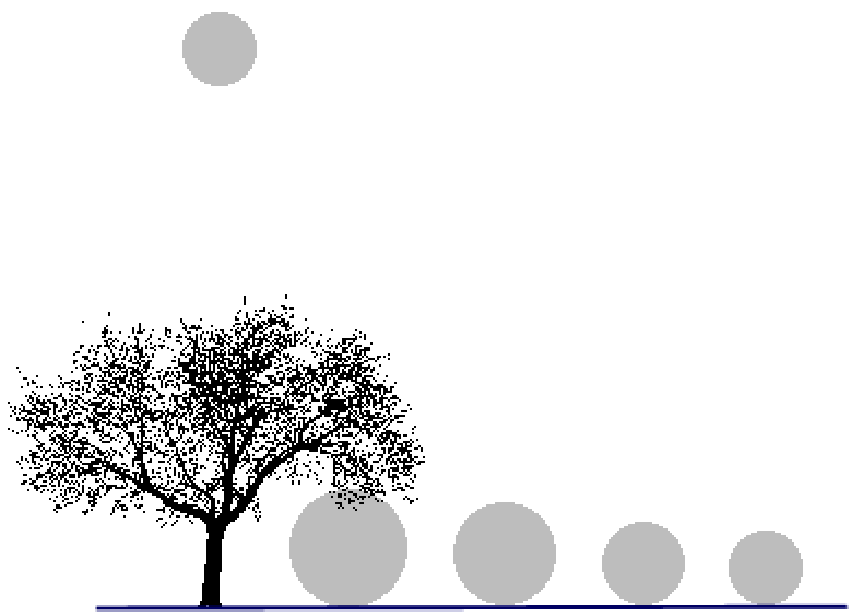
Does the Moon look larger when you see it on the horizon? Painting by Bill Butler.

Your thoughts about the Moon.

Before you investigate, it helps to write down what you expect to find. If the results don't support your prediction, you'll need to explain why. Nature is full of surprises!

Survey of your past observations:

Try to recall how the Moon looks when you see it near the horizon. Based on your own experience, circle one of the four horizon Moons below which looks about the right size, when compared to the Moon higher in the sky:



Thoughts on why:

Why might the Moon appear larger when it is near the horizon? Discuss with your team, and list here, what kinds of factors might affect how large the Moon looks.

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Your prediction

Do you think an image of the Moon taken with the telescope will be larger when the Moon is near the horizon than when the Moon is higher up?

Before going on the record, discuss with your team: What factors affect the apparent size of the Moon that you see? Is the atmosphere involved? How about the distance to the Moon? How about your own perception? Will the telescope "see" the same thing as your eye? Think about these factors, then make your prediction.

_____ Image of Moon near horizon will be <u>bigger</u> than image of Moon higher up.

_____ Image of Moon near the horizon will be <u>same size</u>.

_____ Image of Moon near the horizon will be <u>smaller</u>.

Your prediction revisited

Your teacher will discuss with your class a model of the Earth-Moon system. Based on that discussion, you may (or may not!) wish to change the prediction you made above:

_____ Image of Moon near horizon will be <u>bigger</u> than image of Moon higher up.

_____ Image of Moon near the horizon will be <u>same size</u>.

_____ Image of Moon near the horizon will be <u>smaller</u>.

They say that "seeing is believing." Yet the model of the Earth-Moon system seems convincing, too. The only way to settle this question is through an experiment. Good luck!

Planning your investigation

Your experimental method

How will you settle this issue using the telescope? Discuss with your team what your strategy will be. How many images will you need? When should they be taken? How will you measure the Moon's size in your images?

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The Art of Science: "Blind" Experiments

Careful! It's often easy to find what you *expect* to find, or *want* to find — and ignore what you don't! This is sometimes called *bias*. Many experimenters are not even aware of it.

To remove any possibility of bias, your teacher may have you try a "blind" experiment. In this case, it means labeling your images so that only your team knows which images are which — and then having another team measure your images. (You can do the same for them.) That way, your measurements cannot be influenced by how your think the results should turn out.

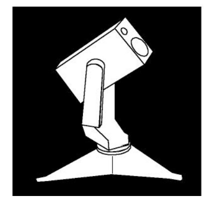
Imaging team: Make sure you've re-labeled the images so the measuring team doesn't know which is which. (But make sure you keep good records so that YOU know which is which — because the results may surprise you!)

Measuring team: Make sure you keep good records of the name and size of each image, because you may have a hard time convincing the imaging team — and yourself — that your measurements are correct!

Carrying out your exploration

Now you're ready to put your prediction to the test, by taking images of the Moon and comparing their size at different altitudes above the horizon. Suggested telescope settings for imaging the Moon are listed below. Be sure to record your measurements carefully on the DATA PAGE below.

'Scope it out: Taking images of the Moon



When to take images: The Moon is near the horizon TWICE every day: once when it rises, and once when it sets. For this exploration, you can take images of the Moon EITHER shortly after it rises and then a few hours later OR shortly before it sets and a few hours *before that.*

When does the Moon rise (or set) at the telescope site you selected? You can find out at the U.S. Naval Observatory Website:

http://tycho.usno.navy.mil/

Or go directly to their moonrise page at:

http://aa.usno.navy.mil/data/docs/RS_OneDay.html

Make sure you use the right day (remember that midnight starts a new day). For the location, enter the telescope site you are using (either Boston, MA; Tucson, AZ; or Hilo, Hawaii).

IMPORTANT: Schedule your Moonrise observation for about 1 hour *after* the Moon actually rises. This will allow enough time for the Moon to rise above buildings at the site. *The telescope will not take images that are too close to the horizon.*

Selecting your target: Use the pull-down menu to select the Moon as a target.

Filter: Use the grey ("neutral density") filter to cut down on the Moon's bright reflected light..

Exposure time: Use a 0.5 second exposure or less.

Saving your image: Be certain to download the image to your computer as soon as it is ready. Remember, images are deleted from the Web server after a week. Download the image in GIF-format (just click and hold on the image with your mouse button, and select **"Save this Image"** or **"Download this Image"**).

IMPORTANT: Be sure to label your images carefully so you are certain which image was taken at which time!

IMPORTANT: Be sure to download (or print) the Image Info file with each image as well. This tells you how high the Moon was above the horizon.

Printing your image: You can print your images directly from your browser. Or, after you have downloaded the images to your computer, you can open them in an image-viewing program and print them from there.

You can *invert* your image so that the Moon is black and the background is white. This will save toner and may make it easier to measure your image.

Measuring your Moon images

Now measure the diameter of the Moon in each of your images. Since you are *comparing* images, you can use any units you wish — pixels, inches, centimeters, etc. If the Moon is not full, you can measure between any two points that are as far apart as possible—as long as you *measure between exactly the same points in both images*.

How high above the horizon was the Moon for each image? To find out, use the IMAGE INFO option when you download each image, and record the value for the ALTITUDE. This tells you how far above the horizon, in degrees, the object was when the picture was taken.

TIP: Using a crescent Moon? Then just measure the distance between the two points of the crescent.

Examining your measurements

From where to where should you measure on the image? How do you know you've gotten the full diameter of the Moon? How accurately do you have to measure? Do you need to measure more than one Moon image for each altitude above the horizon, to be sure you've got a reproducible measurement? Should several different people measure each image and combine their results? What factors could affect your measurement?

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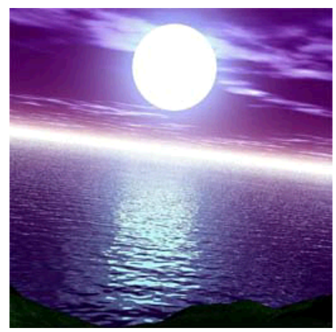

PUZZLER: The full Moon always rises around sunset. Why?

HEADS UP!

Try this experiment the next time you see the Moon on the horizon: First look at the Moon the normal way. Then turn your back to it, bend over, and look at the Moon from between your legs. Does it still look as large? Any ideas about what's going on?

DATA PAGE: Moon Measurements

Is the Moon really larger when viewed near the horizon? Measure the size of the Moon in your images. For each image, also record the Moon's altitude above the horizon (listed in the Image Info file for your image).

MOON IMAGE (name of file)	**SIZE OF MOON** (specify units)	**ALTITUDE ABOVE HORIZON** (degrees)

Part 4. Making sense of your results

What are the results of your investigation?

_____ Image of Moon near horizon is <u>bigger</u> than image of Moon higher up.

_____ Image of Moon near the horizon is <u>same size</u>.

_____ Image of Moon near the horizon is <u>smaller</u>.

How do your results compare with your original prediction? How do they compare with your prediction from the Earth-Moon model?

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Can you think of other examples in your life where your own perceptions may not be a good guide to reality?

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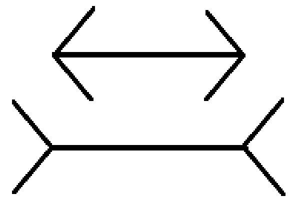
BRIEFING ROOM:
Is seeing believing?

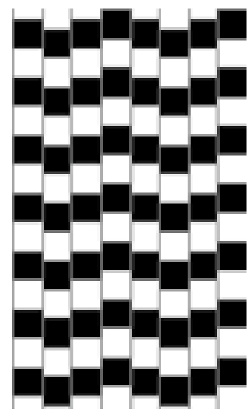
Why should the horizon Moon *look* so large? First, try these experiments:

1. More than 100 years ago, the German psychiatrist Franz Muller-Lyer discovered the illusion at right. Which horizontal line is longer? The bottom one? Use a ruler to find out.

   The eye is not always a good guide to reality. It can be fooled by many factors -- in this case, the arrows at the end of the lines!



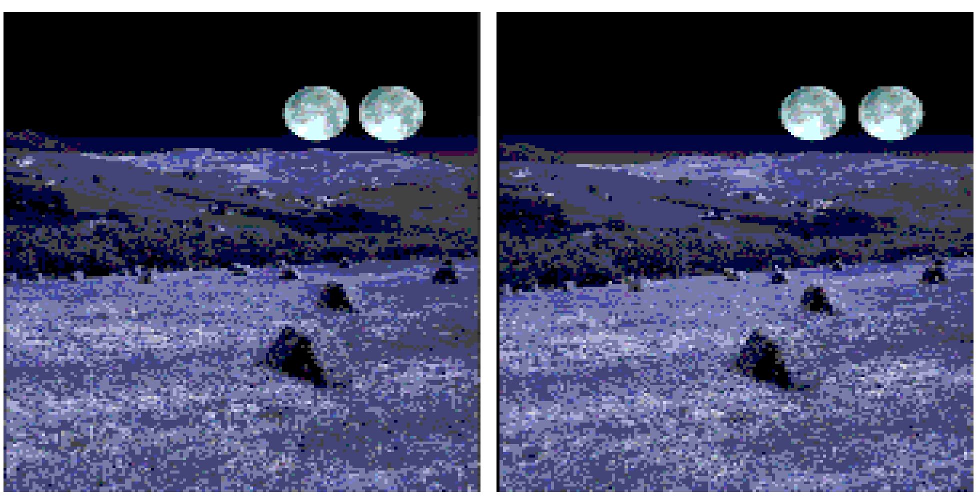
2. In the image at right, are the vertical lines straight? Use a straight-edge to find out. If our eyes fool us so easily, what else are we deceived about?

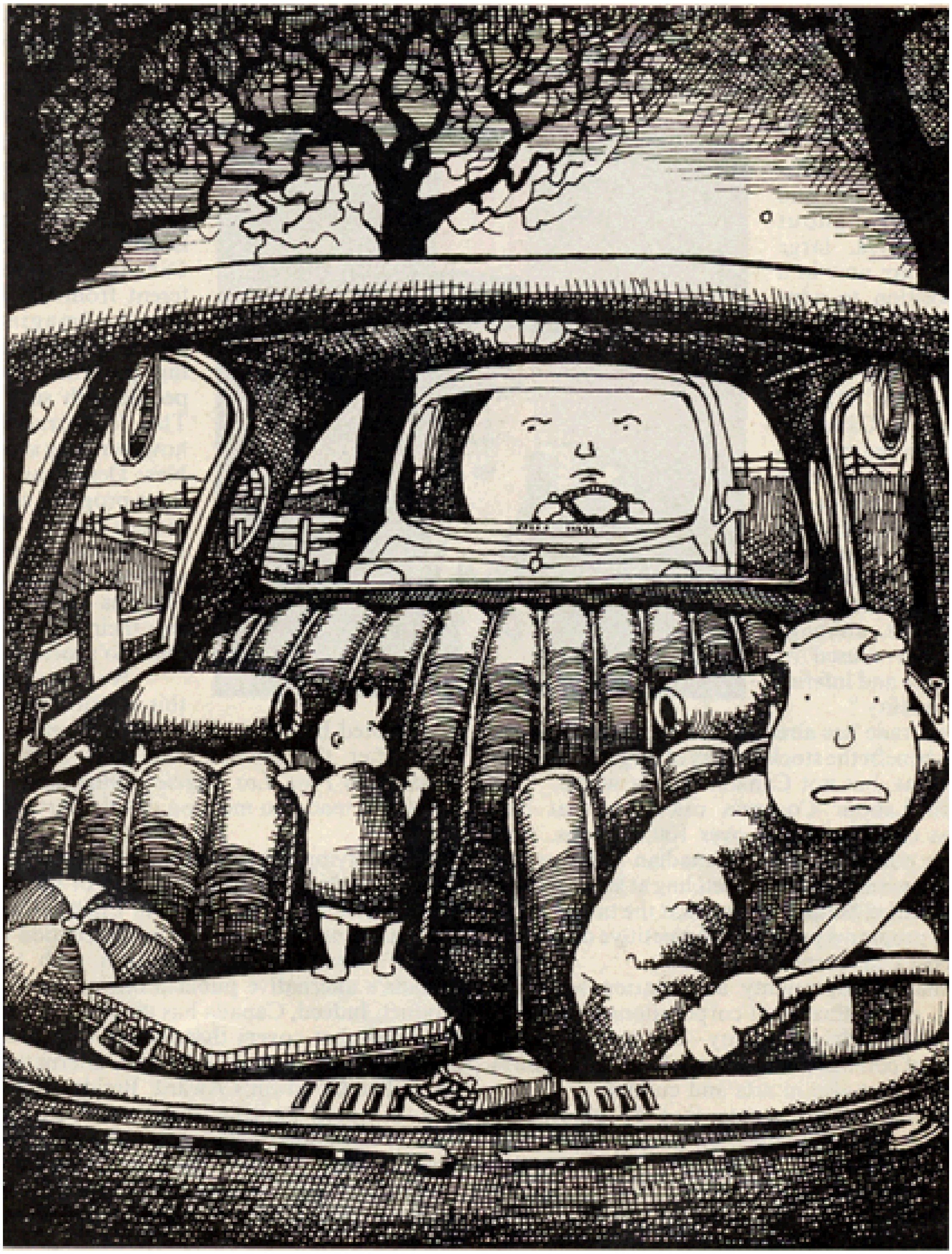


Scientists are not in full agreement about what causes the Moon illusion. But you can explore some interesting experiments and report back to your class:

Try this 3-D recreation of the Moon illusion on the Web at

http://www.research.ibm.com/resources/news/20000103_moon_illusion.shtml





"The Moon isn't really following us, son —that's just an optical illusion." Reprinted from the *Utne Reader*, March/April 1991

Additional projects about the Moon.

Moonstruck? Here are some projects with the telescopes and Moon images that are out of this world!

Going in circles?

What is the shape of the Moon's orbit? If you think it's a circle, guess again. Here's your challenge: How *not* like a circle is the Moon's orbit?

Try taking an image of the Moon every so often (*you* decide how often) as it orbits Earth. This means you will have to take images for... *you* decide how many days. By comparing the size of the Moon in each of your images, you can tell whether the Moon is getting closer or further during its orbit. Note: This effect will be much larger than the effect you measured in "Is the Moon really larger near the horizon?"

From your images, create a gallery showing the nearest approach and furthest approach of the Moon. Then draw a shape for the Moon's orbit that roughly matches your measurements.

Two-faced Moon?

Many people have heard that the Moon always shows one side to Earth, and that the other half is perpetually hidden from view. In reality, you can see as much as 70% of the Moon's surface from Earth, by imaging it at various times during its orbit. Your challenge: create a picture gallery to show that this is true. (You can use archived Moon images to help you.)

Point of view: phases of the Moon

Do the phases of the Moon look the same when seen from different parts of the U.S.? Take and compare two images of the Moon using telescopes in two different locations. How would you explain your results using a diagram or model of the Earth-Moon-Sun system?

Point of view down under

Do people in the southern hemisphere see the same "man in the Moon" as we do? How does the Moon's orientation seen down under compare to our view? This challenge requires a using a telescope located in the southern hemisphere.

The art connection

Artists purposely draw the Moon larger than it would appear in a photo, because it looks more realistic that way. In Van Gogh's *The Sower*, at right, the horizon Moon takes up much of the painting's field of view!

See if you can find other paintings where the artist has exaggerated the size of the Moon—or create your own.

Create a 3-D view of the Moon

You can create a three-dimensional stereo view of an object by taking two images of the object, each from a slighly different viewpoint. By looking at the two images using a stereo viewer (or by fusing the two images with your eyes), you can see the scene in stereo.

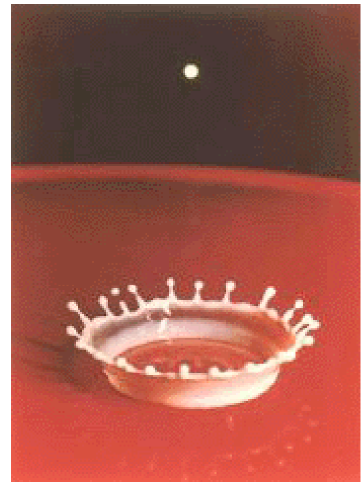
For this challenge, use the fact that the Earth is rotating, to image the Moon from two different vantage points. Image the Moon shortly after it rises, and shortly before it sets. Use these two images to create your stereo pair of photographs. Using the Earth-Moon diagram in your science journal as a guide, show approximately where the two viewpoints are for your telescope images.

Greater craters

What are the largest craters you can find on the Moon? You'll get the best images of craters when the Moon is at one-quarter phase, because the craters and mountains cast long shadows then.

Using the Internet, see if you can find images of craters on Earth that were caused by the impact of asteroids or comets. Why do you think there are so many more craters on the Moon than on Earth? If the young Earth was hit just as many times as the young Moon, why don't we find more craters on Earth?

See if you can find a mountain at the center of a crater on the Moon. How do you account for this mountain? Wouldn't it have been flattened when the asteroid hit? And why is it right at the center? Take a look at the milk drop photos at right, to see what happens when something drops onto a liquid, then see what ideas you can come up with to explain the mountains in the Moon craters. Hint: Rock can melt if the temperature and pressure are high enough!



Top: A milk drop hits a solid surface. Photo by Harold Edgerton

Lower photos: A milk drop hits a bowl of milk. After the "crater" forms, a column of milk rises in the center of the crater, then falls Photos by Dror Bar-Natan.

Lunar eclipse

How does an "ordinary" picture of the Moon differ from the Moon seen during a lunar eclipse. Take some images of the Moon when it is a little more than half-full. Then compare your images to the lunar eclipse shown on the next page. How many differences in the photos can you find? Then draw on your knowledge of the Earth-Moon-Sun system to answer the following: Why is the shadow's shape different? What object is casting the shadow in each case? Where is the Sun relative to the Moon, in each case? Why do you see more detail in the "ordinary" photo of the Moon—such as shadows of mountains and crater wall—but less detail in the lunar eclipse photo?

This part of the challenge is not quite as easy as it sounds: Estimate the size of the Moon compared to Earth, using only an image of a lunar eclipse. Here's how:

The shadow of the Earth on the Moon during the lunar eclipse of 1997. Taken by students at Anchorage High School, Alaska. Larry Weatherwax, teacher.

The shadow of the Moon on the Earth during a total solar eclipse on August 11, 1999. Taken by Russian cosmonauts aboard the Mir space station.

If the lunar eclipses listed at right are convenient, you can take your own image of a lunar eclipse. Or you can use the image on the facing page, which was taken by students at Anchorage High School in Alaska. The image shows the Earth's shadow on the Moon. The Earth is about 8000 miles wide.

Lunar eclipses visible in the United States

Oct. 28, 2004

Oct. 17, 2005

Mar. 3 2007

Aug. 28, 2007

Feb. 21, 2008

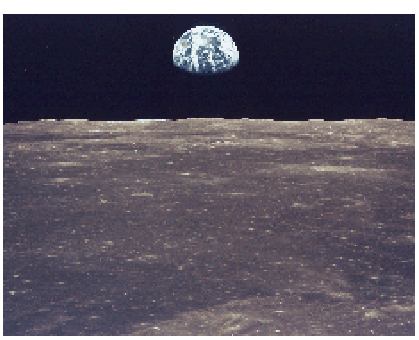
June 26, 2010

Some questions to think about: First *assume* that the Earth's shadow is about the same size as the Earth. How will you figure out, from just a portion of the Earth's shadow in your image, how large the entire shadow is? (Once you reconstruct the Earth's entire shadow, you can compare its size with the diameter of the Moon in your image.)

The harder part of the challenge is to figure out how the size of Earth's shadow on the Moon actually compares to the size of the Earth. Hint: It's smaller—but how much smaller? Draw a diagram of the Earth-Moon-Sun system during a lunar eclipse. Draw a second diagram showing the positions during a solar eclipse. Now examine the photo of a solar eclipse seen from space (next page). The dark part of the shadow is only about 35 miles wide—practically nothing. So the Moon casts a shadow that is smaller than the Moon, by roughly the Moon's actual width. How much smaller is the Earth's shadow than the Earth's width? See if you can figure this out.

Moon motion puzzler

Here's a real brain-teaser that will test your ability to visualize motion: You've often seen the Moon rise and get higher in the sky over the course of an evening. Suppose you were on the Moon, watching the Earth. When seen from a spot on the Moon, does the Earth rise slowly, quickly, or not at all?



Recall that the Earth spins on its axis once a day; the Moon spins on its axis once every 27 days (roughly); and the Moon revolves around the Earth in exactly the same time—once every 27 days (roughly). It helps if you and a friend build a model of the Earth-Moon system and try moving the Earth and Moon. What does each of you see as you move?

What color is the Moon?

This challenge will really surprise you. Would you say the Moon is the color and brightness of

a) a white-sand beach
b) the dirt on a baseball diamond or soccer field, or
c) a dark lump of charcoal?

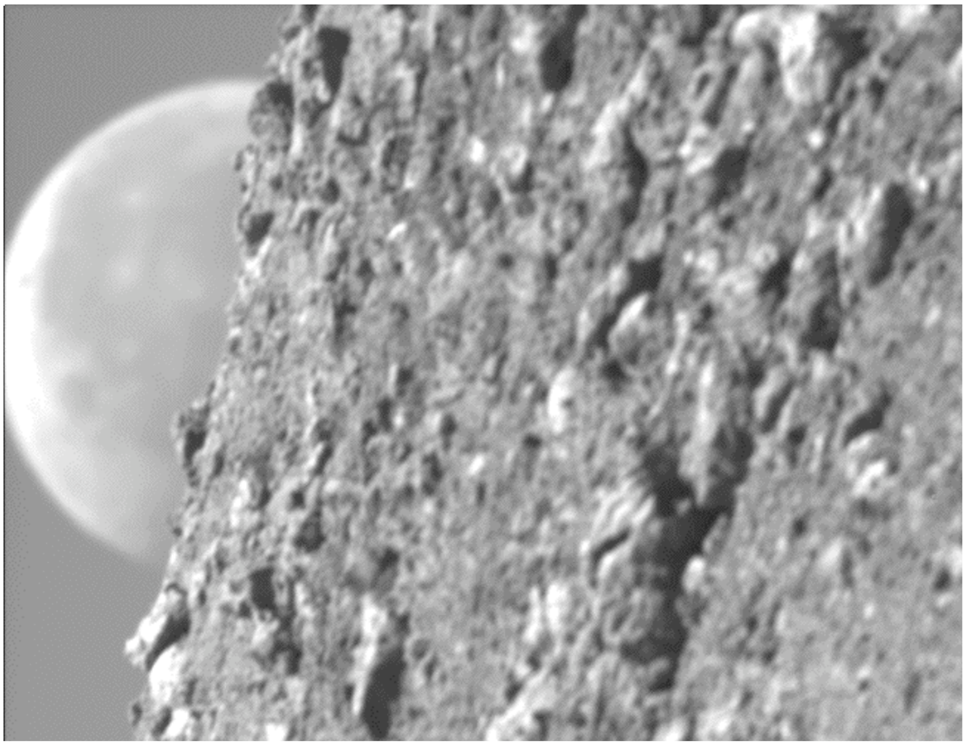
First try a "low-tech" experiment to find out. On a sunny day when the Moon is up during the daytime, go outside and hold in your outstretched arm a baseball, tennis ball, and squash ball — or three objects of corresponding brightness. Position the object so that it looks like a miniature Moon, shadow and all. Glance at the Moon and then at the three objects. Which one best approximates the color of the Moon?

Now try the high-tech experiment. The image below shows the Moon rising over Mauna Kea, a volcanic mountain in Hawaii. The mountain is made of nearly black material. How does the brightness of the Moon in the image compare to the brightness of the mountain? Compare the brightness using the MOImage brightness-measuring program. Download this Moon-mountain image from the archive at this URL:

Then open the image in MOImage. Using the rectangle tool, find an average brightness for the mountain. Then compare it with an average brightness for a rectangle on the Moon. How do they compare? Is the Moon the same brightness as the dark mountain?

Finally, check your result by using the Internet to find images of samples of Moon rock. What color are they? Find images of the astronauts exploring the Moon. What color is the dust on their space suits?

The Moon is as black as coal. It *looks* much brighter, because we see it against the much darker black of outer space, and because it is so brightly by the Sun!



The Moon rising over Mauna Kea in Hawaii. The mountain in the foreground is nearly black in color, but it looks grey because of the bright sunlight. What can you say about the Moon's color by comparison? The image was taken using the grey (neutral density) filter, 1-second exposure, at 11:30 in the morning.

