

Stronger Eyes and Better Numbers



People wanted to measure the altitudes of stars to help with navigation. Latitude is measured by using the Pole Star. The altitude of this star is approximately equal to the latitude north of the equator. The quadrant, a quarter circle with 0° – 90° marked around its curved edge, was a common instrument to use in determining latitude. The navigator lined up the sights of the device on the Pole Star, which would indicate the altitude of the star in degrees.



Throughout ancient times, the knowledge and technology of mapping stars improved over the centuries. Devices such as astrolabes and an increase in mathematical knowledge all improved this mapping procedure. However, people were limited to using only their eyes to view the stars. In Topic 2, you will see how astronomy made a big leap forward with the invention of the telescope.

Telescopes

A **telescope** is used to magnify objects at great distances. A simple telescope magnifies objects using an objective lens and an ocular lens. An **objective lens** is the large one at the front of the telescope. The **ocular lens** is the **eyepiece** through which you view the magnified object.

A Dutch spectacle maker, Hans Lippershey, invented the telescope in 1608. He noticed that a magnified image is produced when certain lenses are placed in front of each other. Later that century, Galileo Galilei, an Italian astronomer, improved the telescope and turned it on the heavens. His observations revealed details of the celestial bodies that required new explanations. Below, and on the next page, are modern-day photographs of celestial bodies showing details similar to those which Galileo himself saw.



Figure 5.8 Galileo observed the Moon's blemishes, which had shadows that lengthened and shortened with the Sun's angle on them. Galileo concluded that the Moon's surface has mountains and craters on it, much the same as Earth.

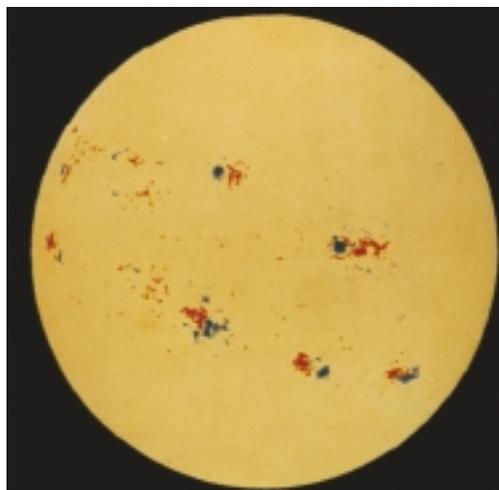


Figure 5.9 Galileo observed that the Sun had spots on it. Over a period of about a month, the spots moved across its surface, disappeared, and reappeared again on the other edge. From this, Galileo concluded that the Sun rotates on its axis.



Figure 5.10 Galileo observed that Jupiter is accompanied by four small ‘stars’ that move back and forth across it. He concluded that Jupiter is orbited by four moons. This photograph shows Jupiter and three of the moons that Galileo saw.



Figure 5.11 When viewing celestial bodies through his telescope, Galileo observed that the planets were disk-shaped — he saw the planets in some detail. However, the stars were still pinpoint in appearance — he could not see the stars with more detail by using his telescope. This observation led Galileo to the conclusion that the stars are much farther away than the planets.

Galileo’s Approach to Inquiry

Before Galileo, many scientists did not test their theories and models by observation. Galileo insisted that the adequacy of models should be assessed with observations. Overall, Galileo’s observations supported Copernicus’s Sun-centred model but not Ptolemy’s Earth-centred model.

One example is the moons of Jupiter. As you read in Figure 5.10, Galileo saw that these celestial bodies orbit Jupiter but not Earth. The Earth-centred model assumes that all celestial bodies orbit Earth. Because Jupiter’s moons orbit Jupiter and not Earth, it became clear to Galileo that Earth is not at the centre of the universe. The Earth-centred model just wasn’t right.



Figure 5.12 Using his telescope, Galileo spotted four moons orbiting Jupiter. Apparently not everything revolved around Earth after all. (With modern telescopes, scientists have found that Jupiter actually has 17 moons.)

Pause & Reflect

1. Which of Galileo’s observations contradicted the idea that Earth is the centre of the universe?
2. **Thinking Critically** Before Galileo’s time, some people believed that everything in the heavens was placed there to please humans and to help us learn our place on Earth. Describe how you agree or disagree with this idea. How did Galileo’s observations change the way people think of Earth’s place in the universe? Write your ideas in your Science Log.

Construct and Test a Telescope

You've learned that simple telescopes are used to magnify objects that are far away. In this investigation, you will construct a simple telescope and find its magnification.

Question

How does the magnification of a telescope relate to the properties of its lenses?

Hypothesis

Based upon your previous studies of light, write an hypothesis that describes how you think the image of the object will appear on the piece of paper.

Safety Precautions

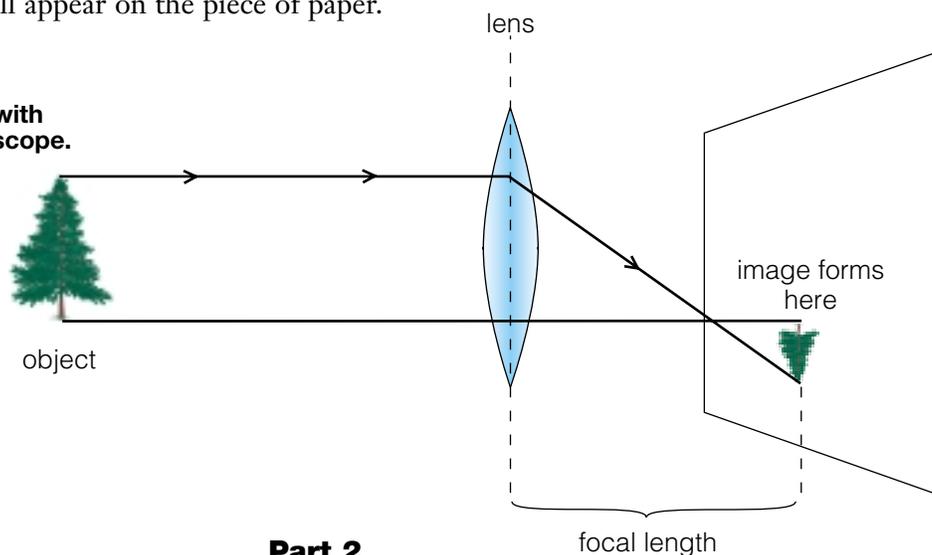
- **Never look directly at the Sun with your eyes or through your telescope.**

Apparatus

2 lenses of different strengths
ruler

Materials

paper tubes
(from toilet paper rolls,
or paper towel rolls)
tape



Part 1

Measure the Focal Length of the Lenses

(The focal length is the distance from the lens to the image of an object that is far away.)

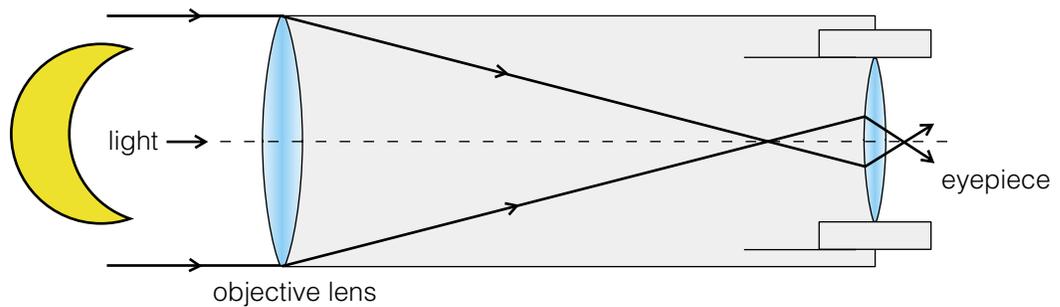
Procedure

- 1 Divide into groups of two or three.
- 2 Hold each lens up and project an image of a far away object onto a piece of paper.
- 3 For each lens, carefully **measure** the distance from the lens to the image of the object. This is the focal length of the lens.
- 4 **Record** the focal length of each lens in your notebook.

Part 2

Construct the Telescope

- 1 Fit the lens with the longer focal length into one of the tubes. Use tape to make a firm fit. This lens is the objective lens of the telescope. The tube should be about as long as the objective's focal length.
- 2 Fit another tube around the second lens. This is the eyepiece or ocular lens of the telescope.
- 3 Slide the tubes together. Use tape as a spacer to get the tubes to fit firmly. Wrap the tape around the end of the smaller diameter tube until you get a snug fit. You should be able to slide the smaller diameter tube in and out of the larger tube. Adjust the distance between

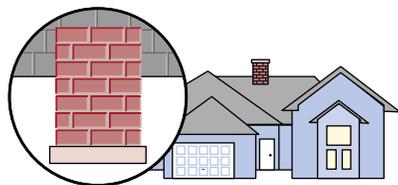


the lenses until you have a clear image of some object. Recall the focal length of your objective lens. Your eyepiece should be a bit farther away from the objective lens than the distance of its focal length. Your eyepiece should be placed a bit beyond the focal length of the objective lens. Experiment with the location that gives you the best image.

Part 3

Testing the Power

- 1 Look through your telescope at an object with both eyes open. Try to **observe** the magnified and unmagnified object at the same time. A chimney is a good object to view.
- 2 **Estimate** the magnification. The magnification of the image is how many times your object's height has been magnified. **Estimate** the magnification by counting (approximately) how many times the actual object's height fits into the magnified image's height and write your estimate in your notebook.



Skill

FOCUS

For tips on estimating, turn to Skill Focus 5.

Analyze

1. Describe the orientation of the image produced by your telescope. Is it upside down, right side up, or backwards?
2. What is the ratio of your telescope's objective focal length to its eyepiece focal length?
3. How critical is it to line up your lenses properly?

Conclude and Apply

4. Refer to your estimate of your telescope's magnification. Compare the telescope's magnification to the ratio of the focal lengths of the two lenses. Can you see a mathematical relationship? Describe this relationship.
5. Check the results of other groups in the class. Does the same relationship apply to their work? Describe why or why not.

Extension

6. How could you make a telescope with a higher power than the one you just built?

DidYouKnow?

Christian Huygens, a Dutch natural philosopher, discovered Saturn's rings in the late 1600s with a telescope that was tens of metres long! He did it by suspending a lens with a long focal length from a tower and holding a short focal length lens on the ground lined up with the other lens. There was no tube.



Figure 5.13 This is a wide telescope.

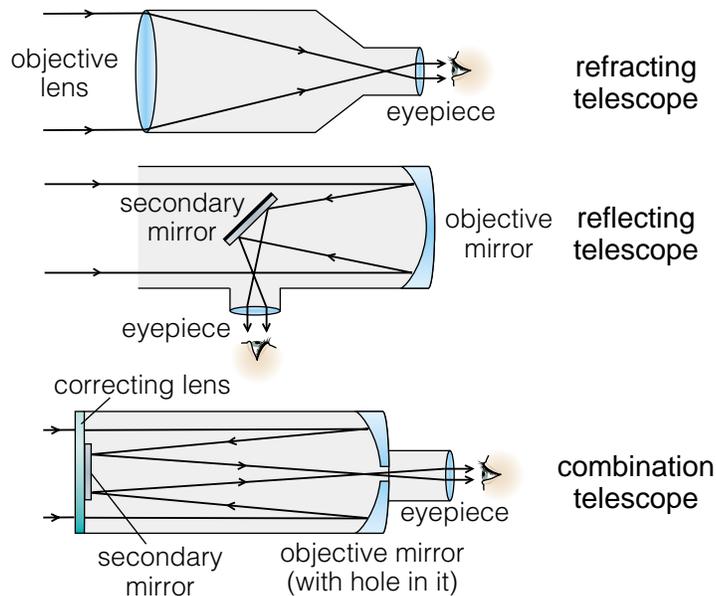
Resolving Power

In the last investigation, you built a simple telescope. To build a more powerful telescope, you need to increase its **resolving power**. This kind of power is the fineness of detail the telescope can produce of the object in view. This depends on the diameter of the objective lens. A telescope with a small diameter objective lens can magnify as much as you want, (which is important) but you see only a larger image with the same detail. A wide telescope such as in Figure 5.13 indicates a larger diameter objective lens, which produces finer detail when viewing. Thus, larger diameter objective lenses are what increases a telescope's resolving power.

Refractors and Reflectors

Many types of optical telescopes have been invented since Galileo's time. **Refracting** telescopes have a lens for their objectives and **reflecting** telescopes have objective mirrors. Isaac Newton designed the reflecting telescope to overcome a problem that the early refractors had. The early refractors could not focus different colours in the same place, but mirrors can. Later, that problem was solved for the refractors and both types of telescope are in use today. Refractors give better images than equal-size reflectors, but reflectors can be made much larger. New designs have elements of both types of telescope.

Figure 5.14 Refracting telescopes have a lens for the objective. Reflecting telescopes have a mirror for the objective. Combination telescopes have a lens at the front and an objective mirror at the back.



Copernicus's Sun-centred Revolution Continues

Although Galileo's telescopic observations helped to confirm Copernicus's Sun-centred model of the universe, Copernicus's model still needed work. Like Ptolemy's Earth-centred model, Copernicus's model contained epicycles for the planets. This meant that predictions based on it were no more accurate for some events than those based on the Earth-centred model. In 1609, Johannes Kepler, a German mathematician, found the answer to this problem. According to his calculations, predictions of the planets' motions would be more accurate if planetary orbits were elliptical rather than circular. An **ellipse** is a figure that looks like a squashed circle.

Kepler figured this out by combining mathematics with actual observations of the planets' motions. He had access to excellent star charts based on observations by Tycho Brahe, an important astronomer of the day. Kepler's task was to work out mathematically the shape of Mars's orbit. However, Kepler's math had to match the actual orbit observed by Brahe. It took Kepler two years to work out this problem. He found that the only way to explain Brahe's observations mathematically was to replace the idea of circular orbits with elliptical ones. Kepler not only found the shapes of the orbits, but also figured out the shape and scale of the entire known solar system.

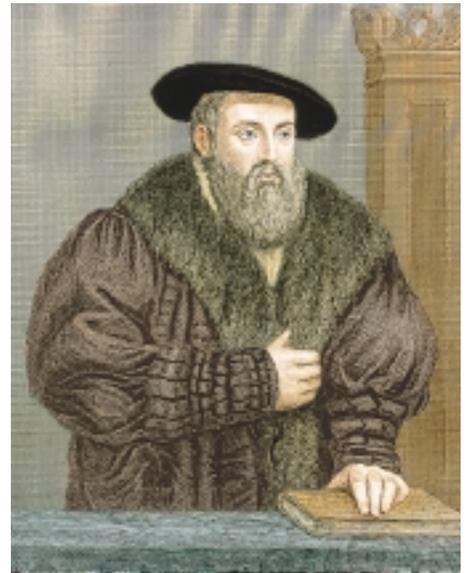


Figure 5.15 Johannes Kepler in his study.

Draw an Ellipse

Kepler discovered that the planets make elliptical orbits around the Sun. Draw your own ellipse to see what one looks like.

Materials

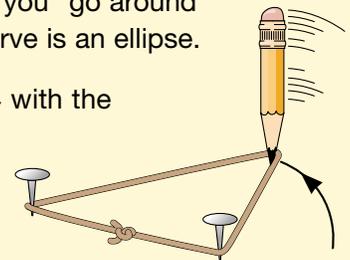
string pins
paper cardboard

Procedure Performing and Recording

1. Place a piece of blank paper on the cardboard. Push two pins into the piece of cardboard. Place them about 5–10 cm apart.
2. Cut a piece of string longer than twice the distance between your pins.
3. Tie the string into a loop and place it around two pins in the piece of cardboard, as shown in the illustration.

Find Out ACTIVITY

4. Put a pencil inside the loop. Pull it tight with the pencil. Slowly trace the curve that results when you “go around” the string. The curve is an ellipse.
5. Repeat steps 1–4 with the pins at different distances (more and less than 5–10 cm apart).



What Did You Find Out? Analyzing and Interpreting

1. Describe how the ellipse looks when the pins are far apart and when they are close together.
2. If the pins are almost touching, what shape does the ellipse look like?

Universal Gravitation

You have read that Aristotle used philosophical and geometric models of the universe. With Kepler, the world now had mathematical models of the universe, which were based on more accurate observations of the celestial bodies.

You learned earlier that Kepler described the elliptical shape of the planets' orbits. Eighty years later, Isaac Newton stated the law of **universal gravitation**. This law provided an explanation for the planets' elliptical orbits.

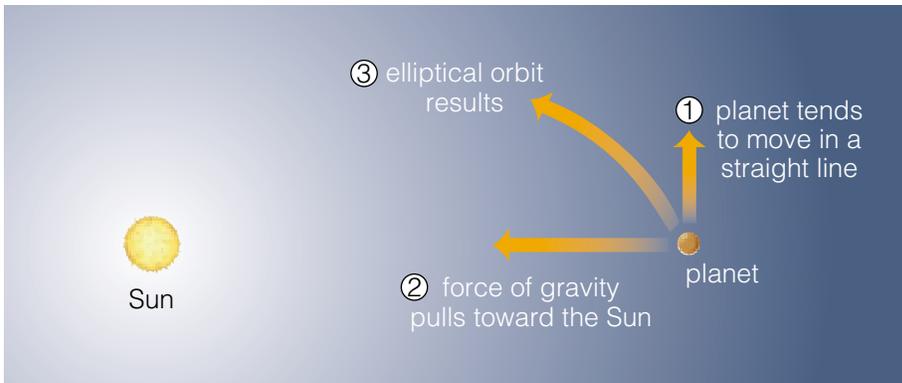


Figure 5.16 An orbit is the result of the attractive force of gravity balancing the tendency of a planet to move in a straight line.

According to Newton's law, there is a gravitational force between all objects that pulls them together. When no forces act on an object, it will move in a straight line at a constant speed. The planets are always moving. They would fly off through space in a straight line if no force acted on them. The force of gravity pulls them in toward the Sun, which balances their tendency to move in a straight line. The result is an orbit for each planet.

Predicting Events

Kepler's and Newton's mathematical approaches to understanding the motion of the objects within the universe changed astronomy forever. Mathematics enables astronomers to make accurate predictions about the motions of objects in the universe. In this activity, you will research a predicted event in the sky. You will see through your own observations if the prediction is accurate.

Procedure **Initiating and Planning**
 Performing and Recording

1. Choose one of the events listed below. Research when it is predicted to occur next. Be sure to choose an event that can be seen in the sky from your location.
 - The time of solar noon at your location (The time when the Sun is due south.)

Find Out **ACTIVITY**



- Sunrise or moonrise
 - The next eclipse
 - The next meteor shower
 - Any other event that you or your teacher can find
2. At the predicted time, try to observe the event.

What Did You Find Out? **Analyzing and Interpreting**

1. How close was the prediction to the actual time of observation?
2. Describe the actual cause of the event that you chose to observe.

- ☀ Initiating and Planning
- ☀ Performing and Recording
- Analyzing and Interpreting
- ☀ Communication and Teamwork

The Scale of the Heavens

The mathematical work of Kepler and Newton made it possible for astronomers to calculate the scale of the solar system. In this investigation you will design and construct your own scale model.

Challenge

Design and construct a scale model of all or a part of the solar system. Here are some ideas:

- Earth and the Moon, including the distance between them
- The distances of the planets from the Sun
- A planet other than Earth and its moons
- The sizes and distances of the planets to the same scale. This is challenging, but it can be done!

Materials

Think of objects that can function as planets, such as pinheads, marbles, balls.

Planetary Data for Your Model

Planet (and the Moon)	Distance from Sun (million km)	Diameter (km)
Mercury	57.9	4 879
Venus	108.2	12 104
Earth	149.6	12 756
Mars	227.9	6 794
Jupiter	778.3	142 980
Saturn	1 429.4	120 540
Uranus	2 875.0	51 120
Neptune	4 504.4	49 530
Pluto	5 915.8	2 300
The Moon	385 000 km (from Earth)	3 475

Design Specifications

A. You may use any objects for your moons and planets.

Plan and Construct

- 1 After you choose what you will model, you must select a scale that works. Use the skills you learned in math to figure out the best scale for you. Your model will not be as precise as the data in the data table, so rounding off the numbers will be necessary.
- 2 Think about what kind of model you will make (drawings, actual objects). It may be necessary to use the whole room, hallway, or even the outdoors to fit your model. Be creative!

Evaluate

1. When you look at your model and the models of the other students, how “empty” does space seem to be?
2. How precise was your model? (How rounded off are your distances?)

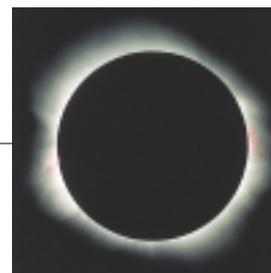
Skill

FOCUS

For tips on using scientific models, turn to Skill Focus 12.

DidYouKnow?

The Sun is about 400 times as far from Earth as is the Moon. The Sun’s diameter is about 400 times the Moon’s diameter. The result of this is that when the Moon comes directly between Earth and the Sun, we see a solar eclipse.



TOPIC 2 Review

1. Why did Galileo conclude that Jupiter had four moons travelling around it?

2. What observation led Galileo to the conclusion that the Sun rotates?

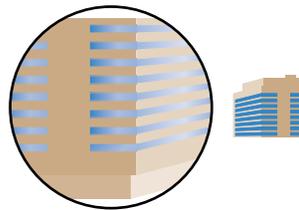
3. What shape are the orbits of the planets?

4. Use this information to answer questions 4 and 5:

The magnification of an astronomical telescope can be found by dividing the focal length of the eyepiece into the focal length of the objective.

Apply Suppose you have a lens with a 120 cm focal length and you want to make a telescope with a power of $60\times$. What focal length lens should you use with your other lens?

5. **Apply** The two diagrams on the right show a building and its image through a telescope. If the objective lens of the telescope is 25 cm, then what is the focal length of the eyepiece?



6. **Thinking Critically** Why were Tycho Brahe's star charts so important in deciding the correct model of the solar system?

7. **Thinking Critically** Describe how planets stay in stable orbits around the Sun.

Pause & Reflect

Sit in a swivelling chair and watch an object in front of you. Swivel the chair to your left without turning your head.

1. Where must your eyes look to see the object now?
2. What motion does the object seem to show relative to you?
3. What part of the Sun-centred model is demonstrated here?

Did You Know?



A friend of Newton's, Sir Edmond Halley, used Newton's theory of gravitation to predict the reappearance of what was later named comet Halley. Halley predicted that the comet had a very elongated orbit around the Sun. It would spend most of its orbit far from the Sun and therefore move slowly. As it approached the Sun, it would speed up and whiz around it. He predicted its return in 1757. He died many years before this date, but the comet did return when predicted. This photo was taken in 1986 when comet Halley was last seen.

If you need to check an item, Topic numbers are provided in brackets below.

Key Terms

frame of reference	astrolabe	resolving power
celestial bodies	compass	refracting
constellations	Earth-centred (or geocentric)	reflecting
planets	Sun-centred (or heliocentric)	ellipse
azimuth	telescope	universal gravitation
altitude	objective lens	
altitude-azimuth co-ordinates	eyepiece (or ocular lens)	

Reviewing Key Terms

1. In your notebook, match the description in column A with the correct term in column B

A	B
• a star's angular height above the horizon	• astrolabe (1)
• a model with Earth as a non-moving frame of reference	• compass (1)
• the true shape of the planets' orbits	• altitude-azimuth co-ordinates (1)
• a device used to measure the altitude of an object	• elliptical (2)
• a model with the Sun as a non-moving frame of reference	• altitude (1)
• used to measure an object's azimuth	• frame of reference (1)
• angles used to specify the co-ordinates of celestial bodies	• geocentric (2)
• a set of axes used to describe the positions or motions of things	• refracting (2)
• a telescope with a lens for the objective	• heliocentric (2)

Understanding Key Concepts

2. In what frame of reference does a building seem not to move? (1)
3. Suppose you are an astronaut working in the *International Space Station*. Explain how the space station and Earth could serve as a frame of reference for you. (1)
4. Galileo approached his observations much as a scientist does today. What observations led him to conclude that the Moon had mountains on it? (2)
5. The Moon is 385 000 km from Earth. Earth's diameter is 12 756 km. How many Earth diameters is the Moon from Earth?
6. Describe in detail the differences between the Sun-centred and Earth-centred models of the universe. (1)
7. **Thinking Critically** Hundreds of years ago, astronomers knew that the planets varied in brightness throughout the year. How did Ptolemy's model of the universe account for this? (2)