3.3 The Copernican Revolution

Our goals for learning:

- How did Copernicus, Tycho, and Kepler challenge the Earth-centered idea?
- What are Kepler’s three laws of planetary motion?
- How did Galileo solidify the Copernican revolution?

Copernicus (1473-1543):

- Proposed Sun-centered model (published 1543)
- Used model to determine layout of solar system (planetary distances in AU)

But . . .

- Model was no more accurate than Ptolemaic model in predicting planetary positions, because still used perfect circles.

Tycho Brahe (1546-1601)

- Compiled the most accurate (one arcminute) naked eye measurements ever made of planetary positions.
- Still could not detect stellar parallax, and thus still thought Earth must be at center of solar system (but recognized that other planets go around Sun)
- Hired Kepler, who used his observations to discover the truth about planetary motion.

Johannes Kepler (1571-1630)

- Kepler first tried to match Tycho’s observations with circular orbits
- But an 8 arcminute discrepancy led him eventually to ellipses…

*If I had believed that we could ignore these eight minutes [of arc], I would have patched up my hypothesis accordingly. But, since it was not permissible to ignore, those eight minutes pointed the road to a complete reformation in astronomy.*
What is an Ellipse?

An ellipse looks like an elongated circle.

Kepler’s First Law: The orbit of each planet around the Sun is an ellipse with the Sun at one focus.

What are Kepler’s three laws of planetary motion?

Kepler’s Second Law: As a planet moves around its orbit, it sweeps out equal areas in equal times.

⇒ means that a planet travels faster when it is nearer to the Sun and slower when it is farther from the Sun.

Kepler’s Third Law: The squares of the periods of the planets are proportional to the cubes of their mean distances from the Sun.

Drawing an Ellipse
Kepler’s Third Law

More distant planets orbit the Sun at slower average speeds, obeying the relationship

\[ p^2 = a^3 \]

\( p \) = orbital period in years
\( a \) = avg. distance from Sun in AU

Thought Question:
An asteroid orbits the Sun at an average distance \( a = 4 \) AU. How long does it take to orbit the Sun?

A. 4 years  
B. 8 years  
C. 16 years  
D. 64 years

Hint: Remember that \( p^2 = a^3 \)

An asteroid orbits the Sun at an average distance \( a = 4 \) AU. How long does it take to orbit the Sun?

A. 4 years  
B. 8 years  
C. 16 years  
D. 64 years

We need to find \( p \) so that \( p^2 = a^3 \)
Since \( a = 4 \), \( a^3 = 4^3 = 64 \)
Therefore \( p = 8 \), \( p^2 = 8^2 = 64 \)
How did Galileo solidify the Copernican revolution?

Galileo (1564-1642) overcame major objections to Copernican view. Three key objections rooted in Aristotelian view were:

1. Earth could not be moving because objects in air would be left behind.
2. Non-circular orbits are not “perfect” as heavens should be.
3. If Earth were really orbiting Sun, we’d detect stellar parallax.

Overcoming the first objection (nature of motion):

Galileo’s experiments showed that objects in air would stay with a moving Earth.

- Aristotle thought that all objects naturally come to rest.
- Galileo showed that objects will stay in motion unless a force acts to slow them down (Newton’s first law of motion).

Overcoming the second objection (heavenly perfection):

- Tycho’s observations of comet and supernova already challenged this idea.
- Using his telescope, Galileo saw:
  - sunspots on Sun (“imperfections”)
  - mountains and valleys on the Moon (proving it is not a perfect sphere)

Overcoming the third objection (parallax):

- Tycho thought he had measured stellar distances, so lack of parallax seemed to rule out an orbiting Earth.
- Galileo showed stars must be much farther than Tycho thought — in part by using his telescope to see the Milky Way is countless individual stars.
- If stars were much farther away, then lack of detectable parallax was no longer so troubling.
Galileo also saw four moons orbiting Jupiter, proving that not all objects orbit the Earth…

… and his observations of phases of Venus proved that it orbits the Sun and not Earth.

The Catholic Church ordered Galileo to recant his claim that Earth orbits the Sun in 1633.

His book on the subject was removed from the Church’s index of banned books in 1824.

Galileo was formally vindicated by the Church in 1992.

3.4 The Nature of Science

Our goals for learning:

• How can we distinguish science from nonscience?
• What is a scientific theory?
How can we distinguish science from non-science?

- Defining science can be surprisingly difficult.
- Science from the Latin scientia, meaning “knowledge.”
- But not all knowledge comes from science…

But science rarely proceeds in this idealized way… For example:

- Sometimes we start by “just looking” then coming up with possible explanations.
- Sometimes we follow our intuition rather than a particular line of evidence.

The idealized scientific method

- Based on proposing and testing hypotheses
- hypothesis = educated guess

Hallmarks of Science: #1

Modern science seeks explanations for observed phenomena that rely solely on natural causes.

(A scientific model cannot include divine intervention)
Hallmarks of Science: #2

Science progresses through the creation and testing of models of nature that explain the observations as simply as possible.

(Simplicity = “Occam’s razor”)

Hallmarks of Science: #3

A scientific model must make testable predictions about natural phenomena that would force us to revise or abandon the model if the predictions do not agree with observations.

What is a scientific theory?

• The word theory has a different meaning in science than in everyday life.
• In science, a theory is NOT the same as a hypothesis, rather:
• A scientific theory must:
  • Explain a wide variety of observations with a few simple principles, AND
  • Must be supported by a large, compelling body of evidence.
  • Must NOT have failed any crucial test of its validity.

Thought Question

Darwin’s theory of evolution meets all the criteria of a scientific theory. This means:

A. Scientific opinion is about evenly split as to whether evolution really happened.
B. Scientific opinion runs about 90% in favor of the theory of evolution and about 10% opposed.
C. After more than 100 years of putting Darwin’s theory to the test, the theory stands stronger than ever, having successfully met every scientific challenge to its validity.
D. There is no longer any doubt that the theory of evolution is absolutely true.
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