Kepler’s laws and a heliocentric universe

Triumph of science over tradition

Goals & Outcomes

• **Appreciating** science in general, and astronomy in specific.
• **Understanding** how knowledge is gained and be critical of what you see and hear. You will begin to ask “How can we test that?” when forming hypotheses or “How do we know that?” when reading new information.
• **Developing** a working knowledge of the scientific method and how to apply it to real world situations.
• **Critically analyzing and evaluating** information, scientific or otherwise
• Learn some simple astronomical nomenclature/terminology.
• Understand how orbits are related to gravity
• Understand and be able to make predictions about orbital motions, as explained by Kepler’s laws as revised later by Isaac Newton.
Big questions

• What are Kepler’s 3 laws?
• What do they deal with?
• Give examples.

Kepler’s laws of planetary motion

• Johannes Kepler (page 72): 1571 - 1630
• Used planet data taken by Tycho Brahe (page 71)
• Kepler realized the motions of planets could be very accurately described with only 3 rules.
• Earlier models involved only circles centered on Earth
• See pages 50 & 69.
• Measurements got better. Theories had to adjust to better data. This is often the way science works.
• Kepler never knew WHY his laws were right or what caused them – he only found rules that described the data.
• Isaac Newton (1642 – 1727) figured out why Kepler’s laws worked. He also revised Kepler’s laws slightly.
Kepler’s 1st law

- See Page 73 and figure 3.19 on page 74.
- Kepler’s version: Orbits of the planets around the Sun
  - are elliptical
  - with the Sun at 1 focus of the ellipse
  - (not at the center)
- Newton: works on any object orbiting anything else.
- More on the next slide.

Ellipses

- Ellipses are “squashed circles.”
- To see an ellipse: instead of looking at a plate from above, tilt the plate.
- Circles are a special symmetrical ellipse.
- Sometimes planets are closer & sometimes further from the Sun!
  - Closest to Sun= perihelion.
  - Furthest = aphelion.
- Give another example of an elliptical orbit
- (page 42 and next slide)
The Earth is in a circular orbit around the Sun.

1. True
2. False

Technically false, but it’s VERY close to a circle (3% difference between closest and furthest).
Kepler’s 2nd Law

• Pages 73. Slightly revised
• Any object moves around its orbit and sweeps out “equal areas in (during) equal times.”
• What does this mean? Let’s discuss figure 3.20.
• See also animations at:
  http://www.sunsite.ubc.ca/LivingMathematics/V001N01/UBCExamples/Kepler/kepler.html AND
  http://physics.syr.edu/courses/java/mc.html/kepler_frame.html
• Check the webpage to see these links.

Simple translation of Kepler’s 2nd law

• Orbit faster when closer to Sun and ...
Preview of tutorial questions

• Who moves faster? A or B? A or C?

A

B

C

1 sec

0.5 sec


• NOTE TO TEACHER: First picture is different compared to 2nd and second picture is different compared to 3rd
• NOTE TO TEACHER: We will do question 3 together **now**.
• NOTE TO TEACHER: After they finish, show animation from 2nd page near perihelion, NOT matching A & B in tutorial.
A consequence of Kepler’s $2^{nd}$ law

- **TEACHER:** Draw an ellipse for a comet’s or extra-solar planet’s orbit.

- Planets orbit fastest when ______
- When is it slowest?
- When is it speeding up?
- When is it slowing down?
- Talk to your neighbor for a minute. I will NOT tell you the answer today, except for the blank above.

Kepler’s $3^{rd}$ law

- Pages 73-74.
- English: further planets orbit at slower AVERAGE speeds, obeying a mathematical relationship: (write on board)
  - Math (p. 74):
  - $(\text{Orbit Time})^2 = (\text{some number}) \times (\text{average Orbit size})^3$
- The “some number” is missing from the book. EXCEPT on pp. 134-137. The number depends on the TOTAL mass (Sun + planet) of the system.
  - Sun is MUCH heavier than ANY planet, so mostly measure mass of the “central” object.
- This (some number) is how we determine the mass of the Earth, Jupiter, Sun, and many other things.
  - What would you need to measure to calculate the Earth’s mass?
Would you be able to measure the Earth’s mass using the Earth’s orbit around the Sun?

<table>
<thead>
<tr>
<th></th>
<th>1. Yes, easily</th>
<th>2. Not easily</th>
</tr>
</thead>
</table>

Can you use Kepler’s 3rd law to figure out the mass of the Milky Way?

<table>
<thead>
<tr>
<th></th>
<th>1. Yes</th>
<th>2. No</th>
</tr>
</thead>
</table>
Student activities

- Lecture Tutorial, pages 25-27
- Ranking Tasks are also good practice.

End of geocentrism

- Prior to Kepler, common belief was: everything moves around Earth
- Nicholas Copernicus (1473 – 1543) gave the first model of planets orbiting the Sun.
- Kepler’s interpretation of Tycho’s data showed Earth not at the center.
Galileo Galilei (1564-1642)

- Galileo nailed the coffin shut on geocentrism.

1. Heavens DO change. He saw sunspots come & go.
3. Venus shows phases, like the Moon. Can’t be explained if Venus and Sun orbit Earth.

(He also knew of a supernova seen by Tycho Brahe (1546-1601)! And he knew of newly discovered comets.)

Still, Church didn’t like it. Galileo put in house arrest! But Church repented.

In 1992.

From 4th edition of textbook: According to Kepler’s laws, Earth would take noticeably longer to orbit the Sun if Earth were double its mass.

1. True
2. False
Big questions

• What are Kepler’s 3 laws?
• What do they pertain to?
• Give examples.
• One more slide. DO NOT SHOW IT ON THE SAME DAY THE STUDENTS SEE KEPLER’S 2ND LAW FOR THE FIRST TIME.

Kepler’s 2nd law consequences – this slide isn’t in your notes.

• Equal areas covered during equal times.
  Consequences:
  – Equal times → planet covers equal areas
  – Move fastest when closest;
    Move slowest when furthest
  – And the part students don’t always figure out:
    • Speed up when getting closer;
      Slow down when getting further