Kepler’s Laws—20 Jan

- Homework 1
  - Due at 6:00am on Thurs, 22nd Jan.
  - On angel.msu.edu, go to Lessons>Homework>Homework1.
  - The lower grade does not count.
- Clicker
  - Register at iClicker.com
  - Use your email address
  - You may use paper answers 2 times.
- The discovery of the laws of motion, the first science.
  - *De Revolutionibus Orbium Coelestium*, Copernicus, 1543
  - *Astronomia Nova*, Kepler, 1609
  - *Philosophiae Naturalis Principia Mathematica*, Newton, 1687
- How Kepler figured out the path of Mars from Tyco’s observations. Discovery of his three laws.

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Questions on reading

1. When Kepler was a college student, the most accurate description of the motion of planets uses the terms
   a. Velocity, position, & acceleration
   b. Circular orbits
   c. Elliptical orbits
2. Same question for Newton
3. Today the most accurate description of the motion of planets uses the terms
   a. Velocity, position, & acceleration
   b. Circular orbits
   c. Elliptical orbits
Tycho Brahe’s Observations

Uraniborg

Brass azimuthal quadrant, 65 cm radius (ca 1576)

Great quadrant (1582)

What is fake on Tycho?

• On Uraniborg, Tycho measured positions of the planets for 20 years
• Highly accurate & reliable
  • Accuracy limited by human eye, not by instruments. Superseded only with telescopes.
  • Tyco measured & compensated for instrument flexure, the biggest error.

Kepler analyzes Tycho’s data

• Kepler was Tycho’s assistant
  • 20 yrs’ data on planetary motions.
  • Tycho tried to fit data with Ptolemy-like model.
• Kepler analyzed the data
  • Found 3-d orbits from 2-d positions in the sky
  • Concentrated on orbit of Mars.
  • Had to subtract off Earth’s (imperfectly known) orbit.
• Discovered 3 “laws,” which describe the motions of the planets.

Kepler (1571-1630)

Brahe (1546-1601)

• Their meeting at Benatek (in Czechoslovakia)
  • …on 4 February 1600, Tycho de Brahe and Johannes Keplerus, co-founders of a new universe, met face to face, silver nose to scabby cheek. Tycho was fifty-three, Kepler, twenty-nine. Tycho was an aristocrat, Kepler a plebian. — Koestler, The Sleepwalkers, p302
Kepler’s First Law 1605

- Orbit of a planet is an ellipse, with the sun at one focus.
- Definition of an ellipse
  - (Distance between planet & focus #1) + (distance between planet & focus #2) is the same for the entire orbit.
- This was an unexpected result in Kepler’s time.
  - Ellipse is a simply defined shape, not any shape. The motion of the planets must have a deeper cause.
  - If the sun is at a focus, it must affect the planet’s motion.

Kepler1 simulation

Kepler’s Second Law 1602

- The line joining the planet and the sun sweeps out equal areas of space in equal amounts of time.
- Planet moves
  - more slowly when it is far from sun
  - more rapidly when close to sun
Kepler’s Laws

- Law 1: Orbit of a planet is an ellipse, with the sun at one focus.
- Law 2: The line joining the planet and the sun sweeps out equal areas of space in equal amounts of time.

2. Winter is a few days shorter than summer for us in the northern hemisphere. Therefore Earth is at A, B, C, or D in January?

- What do I need to find out before I can answer the question?

Kepler’s Third Law 1618

- $P^2 = a^3$
  - $P$ = period of orbit, in years
  - $a$ = semi-major axis of orbit, in AU. (Average Earth-sun distance is 1 AU.)

Fast solar simulation
http://web.cuug.ab.ca/~kmcclary/fastsolar.html
Kepler’s Third Law 1618

- \( P^2 = a^3 \)
  - \( P \) = period of orbit, in years
  - \( a \) = semi-major axis of orbit, in AU. (Average Earth-sun distance is 1 AU.)

1. A 10th object (planet?) was found beyond the orbit of Pluto. ___ has the shorter period.
   A. Pluto
   B. 10th object
   C. Not enough information to answer.

- What do I need to find out before I can answer the question?

Questions concerning Kepler’s Laws

- A planet’s path is an ellipse with the sun at one focus.
- A planet “sweeps” out the same area in an equal amount of time.
- The planets’ periods \( P \) and semi-major axes \( a \) are related by \( P^2 = a^3 \)
- A planet, which has an almost circular orbit, and a comet, which has a highly elliptical orbit, have the same periods. Draw their orbits on a single picture.
  1. Grading: sun’s position
  2. Grading: lengths of major axes.

- What do I need to find out?
Questions concerning Kepler’s Laws

- A planet's path is an ellipse with the sun at one focus.
- A planet "sweeps" out the same area in an equal amount of time.
- The planets' periods $P$ and semi-major axes $a$ are related by $P^2 = a^3$.
- A planet, which has an almost circular orbit, and a comet, which has a highly elliptical orbit, have the same periods. Draw their orbits on a single picture.

1. Grading: sun's position
   A. Centered for comet
   B. Offset for comet

2. Grading: lengths of major axes.
   A. Same for both
   B. Different

The Motions of the Planets

- Ptolemy 140 AD
- Copernicus 1543
- Kepler 1609

Simpler model

More accurate description of data
Kepler’s 3 Laws

• Orbit of a planet is an ellipse, with the sun at one focus.
• The straight line joining the planet and the sun sweeps out equal areas of space in equal amounts of time.
• \( P^2 = a^3 \)
• But why?
  • These are descriptive laws, but there must be deeper reasons for the planets to do this.

Newton’s Laws of Motion & Gravity

• De Revolutionibus Orbium Coelestium, Copernicus, 1543
• Astronomia Nova, Kepler, 1609
• Philosophiae Naturalis Principia Mathematica, Newton, 1687
• Newton invented calculus (MTH 132) & mechanics (PHY 183)
• Nature and Nature’s laws lay hid in night:/ God said, Let Newton be! and all was light. —Newton’s epitaph by Alexander Pope
• Newton: Same laws apply to a falling apple & moving planet.
• Description of motion
• Gravity \( \propto 1/R^2 \) implies K’s 3rd Law

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