

Topic B

“The New Astronomy” Part 2. Kepler (Law #1)


(Web Version: 01-19-01)

1

Tycho Brahe (1546–1601)*

* See text & Study Guide Fig. 3

- Danish nobleman & astronomer
- Arrogant, abusive & argumentative
- But finicky . . .
 - Built astronomical measuring instruments of unprecedented accuracy & size
 - Produced finest set of stellar & planetary positions (naked eye)




2

Tycho Brahe (1546–1601)*

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Revolving Wooden Quadrant (1586), 1.6 Meter Radius.

3

Johannes Kepler (1571–1630)*

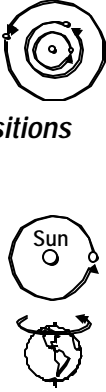
* See text & Study Guide Fig. 3

- German astronomer & mathematician
- Hired by Tycho Brahe (to perfect orbits)
 - Believes Tycho’s positions of Mars accurate to about 1/8°
 - Tycho “mysteriously” dies
- Kepler acquires (“steals”) observations of Mars



4

Kepler’s Model



- Goal — *produce better planetary positions*
- Based on heliocentric view
 - Earth orbits Sun to produce annual motion
 - Earth spins on axis giving diurnal motion

5

Kepler’s Model

- Described by three statements
- Now called “Kepler’s Three Laws”
- Publication of the Laws
 - One & Two — *Astronomia Nova* (1609) [“The New Astronomy”]
 - Three — *Harmonic Mundi* (1619) [“The Harmony of the World”]

6

How to Draw an Ellipse

(1) Tie each end of string to two pins

Materials Needed: Paper, pins, pencil & string

13

How to Draw an Ellipse

(2) Decide upon distance between pins compared to *string's length*

Example
 $\frac{3}{5}$ or
 0.6 (60%)*

* Called *eccentricity*

14

How to Draw an Ellipse

(3) Stretch string tight & draw ellipse

$\frac{3}{5}$ of string's length

15

The Major Axis

(4) Notice string stretches completely across ellipse ... the *major axis*

string's length = major axis

16

The Foci

(5) Each pin is a *focus* of ellipse

string's length = major axis

17

Eccentricity

(6) Distance between pins compared to string's length is the *eccentricity* (e) of the ellipse

In this example
 $e = \frac{3}{5}$
 $= 0.6$
 $= 60\%$

string's length = major axis

18

The Keplerian Ellipse*

Learn

C = Center
 S = Sun (a focus)
 and
 F = Other Focus (empty)

*See Study Guide Fig. 4

19

The Keplerian Ellipse

Also

P = *Perihelion*
 (closest)

A = *Aphelion*
 (farthest)

20

Earth's Perihelion Date

- When Earth at *perihelion*?
 about _____?
- When Earth at *aphelion*?
 about _____?

21

Size of the Ellipse

Learn

PC = *Semimajor Axis*

PC gives size of ellipse

PC is called "a"

22

Mean Distance From Sun

A Definition

"a" is also called the *mean distance* to the Sun

23

Mean Distance of Earth

Mean Distance ("a") from Earth to Sun is about . . .

150,000,000 km
 or
 93,000,000 mi

24

The Astronomical Unit

For Earth
 Mean Distance also called . . .

One Astronomical Unit (AU)

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Distances of Planets

Jupiter

Earth

Sun

Which is easier to use— km (mi) or AU's?

5.2 AU

778,000,000 km

1.0 AU

150,000,000 km

Note — Planet sizes not drawn to scale with Sun

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Question

- Where is planet so distance from Sun equals "a" ?
- Not at P or A since
 - Minimum = PS (*Perihelion*)
 - Maximum = AS (*Aphelion*)

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Answer

- At either end (D or E) of minor axis ("b")
- All 6 dashed lines equal length of "a" !

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Shape of the Ellipse

Recall

- SF compared to PA is eccentricity
- Eccentricity gives shape

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Divide Lines in Half

Now

- SC compared to PC also eccentricity
- Eccentricity — how far Sun (S) from center (C)

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Eccentricity

Eccentricity is called "e"

- e is a ratio (expressed as a fraction or percent)
- $e = SC / a$

31

Example Ellipses

Eccentricity shows how far Sun from center

(circle) $e = 0.00$	(Pluto) $e = 0.25$
$e = 0.50$	$e = 0.75$
$e = 0.90$	

32

The Pluto Orbit

Pluto's Orbit

- $a = 40$ AU
- $e = 0.25$

S₀

- $SC = 10$ AU
- $PS = 30$ AU
- $AS = 50$ AU

S is 25% out from C or 10 AU

33

The Pluto Orbit

Pluto's Orbit

- $a = 40$ AU
- $e = 0.25$

Result

- Pluto varies from the mean of 40 AU by ± 10 AU (25%) !

34

Neptune's Orbit

Neptune's Orbit

- $a = 30$ AU
- $e = 0.009$

Result

- Orbit about 3/4 size of Pluto's orbit
- Orbit nearly perfect circle

35

Pluto & Neptune's Orbit

Result

- Pluto's perihelion is 30 AU
- Neptune's $a = 30$ AU

Question

- Do orbits touch at Pluto's perihelion?

36

The Real Case

Real Data

- Pluto's perihelion really 29.5 AU !
- Neptune's $a = 30$ AU

Conclusion

- Pluto's perihelion inside by 1/2 AU !

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Question

Can Neptune & Pluto collide?

It appears so

but ...

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Answer

- Orbits tilted about 15°
- Orbits clear by 2.5 AU!
- As they orbit actually never closer than about 18 AU

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Pluto Sometimes 8th Planet

- Discovered 1930
- Orbit Period = 248 yr
- Spends 20 yr inside Neptune's orbit
- When last? Feb. 11, 1999 (5:08 a.m. EST)
- Next? 2231 Apr. 5

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Earth's Orbit

Orbit

- $a = 1.0$ AU
- $e = 0.017$ (1.7%) or approx. 2%

So

- PS = 0.98 AU
- AS = 1.02 AU

Variation in distance only about 0.02 AU

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Earth's Variation < 2 Million Mi.

Orbit

- $a = 1.0$ AU
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So

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Earth's Eccentricity & Seasons

Questions — Does the Earth's variation in distance

- Cause the seasons? T or F
- Noticeably influence the seasons? T or F

Answer

43

Cause of Earth's Seasons

Rays at shallow angle
 Sun lower in sky
 Fewer hours daylight

Rays at steeper angle
 Sun higher in sky
 More hours daylight

- *Axis tilt* causes seasons
- Distance variation *too small* to affect seasons

44

How Should Distance Influence Seasons?

- N. Hemisphere — Seasons more *moderate*
- S. Hemisphere — Seasons more *severe*

45

But Eccentricity Small and . . .

- Northern Hemisphere has most land mass
- So southern oceans help moderate any effect

46

Mars

Orbit Period = 1.9 years
 Day = 24.6 hours
 Axis Tilt = 25.2°

Result — Seasons like Earth (twice as long)

but

- 1) $e = 0.09$ (5x Earth's)
- 2) No oceans & little atmosphere

Conclusions

- N. Hemisphere more *moderate* climate
- S. Hemisphere more *severe* climate

47