Physics 107
Ideas of Modern Physics

(www.hep.wisc.edu/~herndon/107-0609)

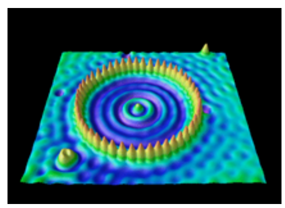
- Main emphasis is Modern Physics:
  Post-1900 Physics
- Why 1900?
  - Two radical developments:
    Relativity & **Quantum Mechanics**
- Both changed the way we think as much as did Galileo and Newton.

Goals of the course

- Learn a process for critical thinking, and apply it to evaluate physical theories
- Use these techniques to understand the revolutionary ideas that embody modern physics.
- Implement the ideas in some basic problems.
- Understand where physics is today, and where it is going.

What will we cover?

- Scientific observation and reasoning.
- Motion and energy.
- Relativity.
- Quantum Mechanics.
- Gravity.
- Particle theory and cosmology.



Modern Physics:

From the microscopically small
Single atoms
and quantum waves

To the incredibly large
Entire galaxies and the universe

How do we do this?

- Lectures
- Demonstrations
- In-class interactive questions
- Homework
- Discussion sections

HW 1: Chap 3 Conceptual 6, 28, 32
Chap 3 Problems 6, 10, 16

What do you need to do?

- Read the textbook
  - ✧ Physics Concepts and Connections
- Come to the lectures
  - ✧ 9:55 MWF in 2241 Chamberlin Hall
- Participate in discussion section
  - ✧ One per week, starting Sept 11th
- Do the homework
  - ✧ Assigned most Wednesdays, due the following Wednesday
- Write the essay
  - ✧ On an (approved) physics topic of your choice, due Dec 8
- Take the exams
  - ✧ Three in-class hour exams, one cumulative final exam

What do you get?

- An understanding of the physical universe.
- A grade
  - 15% HW and Discussion Quizzes
  - 15% essay
  - 20% each for 2 of 3 hour exams (lowest dropped)
  - 30% from cumulative final exam

Where's the math?

- Math is a tool
  that can often help to clarify physics.
- In this course
  we use algebra and basic geometry.
- We *will* do calculations, but also focus on written explanation and reasoning.

Observation and Science

- Look around - what you see is the universe.
- What can you say about how it works?

Aristotle's ideas about motion

- Terrestrial objects move in straight lines.
  Earth moves downward, Water downward,
  Air rises up, Fire rises above air.
- Celestial bodies are perfect.
  They move only in exact circles.
- Where did Aristotle concentrate his work?
  - Celestial bodies, most interesting problem of the day

Motion of the celestial bodies

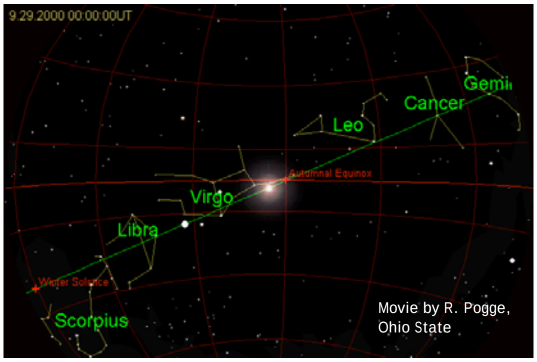
Apparent motion of stars:

Rotation about a point every 24 hours.

Moon, sun, and planets were known to move with respect to the stars.

Motion of the stars over 6 hrs

Daily motion of sun & planets over 1 year



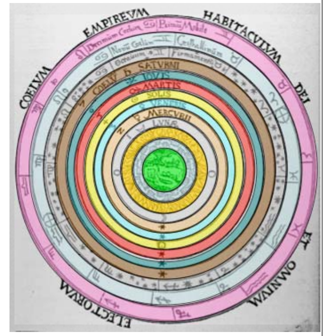
Aristotle’s crystal spheres

Earth/Water/Air/Fire

Prime mover (24 hrs)
Cristal sphere (49000 yrs)
Firmament (1000 yrs)

Saturn (30 years)
Jupiter (12 years)
Mars (2 years)
Sun (1 yr)
Venus (1 yr)
Mercury (1 yr)
Moon (28 days)

Already Complex!



You figure it out!

Assuming that the planets and stars are moving around the earth you would expect:

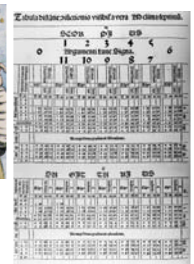
A. The planets to move faster than the stars since they are closer.
B. The stars to move faster than the planets.
C. We wouldn’t know what to expect.

I would say it would be helpful to have more information!

Detailed Observations of planetary motion (Ptolemy)

An instrument similar to Ptolemy’s

85-165



Observational notes from Ptolemy’s Almagest

Retrograde planetary motion

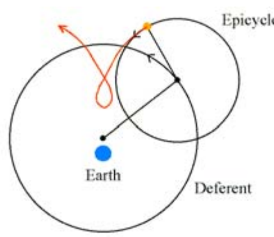
Continued observation revealed that the problem was even more complex than first believed!

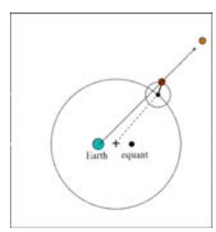
Retrograde motion of Mars.

Apparent motion not always in a perfect circle.

Mars appears brighter during the retrograde motion.

Epicycles, deferents, and equants: the legacy of Ptolemy

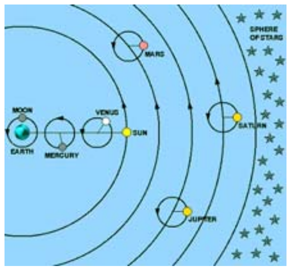




Epicycle reproduced planetary retrograde motion

Ptolemy's universe

- In 'final' form
  - 40 epicycles and deferents
  - Equants and eccentrics for sun, moon, and planets.
  - Provided detailed planetary positions for 1500 years
  - Very complex!
  - However good for what was needed, navigation.



More detailed observations, + some philosophy (Copernicus)

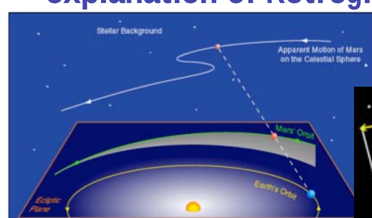
- Ptolemy's system worked, but seemed a little unwieldy, contrived.
- Required precise coordination of planetary paths to reproduce observations.
- Imperfect circular motion against Aristotle.
- Copernicus revived heliocentric (sun-centered) universe

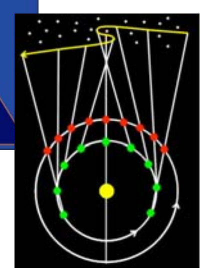
1473-1543

The heliocentric universe

- Sun-centered
- Planets orbiting around sun.
- Theory didn't perfectly predict planetary motion. Only discovered later.
- But the (imperfect) theory is attractive in several ways.

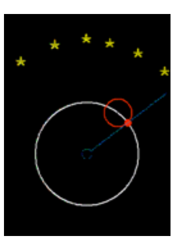
Advantage: "Natural" explanation of Retrograde motion



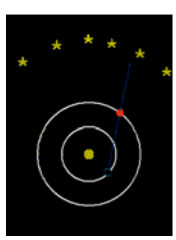


Retrograde motion observed as planets pass each other.

Comparing Ptolemy and Copernicus



Ptolemy's Earth-centered



Copernicus sun-centered

Which is the better theory?

How can we tell if it is 'correct'?

Both explained contemporaneous observations.

But a rotating and revolving Earth seemed absurd!

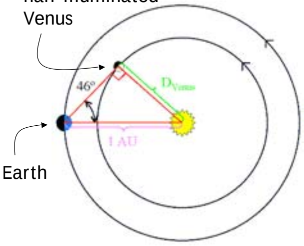
Both motions require incredibly large speeds:
Speed of rotation ~ 1280 km/hour
Orbital Speed: 107,000 km/hr = 30 km/sec!

No observational evidence of orbital motion:
Relative positions of stars did not shift with Earth's motion (parallax)
Stars weren't brighter when Earth is closer (opposition).

No observational evidence of rotation:
Daily motions are as easily explained by a fixed earth.
The motions do not require a rotating earth.

Advantage:
A 'good' theory makes predictions

Planet	Copernicus	Actual
Mercury	0.376	0.387
Venus	0.719	0.723
Earth	1.00	1.00
Mars	1.52	1.52
Jupiter	5.22	5.20
Saturn	9.17	9.54



But, at the time, these predictions could not be tested!

20 years of detailed observations (Tycho Brahe & Johannes Kepler)

- Brahe's exacting observations demanded some dramatic revisions in planetary motions.

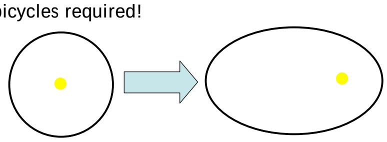
1546-1601

Both Ptolemy's and Copernicus' theories were hard-pressed at this detailed level.

Kepler's elliptical orbits

- Contribution of Kepler:
  - first consideration of non-circular orbits in over 1000 yrs of thinking.
  - No more epicycles required!

1571-1630



Detailed observations required a radical new concept for an explanation.

Some common threads

- 'Philosophical' considerations, such as complexity and symmetry, can lead to revolutionary developments.
- Thoughtful consideration of possibilities that at first seem outrageous
- But final evaluation based on comparison with detailed experimental measurements.
  More detailed observations test, and sometimes force changes to theories.

We will see this throughout the course:
In relativity, in quantum mechanics,
and in particle field theories.

An important difference

- 'Ancient' theories focused on description of motion, empirical laws, without answering 'why?'
- Symmetries were of shape and motion.
- Later developments focus on the **physical laws** that govern motion.
- The actual motion can be quite complex, but the physical laws demonstrate astounding simplicity, beauty, and symmetry.