Lecture 2

Scientific Knowledge: What does it mean? Example: Description of Motion

The big picture: our world view

What is Science?

What is knowledge? What do we know?

How can you tell if a theory is "scientific"?

Is science merely "conventions"?

?

Is the knowledge guaranteed by the method?

How do new scientific concepts arise? Case Study of Motion.

Announcements

- Homework 1
  Due Monday, September 8
- Today:
- World views
  - Purpose of creation of knowledge
  - Role of physics (and mathematics)
  - Aristotelian view vs. Galilean view
- Example in Physics: Description of motion
  - position, velocity, acceleration
- Example of motion: Falling Bodies
  - Demonstrations
  - Which view is better?

Central Concepts for Today

- World View:
  - How do we make sense of the world?
- Epistemology:
  - What do we know?
  - How do we know what we know is true?
  - What questions do we ask?
- Methodology:
  - How do we learn?
  - How do we answer questions?
- Science:
  - What distinguishes scientific knowledge?
  - How does science evolve? How has science evolved?
- Motion:
  - Space, Time

The Big Picture: World Views

- How we make sense of the world
- It is important to look at ancient times
  - What were world views?
  - We will not spend much time on them, but it is important to see that they made sense
- Help us understand our own times
  - In the last 1000 years there have been a complete revolution in our world views - article by Powers
  - In the last 100 years there have been complete revolutions in physics
- Major adjustments in our views of what constitutes the basic laws of nature
  - Laws that describe Nature often do not jive with our intuitive everyday experiences

The Role of Physics in the Big Picture

Physics is the study of the basic phenomena of of the natural world

- Of all the sciences:
  - It is the one most amenable to formulation of simple, direct questions
  - that can be answered by careful study of nature
- For example, only very recently has biology begun to reach such a point
- Example in Physics
  - Description of motion of bodies in space and time

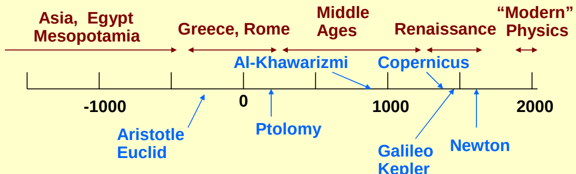
Why is this the "Big Picture"? A brief taste

- " 'It struck me that the more we learn about the changes in human life after the 16th century' – when most scholars mark the onset of the modern world – 'the clearer it becomes that [the change] was unprecedented and radical' "
- "People began to value institutions such as private property, to question religion's public role, and to adapt a Newtonian, scientific world view"
- Viewed as regression by some - a spiritual loss (Nietsche) – unleashing of unstainable capitalism (Marx) …
- Unquestionably an enormous effect on our lives

Robert Pipin, The University of Chicago Magazine, August, 2003

Lecture 2

Timeline



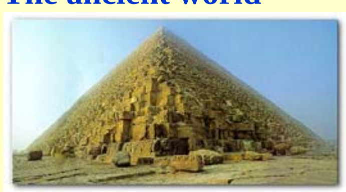
- The ideas of classical Greece dominated Western thought for centuries
  - Aristotle defined physics!
- Islamic Culture preserved Greek hertitage --- originated "Hindu-Arabic numerals", Algebra, ...
- The Renaissance of intellectual thought in Europe:
  - Fibanacci, Copernicus, Galileo, ….
- (See Timeline descriptions on WWW pages)

The ancient world

- Mesopotamia (now Iraq)
  - "Fertile crescent"
  - Birthplace of civilization
  - Settled agriculture
  - From at least 10,000 BC
  - First written language ~3,000 BC
- Well-developed mathematics & Astronomy
  - Weights and measures standardized in Babylon in 2500 BC
  - Measured positions of planets & Stars
- Great civilization until it was conquered by Alexander the Great around 330 BC.

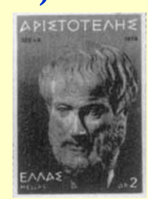
The ancient world

- Egypt



- One of the greatest civilizations
  - Rather static for thousands of years
  - From at least 5,000 BC
- Well-developed mathematics & Astronomy
  - Used for practical purposes
    - Great feats of engineering
    - Predicting the floods of the Nile River

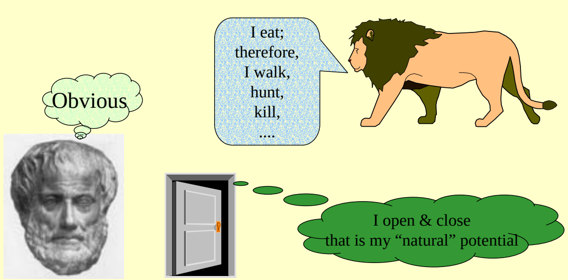
Aristotle (384-322 BC)



- Student of Plato (427 - 347)
- Aristotle was noted for his works on Logic, Metaphysics, Ethics, Politics, ….
- Alexander the Great was his student!
- Webster's Dictionary
  - Aristotelian: A person characterized by empirical or practical thinking
  - Platonist: A person characterized by idealistic or visionary thinking
- Aristotle's Physics
  - Characterized by observation and empirical reasoning
  - But more deeply Aristotle believed in "Metaphysics" as the ultimate cause for everything observed
  - "Teleology" - Belief in "ultimate cause" at a deeper level than what one perceives (see March p 6)

Teleology

- The idea that everything has a purpose – a "final cause"



Aristotle's description of motion

- Motion belongs in the heavens
  - Stars keep circling in assigned routes.
- "Stasis" belongs on Earth
  - Things on Earth come to rest.
  - Motion is an imperfection, or a path to removing an imperfect placement.
- Aristotle's views held sway for more than 1000 years
  - Until the Renaissance & Galileo

Lecture 2

Stassis on Earth – Motion in the heavens

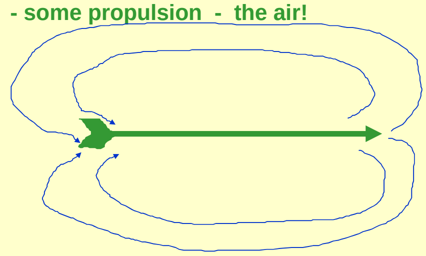
- What could be more natural!

My purpose is to rest

My purpose is to move

The Motion Problem

- Aristotle' description of motion:
  A contest between propulsion and resistance
- Why does an arrow keep moving? At least for a while.
  - Aristotle: There must be a cause for the motion - some propulsion - the air!



Is Aristotle right?

- Observations
- The earth appears to be at rest
  - Obvious
- "Stasis" belongs on Earth
  - Things on Earth come to rest.
- Motion belongs in the heavens
  - Heavenly bodies appear to be in eternal motion

Is Aristotle right?

- How does one define "right"?
- Are observations "right"?
  - Do you know anything on earth that keeps going indefinitely without some "cause"? Demos: Examples of motion.
  - Evidence that the earth is not at rest?
  - Do you know a heavenly bodies that is not in "eternal motion"?
- Are the methology, epistemology "right"?
- Teleology?

Is it essential to the observations?

The Big Picture: World Views

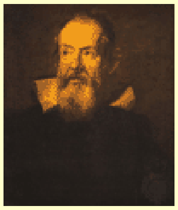
- The "Renaissance" was a rebirth
  - Rediscovery of ideas from ancient Greece
  - Preserved by the Moslem world
- Introduction of Arabic Numerals, Algebra
  - Introduced to Europe in the Renaissance
  - Essential for the next steps in science
- Revolutions in Science
  - Way of understanding the world
  - Physics has a central role
- Galileo was one of the key players
  - Development of the new ideas of experimental science
  - Active study of nature to discover the underlying laws

Mathematics and Physics (Science)

- Euclid (Alexandria, c. 300 BC)
  - Laws of Geometry
  - Euclidian Space - 3 dimensions - obeys laws such as: sum of angles in triangle = 180°
- Al Khawarizmi (Bagdad, 780-850 AD)
  - Arabic numerals, Algebra
  - Built upon older Hindu-Arabic work
- Fibanacci (Pisa, c. 1170-1240)
  - Important in introducing Arabic numerals in Europe (which was then very backward!)
  - Many advances in "pure" mathematics

Lecture 2

Galileo Galilei (1564-1642)



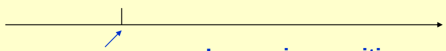
- Mathematician, physicist, astronomer
  - 1589: lecturer of mathematics at Pisa
  - 1591: professor of mathematics at Padua for 18 yrs
- Galileo realized that mathematics could provide the key to formulations (and reformulations) of concepts and laws to make clear, experimentally testable statements
- “The book of nature is written in mathematical characters”, Galileo in “The Assayer”
- More about Galileo later !

Galileo & Physics

- Galileo’s Approach:
  - Use observation (like Aristotle)
  - In addition, Galileo saw the need for controlled experiments to search for simpler descriptions (like the Platonic ideals) behind the complicated details
- Dialogue on Two New Sciences published in 1636 concerning laws of motion.
- The Problem: Describe the motion of freely falling bodies toward the Earth. Contrast with the predictions of Aristotle and his followers

Speed and Velocity

For motion along a line



Reference position   Increasing position ⟶

Velocity = $\frac{\text{Change in position}}{\text{Elapsed time}}$ = slope of position vs time

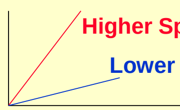
- Velocity can be positive (increasing position with time) or negative (decreasing)
- Speed = magnitude of velocity (always positive)
- Velocity = speed and direction

Quantitative Description of Motion

Consider motion along a line

Speed = $\frac{\text{Distance moved}}{\text{Elapsed time}}$ = slope of distance vs time

Constant Speed



Typical Speeds in Aristotle’s and Galileo’s Times

- There was not a great range of readily observed speeds or velocities
- Rough estimates given below:

Object	Distance Moved	Time Elapsed	Average Speed	Speed in m/s
sprinter	100 m	10 s	10 m/s	10 m/s
arrow	50 m	~1.5 s	~33.3 m/s	~33.3 m/s
ship	100 km	12 hr	8.25 km/hr	2.29 m/s
Sound in air	300 m	~1 s	~100 m/s	~ 300 m/s
snail	10 cm	1 min	10 cm/min	0.00167 = 1.67×10^{-3} m/s

Typical Speeds familiar to us

Object	Distance Moved	Time Elapsed	Average Speed	Speed in m/s
Auto	60 mi	1 hr	60 mi/hr	26.7 m/s
Jet Plane	500 mi	1 hr	500 mi/hr	220 m/s
Earth satellite	40,000 km	90 min	$2.67\times10^{+4}$ km/hr	7,400 m/s = 0.74×10^{4} m/s
Sound in dry air	340 m	1 s	340 m/s	340 m/s
Bullet				~400 m/s
Continental drift	1 cm	1000 yr		~3.2×10^{-12} m/s (1yr ~3.2×10^{7}s)
Electron in TV tube				3.0×10^{7} m/s
Light in vacuum				3.0×10^{8} m/s

- (Nothing can go faster than the speed of light --- as we discuss later)

Lecture 2

Is Mathematics Really Important?

- Yes!
  - Laws of Geometry formulated during the classical age of Greece
  - But many concepts were totally unknown before the middle ages
- Without the decimal system and algebra where would we be?
  - The key concept is "zero"
- Try computing speed in Roman numerals!

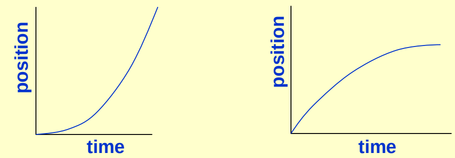
$$\text{Speed of ship} = \frac{100\ \text{km}}{12\ \text{hr}} = \frac{\text{C} \times \text{M}\ \ \text{m}}{\text{XII} \times \text{MMM}\ \ \text{s}} = ????$$

Accelerated Motion

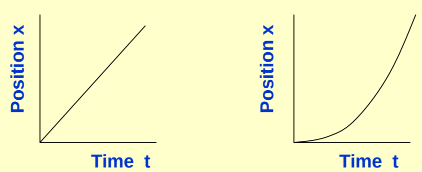
$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Elapsed time}}$$

Increasing velocity - positive acceleration

Decreasing velocity - negative acceleration



Constant velocity vs ConstantAcceleration



Constant velocity

$x = x_0 + v\ (t - t_0)$
or
$x = vt$

Constant acceleration

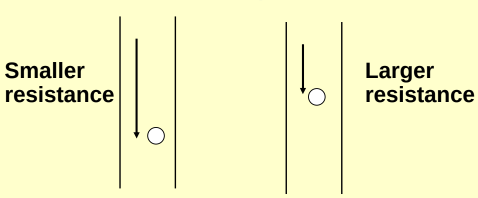
$x = x_0 + v_0\ (t - t_0) + 1/2\ a\ (t-t_0)^2$
or
$x = 1/2\ a\ t^2$

Motion of Falling Bodies

- Two Competing Descriptions:
  - Aristotle: Bodies falling in the same medium fall with speeds proportional to their weights.
  - Galileo: In a medium totally devoid of resistance, all bodies will fall at the same speed and during equal intervals of time receive equal increments of velocity.
  - The key to Galileo's advance was to propose a law that applies to an idealized situation (no resistance) and to test it by controlled experiments

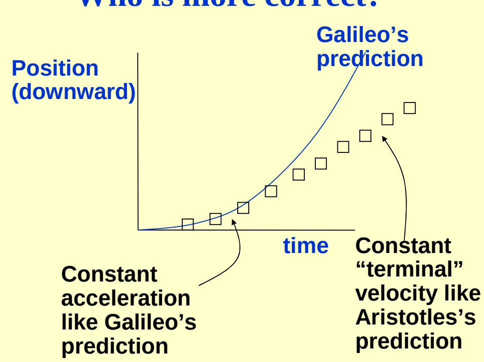
Demonstrations

- Falling bodies
  - When resistance is negligible
  - When resistance is important



- Clever ways Galileo found to argue the effects of resistance although he could not eliminate it completely

Actual Measurements of Real Bodies Who is more correct?



Exercise discussion

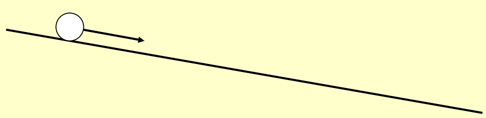
- Who is more nearly correct? For Real bodies:
- Two Competing Descriptions:
  - Aristotle: Bodies falling in the same medium fall with speeds proportional to their weights.
  - Galileo: All bodies will fall at the same speed and during equal intervals of time receive equal increments of velocity.

Exercise discussion - suggested answers

- Neither is completely correct for real bodies
- Galileo created simple laws that could be tested (Aristotle would have been happy) and he proposed that creating laws to describe the idealized situation is the best way to view the problem
- Leads to deeper reasoning - as shown later by Newton
  - idea that one should look for some additional effect on motion due to resistance in real system

Demonstration - Ball on Incline

- Galileo argued that the ideal case of no resistance is the more important, even though he could not actually reach that limit
- For quantitative measurements to demonstrate his laws, Galileo used inclines to "slow down" the experiment and allow timing with clocks of his day

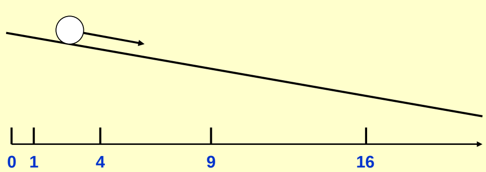


Rolling Ball on Incline

- Effects of resistance are made small by rolling
- Argue ball rolls down due to same cause as falling bodies. Reasonable? Obvious?
- Argue equations will be the same as for falling bodies (but reduced acceleration). Reasonable? Obvious?
- For constant acceleration, the total distance traveled from the start x increases as the square of the time t, $x = 1/2\ a\ t^2$. For equal intervals of time t, x increases in the ratios:
  1 : 4 : 9 : 16 : 25 : .....

Rolling Ball on Incline

- For equal intervals of time t, x increases in the ratios:
  1 : 4 : 9 : 16 : 25 : .....
- This can be restated as the distance traveled during each interval increases in the ratios:
  1 : 3 : 5 : 7 : 9 : .....



Methodology

- Inductive method
  - From the specific to the general.
  - Example: sun rises in east mon, tues, & wed
    predict: sun will rise in east thursday
  - Used by Aristotle to develop knowledge of physics
  - Importance in science - see e.g., Sir Francis Bacon (1561 - 1626)
- Deductive method
  - From the general to the specific.
  - Example: Physics 150 meets Mon & Wed
    Today is Wednesday
    Conclusion: Physics 150 meets today
  - Used by Plato to analyze questions
  - Importance in science - see e.g., Rene Descartes (1596 - 1650)

Lecture 2

Methodology of Experimental Science

- Combines Inductive and Deductive Reasoning
- From specific observations, the observer proposes general, universal laws.
- Carry out experiments (carefully chosen specific observations) to test the law.
  - If the law fails the experimental tests:
    - Look for reasons, aspects that may be correct or can be changed
  - If the law passes the experimental tests:
    - It is a possible general law
- Continue to test the law - look for exceptions

Summary

- World views
  - How do we make sense of the world?
    - Affects all asoects of our lives
  - Role of physics - the study of the natural world
  - Aristotelian view: Teleology - to find the ultimate purpose of each thing; Empiricism - describe world by generalizations from observations
  - Galilean view: Experimental Science - To describe the natural world by a set of mathematical laws that can be tested by careful experiments
    - The beginning of a revolution
- The physics of motion
  - position, velocity, acceleration
- Example of Falling Bodies
  - Demonstrations
  - In the real world neither Galileo nor Aristotle is right!
  - Then is one better?

Next Time

- Description of motion continued
  - Demonstration of falling bodies, projectiles
  - Don't miss "Shoot the Monkey" !
- Toward a Science of Mechanics
  - Principle of Inertia
  - Superposition Principle
- Reading
  - March, Chapter 2
- Homework
  - Homework 1 due Mon. September 8
  - If you have trouble, please ask! We do not want to make stumbling blocks