Lecture 3

Toward a Science of Mechanics Galileo

Falling bodies

Projectile motion

Principle of Inertia

Principle of Superposition

Inquisition!

Dialogues

Who are we?

From questionnaires first class – incomplete

- Freshpersons 6
- Sophomores 8
- Juniors 3
- Seniors 1

- Majors:
  - Accounting
  - Advertising
  - Architecture
  - Business
  - Economics
  - English
  - General
  - History
  - Journalism
  - Linguistics
  - Marketing
  - Mechanical Engineering
  - Music Performance
  - Political Science – Pre-Law
  - Undecided

Announcements

- Homework 1 due today
  - Hand in in class
- Homework 2
  - Homework 2 given out today, Due Wed., Sept. 17
  - Essay questions
  - Problems on astronomy, Newton's Laws
- At end of class today
  - Getting ready for the next class - what we see in the sky - the heavenly bodies
  - Mars!

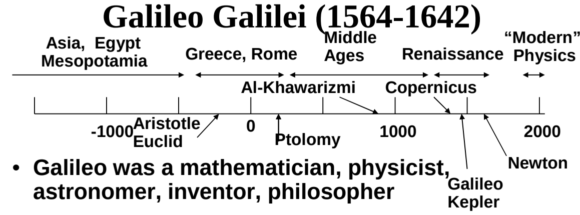
Today Galileo - from Projectiles to Principles

- Motion of bodies with constant acceleration a
- Freely Falling Bodies:
  - a = 9.8 m/s^2 in vertical direction
  - We can approximate as a = 10 m/s^2
- Projectiles - Motion in 2 dimension
  - Demonstrations
- Galileo's principles –
  - Principle of inertia
  - Principle of superposition
- Foundations for Newton's laws

The Big Picture: World Views

- How does a mundane topic like "falling bodies" lead to important parts of a "world view"?
- In the hands of Galileo what emerges are "universal principles" that affect how we think about our place in nature
- Does the earth move?
  Is the earth at the center?
  (Continued next time)

Galileo Galilei (1564-1642)



- Galileo was a mathematician, physicist, astronomer, inventor, philosopher
- Last time:
  - We emphasized Galileo as a mathematician who formulated concepts and laws to make clear, experimentally-testable statements
- Today:
  - We emphasize Galileo's insight and boldness to propose the laws as universal principles that are the foundations for further developments physics
- Still more about Galileo later !

Lecture 3

Historical setting – Middle Ages

- **Selected Events**
  (http://eawc.evansville.edu/chronology)
  - **768 Carolus Magnus (Charlemagne) succeeds his father**
  - **824 Charlemagne dies – no successor**
  - **850-1039 – Al Khawarizimi, Ibn, Sina, Ibn Al-Haitham**
  - **1050-1220 Agricultural advances - Europe prospers**
  - **1066 – William the Conqueror invades England**
  - **1095 – First Crusade**
  - **1168 - English scientist Robert Grosseteste translates Aristotle's *Ethics* - makes advances in optics, math, astronomy**
  - **1212 - Spain reconquers Iberian peninsula from the Muslims in the name of Christianity**
  - **1225-1274 - Thomas Aquinas, the most influential scholastic theologian**
  - **1244 - Jerusalem is lost by the West (not recaptured until 1917)**
  - **1337-1453 - Hundred Years' War (1430 – Joan of Arc burned)**
  - **1453 - Ottoman Turks take Constantinople - end Byzantine civilization**

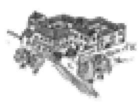
The Renaissance & Reformation (~1400-1600)

- **Selected Events**
  (http://vschool.houstonisd.org/orientation/timeline.htm)
  - **1434 - Cosimo de' Medici establishes rule in Florence**
  - **1454 - Gutenberg Bible - Printing Press**
  - **1483 - 1546 - Martin Luther**
  - **1492 - Columbus sails to new world**
  - **1495-1497 - Leonardo da Vinci paints The Last Supper**
  - **1501-1504 - Michelangelo sculpts statue of David**
  - **1503 - Leonardo da Vinci paints Mona Lisa**
  - **1508-1512 - Michelangelo paints ceiling of Sistine Chapel**
  - **1509- 1564 - John Calvin**
  - **1517 - Luther posts his 95 Theses in Wittenberg**
  - **1564 - 1616 Shakespeare**
  - **1564 – 1642 – Galileo Galilei**
  - **1584 - Sir Walter Raleigh founds first English colony in Virginia**

Galileo Galilei

was born near Pisa in February 15, 1564 -- **the same year in which Shakespeare was born and the year in which Michelangelo and Calvin died.**

After studying at the University of Pisa (he enrolled as a medical student), Galileo was appointed to the chair of mathematics (at 25).. Actually he never finished his degree, but he was recognized as being extremely talented in mathematics.

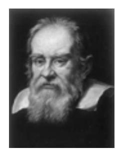


At 28 years old he moved to Padua (150,000 people), in the Venetian Republic (until he was 46). This was an extremely active and exciting city, and he was one of the main participants in this intellectual and social activity. A good friend of his in Padua was Sagredo, a Venetian wealthy nobleman, who appears later in his famous book "Dialogue Concerning the "*Two World Systems*" and "*The Two Sciences*".

With his mistress, Marina [Gamba] of Venice, who he met in Padua, he had two daughters and a son. There is a recent book with the letters and history of one of his daughters, *Maria Celeste*, who became a nun in a convent. He was very attached to her, and they had a very close correspondence. See *Galileo's Daughter*, by Dava Sobel. Very interesting material can be found in these letters, and book.

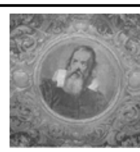
Maria Celeste

Galileo Galilei

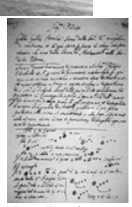


1581	Constancy of period of pendulum
1589	Showed that objects fall at the same rate independent of mass
1592	Suggests that physical laws of the heavens are the same as those on Earth
1592	Primitive thermometer
1600	Study of sound and vibrating strings
1604	distance for falling object increases as square of time
1609	builds a telescope
1610	Observes the phases of Venus
1610	Observes moons of Jupiter
1610	Observes craters on the moon
1610	Observes stars in the Milky Way
1610	Observes structures around Saturn
1612	Hydrostatics
1613	Principle of inertia
1624	Theory of tides
1632	Galilean relativity
1632	Support for Copernicus' heliocentric theory
1638	Motion and friction

This is the chair from which Galileo gave his lectures



Lectures are not what they used to be



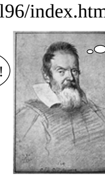
Script where Galileo talked about the satellites of Jupiter

Read about it here

http://es.rice.edu/ES/humsoc/Galileo/Student_Work/Trial96/index.html

The earth does move!

Woops!

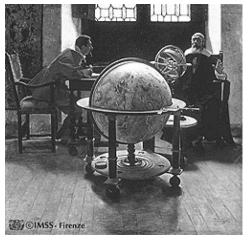


I think we will stick to other things

Retraction!

http://www.its.caltech.edu/~newman/sci-cp/sci-9211.html

Lecture 3



Galileo and Viviani

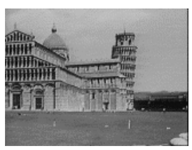
Nineteenth century. Tito Lessi.

This painting depicts the aged Galileo with Vincenzo Viviani, his last disciple. In 1639, when he was seventeen years old, Viviani went to stay with Galileo whom he worked with until the death of the great scientist in 1642.

Grave where Galileo is buried in **Santa Croce Church** in Florence, Italy

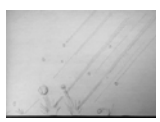
Monument at Galileo's Tomb

The remains of Galileo were moved to this spot on 12 March 1737, the date on which the index finger of his right hand was removed.



Did Galileo ever **perform** his famous **experiment** on the leaning tower? Probably not; anyway a similar experiment-demonstration had already been published by Benedetti Giambattista in 1553, and the test had also been made and published by the Flemish engineer Simon Stevin in 1586.

Galileo said he first thought about falling objects during a **hailstorm**, when he noticed that both large and small hailstones hit the ground at the same time. If Aristotle were right, this could only happen if the larger stones dropped from a higher point in the clouds -- but at virtually the same time -- or that the lighter ones started falling earlier than the heavier ones -- neither of which seemed very probable to Galileo. Instead, the simplest explanation was simply that heavy or light, **all hailstones fell simultaneously with the same speed**. We will now go over his experiments and theories.

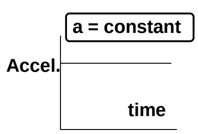


Demonstration

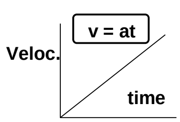
- **Falling bodies (Continued from last time)**
  - **When resistance is negligible**
  - **When resistance is important**
- **Galileo argued that the ideal case of no resistance is the more important, even though he could not actually reach that limit**
- **Today we can demonstrate "falling in a vacuum"**
- **The Penny vs. the Feather**

Equations for Constant Acceleration

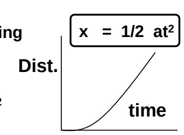
- **Acceleration:**
  - **Accel. = change in velocity per unit time**
  - $a = \Delta v / \Delta t$



- **Velocity:**
  - $\Delta v = a \Delta t$
  - **or** $v = v_0 + a (t - t_0)$



- **Distance:**
  - **more difficult, since velocity changing**
  - **distance = avg velocity × time**
  - **average velocity at time t =** $1/2\ at$
  - **So distance =** $x = (1/2\ at)\ t = 1/2\ at^2$



Exercise: Motion with constant acceleration

- **1. A car stops from 60 miles per hour, coming to rest in 6 seconds.**
- **What is the acceleration?**
- **What is the average velocity during this time?**
- **What is the distance required for the car to stop?**

•2. A car with constant acceleration goes from 0 to 40m/s in 100m.

•What is the average velocity?

•How long does it take the car to go 100m?

•What is the acceleration?

Lecture 3

Freely Falling Bodies

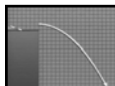
- Modern Statement:
- For freely falling bodies near the earth’s surface (the only place known to Galileo!), in the absence of resistance, all bodies fall with the same constant acceleration of
  9.81 meters per second per second
  or
  9.81 m/s^2 ~ 9.8 m/s^2
  downward
- It is useful to approximate this as 10.0 m/s^2

Exercise: Freely falling body

- A ball is thrown upward at 10m/s.
  - What is its speed?
  - What is its velocity?
- How long until it reaches the top?
  - (Neglect air resistance)
- How high does it go?
- How long until it returns to the starting point?
- What is its speed when it returns?
- What is its velocity when it returns?

Galileo & Physics of Motion

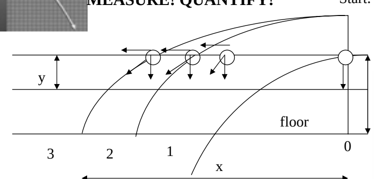
- Motion of falling bodies (vertical motion):
  - In a medium totally devoid of resistance, all bodies will fall at the same speed and during equal intervals of time receive equal increments of velocity - that is Constant Acceleration
  - Tests by controlled experiments
- Principle of inertia: An object moving on level surface (horizontal motion) will continue to move in the same direction at constant speed (that is constant velocity) unless it is disturbed.
- Principle of Superposition: If a body is subjected to two separate influences, each producing a characteristic type of motion, it responds to each without modifying its response to the other.

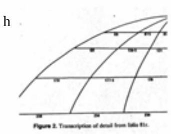


Projectile motion (parabolic path)

MEASURE! QUANTIFY!

Start: give an initial “x” velocity; no initial “y” velocity

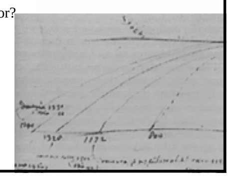




What is the path of the red balls ?

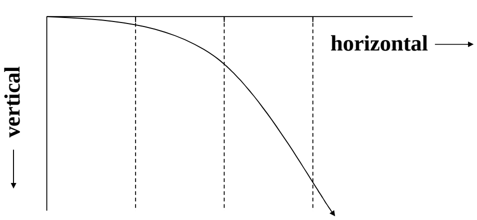
How long does it take the different balls to drop to the floor?

Here is a page from one of Galileo's manuscripts in which he writes down the figures he obtained in performing this experiment himself.



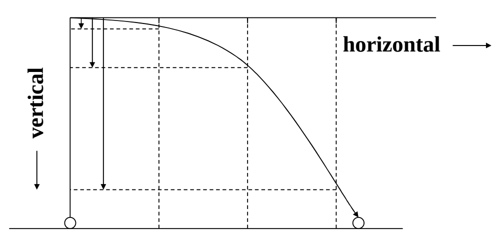
Trajectories

- Objects moving vertically and horizontally at the same time
- Separate motion into vertical and horizontal components
- Vertical: change of height varies as square of time
- Horizontal: equal displacement in equal times



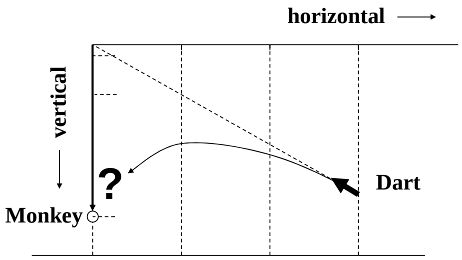
“Two Ball Drop” Demo

- One ball drops vertically
- One ball is projected with starting velocity that is horizontal
- Do the two balls hit the ground at the same time?



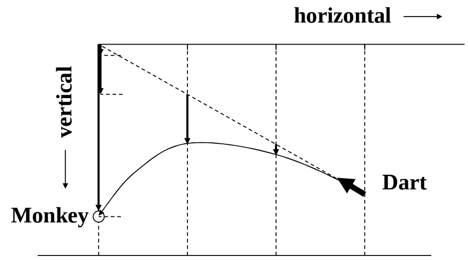
"Shoot the Monkey" Demo

- Stuffed Monkey drops just as dart is fired
- The dart is aimed exactly at the original position of the monkey
- Does the dart hit the Monkey?



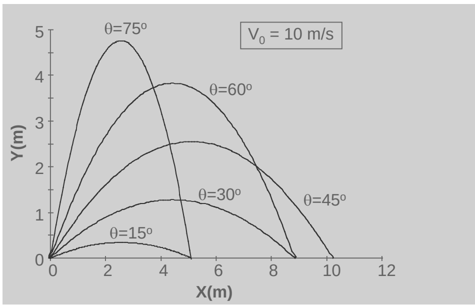
"Shoot the Monkey" Demo

- Stuffed Monkey drops just as dart is fired
- Does the dart hit the Monkey?
- Hint: Each Falls with same acceleration.



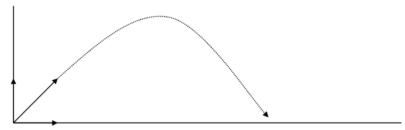
Trajectories

- Fix the initial speed of the projectile but vary the initial angle at which it is shot:



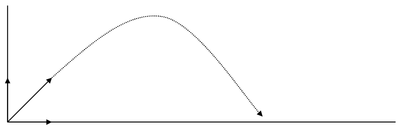
Path of Projectiles

- Assuming there is no resistance (friction) the motion of a projectile is always is in the shape of a parabola
- We will also return to this later
- What about real projectiles: baseballs, cannonballs, . . . ?
- Air resistance causes changed that are NOT described by simple equations!



Exercise on Projectiles

- A ball is thrown with upward velocity of 10m/s and horizontal velocity of 8 m/s.
- How long until it reaches the top?
  - (Neglect air resistance)
- How high does it go?
- How long until it returns to the starting height?
- How far does it go along the ground?



Toward a Science of Mechanics

- Galileo did more than just describe motion of projectiles. He used the ideas to build graet general principles:
- Principle of inertia: An object moving on level surface (horizontally) will continue to move in the same direction at constant speed (constant velocity) unless it is disturbed.
  - Explains motion – a revolution from Aristotle
  - (This becomes even more general in the hands of Newton.)
- Principle of Superposition: If a body is subjected to two separate influences, each producing a characteristic type of motion, it responds to each without modifying its response to the other.

Lecture 3

Galileo's Conclusions on Motion

- All bodies in motion continue in motion unless affected by something external
- Motion on earth slows down because something stops the object:
  Some obvious mechanism that stops the object
  Less obvious effects we now call friction

Galileo's Relativity

- Reasoning from principle of Superposition:
  All Motion is Relative
- No experiment inside a steadily moving ship will show that is is moving. Only by looking outside can one detect motion -- i.e., relative motion.
- Therefore there's no reason to expect to sense that the Earth is moving. There is no reason to say the earth is at rest!
- No reason to put the earth at the center of the universe!
- Profound consequences upon the world view --- for which Galileo was persecuted

Summary

- Mathematical description of motion of bodies with constant acceleration ***a***.
- Freely Falling Bodies:
  - Demonstration: Feather and Penny in vacuum
  - $a \sim 10\ m/s^2$ in vertical direction
- Projectiles - Motion in 2 dimensions
  - Demonstrations:
    Shoot The Monkey (Most famous demo in Physics?)
- Galileo's fundamental principles
  - Principle of inertia
  - Principle of superposition
  - Foundations for Newton's work later
- Profound consequences upon our world view
  - No reason for and earth-centered view
  - More about this next time!

Next Time

- Astronomy
  - Can one tell whether the earth turns or the stars revolve around the earth?
  - How did Greek scientists (around 300 BC) know the earth was spherical and measured its radius!
  - Is the sun at the center? Ptolomy vs. Copernicus
  - Kepler provides the first accurate description of the orbits of the planets
  - Galileo and the telescope - direct observation of orbits!
- Reading
  - March, Chapter 4; Read "Timeline " about related Scientists
  - Extra reading (Optional) for the interested in history of astronomy : Thomas Kuhn, "The Copernican Revolution"

Getting ready for next time

- You can observe Mars – imagine what an ancient person (society) would think
  - Look for Mars in the night sky before the next class
  - Mars is twice as close as the closest point last year
  - Four times as bright!
  - Easy to spot in the sky – bright even near an almost full moon
  - Before next time – think about this question:

    Is there a reason why Mars appears in the sky close to the moon when
    1) Mars is very bright and
    2) the moon is near full?