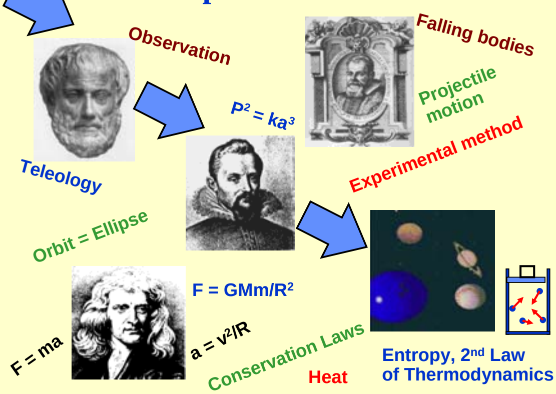
Development of Science



Announcements

- Today - Review before Exam I
  Homework 4 due
- Wednesday, October 1: Exam I
  Covers Chapters 1 - 5 of March; 1 – 2 of Lightman
  Development of science through classical physics
  (except electricity and magnetism and waves not covered)
- Monday, October 6: Solutions to exam;
  Continue Classical physics – Electromagnetism and electromagnetic waves

Nature of Exam

- Questions: True/false; multiple choice
- Problems: Work out numerical answer
- Essay questions: Give answer in short paragraph
- Equations are provided on cover sheet:

Nature of Exam

- Questions: Multiple choice; short written answers
- Problems: Work out numerical answer
- Essay questions: Give answer in short paragraphs
- Equations are provided on cover sheet:

Formulas used so far in the course:

$x = x_0 + vt$ $\quad v = v_0 + at$ $\quad x = x_0 + vt + \frac{1}{2}at^2$

$v_{av} = (x_f - x_i)/t$

$p = mv$

$F = ma$ $\quad a = v^2/r$ $\quad F = GMm/r^2$

$KE = \frac{1}{2}mv^2$ $\quad PE = mgh$

$P^2 = (\text{const})\,R^3$

Additional Information:
Force: 1 Newton (N) = Kg m/s^2; Energy: Joule (J) = N m; Power: Watt = J/s
Heat: 1 calorie = 4.184 J (We do NOT use the dietary unit Calorie (capital C) = 1000 calories)
If needed, you may use g = 10.0 m/s^2 or the more exact value 9.8 m/s^2.

Overview of course (from Lecture 1)

- To discover what science (physics) is about
  - Is it objective discovery of facts about nature?
  - Is it human invention of ways to describe what we see around us?
  - What are the great ideas of science (physics)?
  - How does science (physics) affect our world view?
- The approach we will take is to describe the conceptual structure of physics in a historical perspective (following the texts with additions)
  - How has physics evolved?
  - Revolutions in science – in human thought
  - How has it affected world views?

Role of Mathematics (various)

- The natural language of science is mathematics
  - The workings of nature appear to be described by simple laws
  - Mathematics allows laws to be written in succinct form
  - Mathematics allows the equations to be transformed to make bold conclusions and to make unambiguous tests of the laws
- Allows important applications to ordinary experience
  - Quantitative problems are an essential part of physics
  - In this course we consider simple but important example problems

Role of Physics in the "Big Picture"? A brief taste (from Lect. 2)

- " '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

Review -- 1

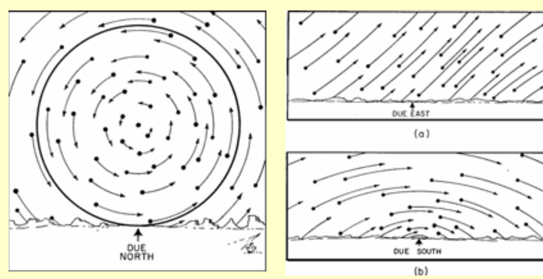
- What is Scientific Knowledge?
  - What questions are "scientific"
  - What statements are scientific? --- Examples
  - Feynman's answer: "The test of all [scientific] knowledge is experiment."
  - What are other types of knowledge? --- Examples
- How did our present definition come about?
  - What steps in history were particularly important?
  - Powers answer: "… no single idea has had a more profound or ubiquitous impact on what the human race has become, or what it has worked upon the face of the planet, than the vesting of authority in experiment."
  - When did this happen? What were other movements in human history that occurred in the same period(s)?
  - How did this happen? How did (does) science advance?

Review -- 2

- What have people observed in the sky since long before recorded history?
- Sun, Moon, Stars, Planets
- Ancient Observations - which are still useful!
- Ancient Cosmologies - facts or invention?
- Problem of the Planets (Wanderers)
- The strange motion of the planets exemplifies two competing world views
  - Each view appears to be the product of a deep human desire to "know"
  - Astrology treats the motion as somehow related to life on earth - leads to fortune telling, horoscopes, ….
  - Astronomy searches for explanations in simple laws - leads to new science

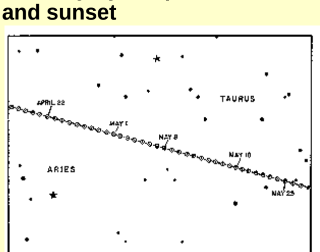
What do we observe in the sky?

- Sun, Moon, Stars in eternal, regular motion
- From a point in the Northern Hemisphere, the stars appear to move as shown:



Motion of Sun, Moon, Planets along the "Zodiac"

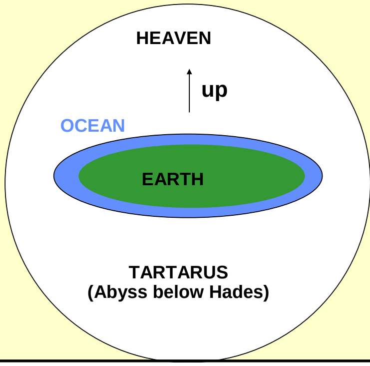
- Sun moves through the constellations
- Observe directly by the position of the stars at sunrise and sunset



Problem of the Planets

- The motion of each planet - Mercury, Venus, Mars, Jupiter & Saturn - follows a different path at a different speed along the "Zodiac"
- Their speed varies and sometimes they move backward!

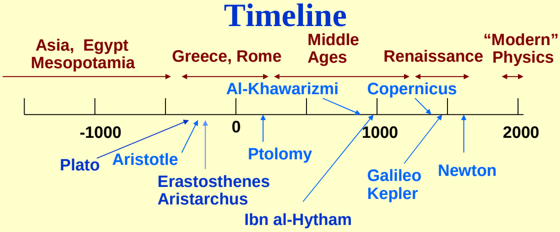
In the Beginning . . . Ancient Cosmology: Babylon, Egypt, ...



Review -- 3

- The development of Science
- Golden Age of Classical Greece Culture
  500BC - 200AD
- Dark Ages of Europe
  Golden Age of Islam
  200AD - 1300AD
- Renaissance
  1300's -- 1600's
- "Classical Physics" culminated in "experimental method", Newton's laws, conservation laws, 2nd law
  (and later Maxwell and others)
  1600's - 1800's.

Timeline



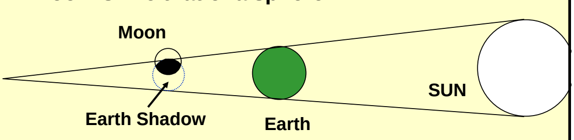
- See Timeline description of lives of various scientists on WWW pages.

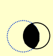
Review -- 4

- Great Advances in Science
  500 BC -- 200 AD
  - Accurate description of the motions of the sun, moon, stars. Essential for calendar.
  - Philosophy dominated by Plato and Aristotle
  - Plato believed in higher order, ideals
  - Aristotle was observational scientist – defined Physics (Natural Philosophy)
    - Ideas of Motion: Perfect perpetual motion in heavens; Natural state of rest for objects to earth
  - Evidence for spherical earth, moon, sun and measurements of their sizes and distances centuries B.C. ! (Erastosthenes, Aristarchus)
  - The only problems: The "planets"
    - Complex earth-centered models assuming motion described by circles (Ptolemy, around 150 AD)

What observations indicate that the earth is spherical?

- In a lunar eclipse, the shadow of the earth on the moon is like that of a sphere

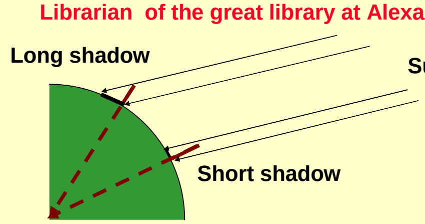




Appearance of Moon during eclipse

Measuring the earth Eratosthenes, 4th Cent. BC

Librarian of the great library at Alexandria

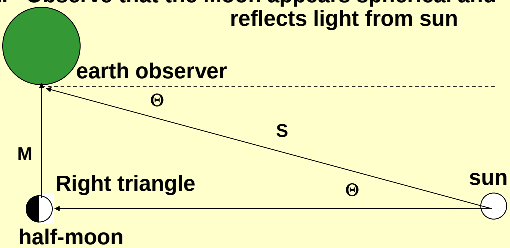


•Shadows depend upon
•North-South Location

By other measurements and geometry, Greek scientists found the distance to the moon and sun!

Amazing Discoveries and Measurements Ancient Greece

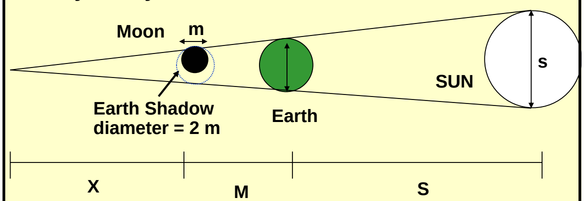
- 1. Observe that the Moon appears spherical and reflects light from sun



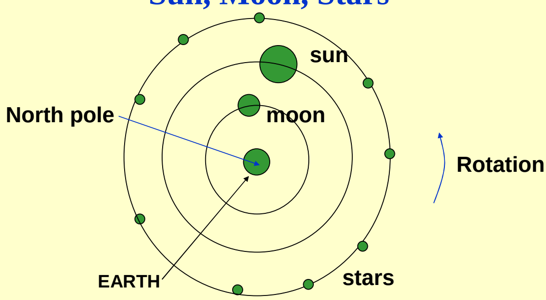
Dark side of moon blocks view of stars - showing it is a solid sphere.
Measured distanced to Moon and Sun!

How large is the Moon? How Far?

- (also due to Aristarchus)
- In a lunar eclipse, the time the moon is in the shadow of the earth depends on the moon's size & distance.
- Observation: At the moon the earth's shadow is very nearly twice the diameter of the moon



Earth Centered Model of Sun, Moon, Stars



Very Logical Picture! But no way to know distance to stars before time of Galileo.

Review -- 5

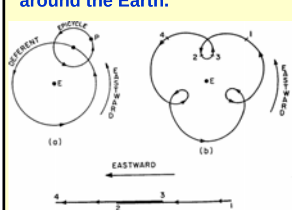
- Pre-Renaissance Science
  200AD - 1400AD
  - Physics dominated by Aristotle's thinking:
  - Perfect perpetual motion in heavens; tendency to come to rest for objects on earth
  - "Dark Ages" in Europe
  - "Golden Age" of Islam
  - Preserved heritage of Classic Greek Science
    Al-Khawarizmi, mathematician and astronomer whose major works introduced Hindu-Arabic numerals and the concepts of algebra into European mathematics.
  - Great scientists such as Ibn al-Haytham who discovered laws of optics (credited by Powers for the scientific method), and Ibn Sina who wrote great works on medicine and other fields

Alternative Pictures of the Universe: How to determine which is "correct"?

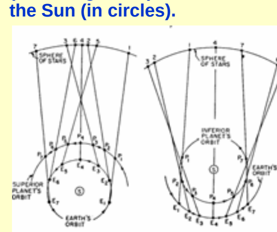
- Earth centered model (Ptolemy ca. 150AD)?
- Sun Centered Model (Aristarchus ca. 250 BC and Copernicus (1473-1543))
- Problem of the Planets - These tiny points of light moving in strange patterns in the sky lead to new understanding of physics - the "Copernican Revolution"

Alternative Pictures: How to determine which is "correct"?

- Ptolemy (150AD):
  Planets move on circles (epicycles) centered on another circle (deferent) which moves uniformly around the Earth.



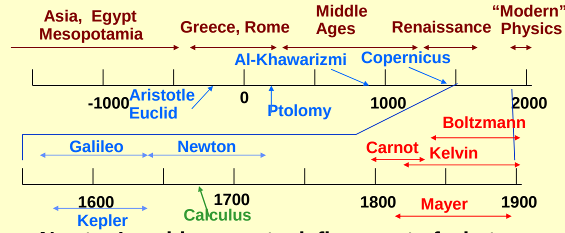
- Aristarchus (c 250 BC)
  Copernicus (1473-1543)
  Sun is the center of the universe. All planets (including Earth) move about the Sun (in circles).



Review of Course -- 6

- Early Renaissance
- Copernicus: sun-centered system (early 1500's)
- Brahe: Accurate measurements of positions of planets (late 1500's)
- Kepler: Uses Brahe's data - Kepler provides first accurate description of the motions of motion of planets (1609)
  - Planets move in elipses with sun at one focus
  - Kepler's three Laws for planetary motion
- The earth is just another planet moving around the sun! Profound impact upon our view of the universe!

Development of Classical Physics



- Newton's achievements define most of what we know as classical physics
  - The fundamental underpinnnings of the inventions and changes of the industrial revolution
  - The deterministic world view of the "Modern History" starting around 1600
- Conservation Laws, heat, 2nd law

Review of Course -- 7

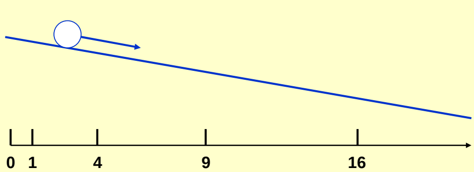
- Renaissance
- Galileo: Key figure of the scientific revolution that culminates with Newton
  - Experimental Method: Not just observation, but controlled experiments to test principles designed to apply in idealized cases
  - Motion of falling bodies, projectiles
  - Principle of superposition: (Galilean Invariance: Motion at a constant velocity does not change the laws of physics)
  - Principle of Inertia: (A body in motion will tend to stay in motion.)
  - Astronomical observation using telescope starting 1609 - 1610
    - Moons of Jupiter, …

Galileo and Falling Bodies

- Galileo Proposed that all freely falling bodies fall with the same acceleration independent of their mass
- Using mathematics he showed this leads to expression $x = 1/2\ g\ t^2$
  - Difficult to test in Galileo's time
  - One of his brilliant ideas: Rolling on an incline is like "gravity slowed down"
  - But is this true? Does it really test the law that all bodies fall with the same acceleration?

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 : …..



Galileo Continued

- But the real contribution of Galileo were the general principles
  - Experimental Method: Not just observation, but controlled experiments to test principles designed to apply in idealized cases. Still the basic of the scientific method.
  - Principle of superposition: (Galilean Invariance: Motion at a constant velocity does not change the laws of physics) Fundamental consequence that there is no need to think of the earth at rest.
  - Principle of Inertia: (A body in motion will tend to stay in motion.) Same as Newton's first law.

Review of Course -- 8

- Newton put it together – his ideas led to what we call “Classical Physics”
- Newton formulated the laws that describe motion in terms of forces and masses
  - Newton born the year Galileo died (1642)
  - Three Laws
    - 1. Inertia: A body keeps moving in straight line unless a force acts on it
    - 2. F = ma
    - 3. Action/Reaction - equal and opposite forces
  - Key new ingredient: force

Newton’s Laws continued

- Key ingredient is forces - must be specified
  - Examples: Falling bodies (F = mg) due to gravity; Circular motion (a = v^2/R) implies a centripetal force
  - Universal Law of Gravity (F = G Mm/R^2)
  - Apple, Moon, Planets obey the same laws!
  - Derived Kepler's laws from more fundamental principles.
  - Unites the motion of earthly and heavenly bodies. Profound impact upon our view of the universe!

Review of Course -- 9

- Conservation Laws - Most compact, powerful laws of physics
- Conservation of total momentum (vector)
  - Isolated system (no outside forces) has conserved momentum magnitude and direction
- Conservation of energy -- a holistic principle involving many types of energy
  - 1^{st} Law of Thermodynamics
  - Types of energy:
    - kinetic energy (motion) KE = (1/2)mv^2
    - Potential energy that can be recovered (e.g., Gravity near earth: PE = mgh)
    - Heat , other, ….
    - Total energy conserved in isolated system
    - Work is the transfer of energy by forces and displacement (W = Fx cos(θ))

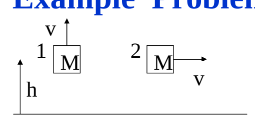
Review of Course -- 10

- 2nd Law of Thermodynamics
  - Very different in character from 1^{st} law
- In an ISOLATED system:
  - The system naturally evolves toward more probable configurations
  - The system evolves toward distributing its total energy equally among all its parts (conserving energy of course)
  - Heat flows from hotter to colder bodies
  - The system evolves toward decreasing order
  - The system evolves toward increasing entropy
  - The system’s ability to covert work into heat is always diminishing
- Conclusions:
  - The universe is winding down – heading toward “thermal death”
  - The universe had a beginning
  - The direction of time is determined by this inevitable, irreversible tendency
  - There is a maximum efficiency for any heat engine that depends only upon the input and output temperatures: $e = 1 – T_{out}/T_{in}$

Sample Discussion Questions

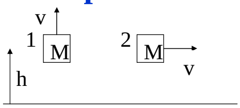
- Compare and Contrast Aristotle’s and Galileo’s scientific methods:
  - Give one difference
  - Give one similarity
  - Point out a case in which they tended to come to different answers
- Give an argument to convince someone that the earth rotates on its axis rather than the stars revolving around a fixed earth.

Example Problem



- Sketch the path of each object until it hits the ground.
- What principles does this problem illustrate?
  - Superposition of velocities
  - Principle of inertia
  - Newton's 1^{st} law; 2^{nd} law; 3^{rd} law
  - Law of gravity

Example Problem



- The (category) of object 1 is (blank) object 2.
  - for each category provided below, fill in the blank with (a) less than, (b) greater than, (c) equal to or (d) none of the above
    - gravitational potential energy at the start
    - kinetic energy at the start
    - total energy
    - acceleration
    - time in flight
    - final displacement (assuming the objects stop when they hit the ground)
    - final vertical displacement

Sample Problem

- **A mass of 3 kg is swung in a horizontal circle attached to a rope of length 2m.**
- **If the speed of the mass is 10 m/s, what is the acceleration?**
- **Force on the mass due to the rope?**
- **If the rope were twice as long and the mass completed a circle in the same amount of time, would the acceleration of the mass be larger, smaller, or the same.**
- **What law(s) or principle(s) does this problem illustrate?**

Universal Law of Gravitation

•Two equal masses M at a distance R act on each other with a gravitational attraction.

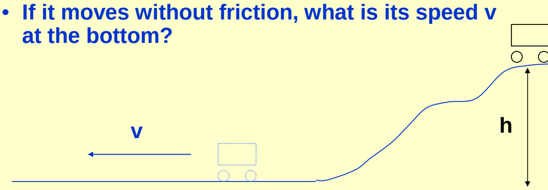
•If each mass is doubled, the force increases by (a factor of 2) (a factor of 4) (a factor of 1/2) (stays the same)

•If one mass is much larger than the other, the magnitude force on the larger mass is (the same) (larger) (smaller) than the force on the smaller mass

•If the two masses are free to move, they move toward each other. The acceleration of the larger mass is (the same) (larger) (smaller) than the that of the smaller mass

Example Problem

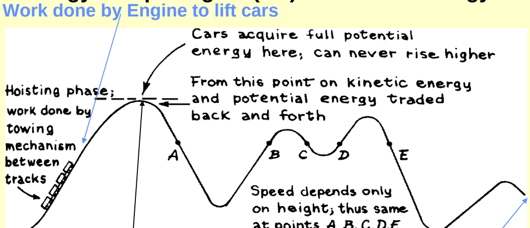
- **A toy car is released from rest at a height h = 2 m.**
- **If it moves without friction, what is its speed v at the bottom?**



What questions can you make for a Roller Coaster?

Energy at top = mgh + (1/2) mv² + Heat energy

Work done by Engine to lift cars



Potential energy largest = mgh

Kinetic energy largest = 1/2 mv²

Brakes convert remaining Kinetic energy to heat

Other Problems

- **Constant Acceleration**
  - **falling body**
  - **Automobile, ….**
- **Kepler's Laws**
- **Law of Inertia**
- **Action/Reaction**
- **Heat and effiicency of engines**
- **. . . .**

Impact of Science (Physics)

- Scientific Method (Galileo, Islamic Scientsists)
  - Find simple, general laws
  - Use mathematics to establish consequences of the laws
  - Carry out controlled experiments to test if the laws describe nature
- Classical Physics
  - Dominated by Newton's ideas
    - Three laws of motion; Law of Gravity
  - Provided ideas for models of the universe and all knowledge in 18^{th} - 19^{th} Centuries
- Enormous impact upon our "world view" - how we view the universe and our place in it