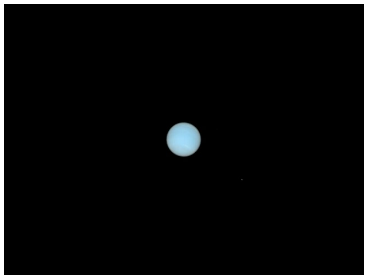
Physics 141.
Lecture 5.



Images from Hubble: Neptune's dynamic atmosphere and its satellites.

http://hubblesite.org/newscenter/newsdesk/archive/releases/2005/22/video/a

1

Physics 141.
Topics for today.

- Homework:
  - The solutions to homework set # 1 are available on the WEB (see previous email for details about how to access this password protected areas).
- Laboratory # 1: now what?
- Exam # 1.
- A quick quiz.
- Chapter 3: the gravitational force.

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Physics 141.
Course Information.

- Homework set # 2 is due on Friday 9/13 at noon.
- Homework set # 3 is due on Friday 9/27 at noon.
- Midterm Exam # 1 will take place on Thursday 9/17 between 8.00 am and 9.20 am in Hoyt. It will cover the material covered in Chapters 1 – 3 and error analysis.
- We will have a lecture on 9/17 at 9.40 am.
- I will review the material being covered on Exam # 1 on Thursday during lecture.
- Notes:
  - You need a number 2 pencil to complete the multiple-choice part of the exam.
  - You need to know your student ID #.
  - You do NOT need a calculator on the exam.
  - If you are late to start the exam, you will have less time to finish.

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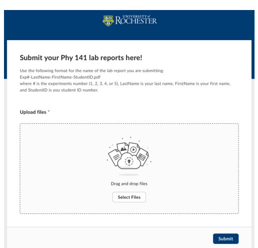
Physics 141.
Course Information.

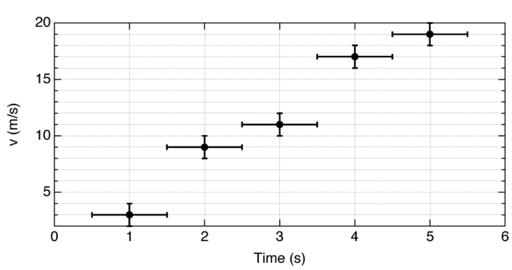
- Laboratories:
  - The laboratories are a required component of the course.
  - Lab # 1 took place on Monday in B&L 407. This lab focused on the measurement of the gravitational acceleration using two different techniques.
  - The Capstone software is available for data analysis. Use the links on our website to access the installers for MAC and Windows, and the details provided in an email to the list for the username and password.
  - B&L 407 will be open next week during regular lab hours if you need to redo part of a measurement or if you need help with data analysis and/or interpretation. One lab TI will be present at all times.
  - Lab reports are due next week on Friday at 12.00 pm. This lab report should include a detailed error analysis:
    - Never reject data because they do not match your expectations.
    - Determine whether you need to use normal or weighted averages when you want to combine several data sets.
    - Your lab report will not be better the closer your results match the known value of the gravitational acceleration.
  - Lab reports must be uploaded in pdf format to BOX. Details on the next slide.

Physics 141.
Course Information.

- Lab reports must be uploaded in pdf format to BOX:
  - https://rochester.app.box.com/f/4f55d401faa0499bafc9ae2f0580b98e
- Use the following format for the name of the lab report you are submitting:
  Exp#-LN-FM-StudentID.pdf
  where # is the experiment number (1, 2, 3, 4, or 5), LN is your last name, FN is your first name, and StudentID is you student ID number.
- Note: this information and the link are also available on the course information page.



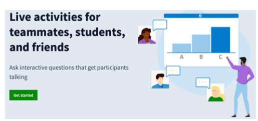
An introduction to scientific data analysis using real scientific tools (not Excel).



Useful Information for Exam # 1.

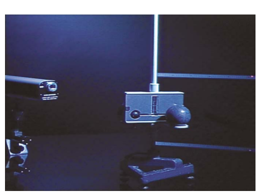
Quiz lecture 05.
PollEv.com/frankwolfs050

- The quiz today will have four questions.
- I will collect your answers electronically using the Poll Everywhere system.
- The answers for each question will be entered in sequence (first 30 s for question 1, followed by 30 s for question 2, etc.).



Applying the momentum principle.

- In order to apply the momentum principle, we need to know the details of interaction (magnitude and direction).
- In many interesting applications, we know the interaction because its properties have been studied in detail in the laboratory.
- A good example is the gravitational force. The general form of the gravitational force was proposed by Newton and sensitive experiments, such as the Cavendish experiment, can be used to measure the gravitational constant *G*.



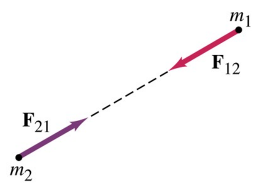
www.physicscurriculum.com/ Photos/Mechb1.JPG

The gravitational force.

- The gravitational force is given by the following relation:

  $$\vec{F}_{grav} = G\frac{m_1 m_2}{r_{12}^2}\hat{r}$$

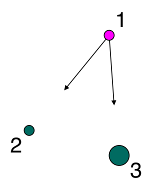
- The constant G is the gravitational constant which is measured to be 6.67 x 10^{-11} N m^2/kg^2.
- Note: the gravitational force does not depend on the momentum of the particles.



Applying the superposition principle.

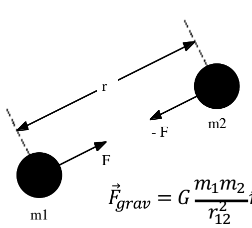
If several forces are acting on our object, we can use the **Superposition Principle** to determine the net force acting on our object:

The net force on an object is the vector sum of the individual force acting on it by other object. Each individual interaction is unaffected by the presence of other interacting objects.



The shell theorem.

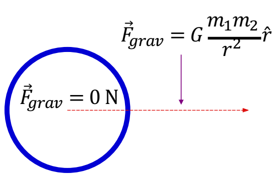
- The gravitational force law is only valid if the masses involved are point masses (mass located at a single point).
- In reality, we always are dealing with objects that are not point-like objects, but have their mass distributed over a non-zero volume.
- Using the principle of superposition you can show that the gravitational force exerted by or on a uniform sphere acts as if all the mass of the sphere is concentrated at its center.



$$\vec{F}_{grav} = G\frac{m_1 m_2}{r_{12}^2}\hat{r}$$

The shell theorem.

- Consider a shell of material of mass m_1 and radius R.
- In the region outside the shell, the gravitational force on a point mass m_2 will be identical to what it would have been if all the mass of the shell was located at its center.
- In the region inside the shell, the gravitational force on a point mass m_2 is equal to 0 N **(everywhere)**.



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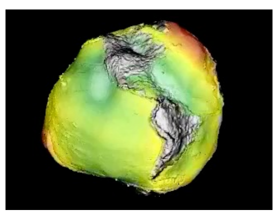
The gravitational force and the gravitational acceleration.

- Close to the surface of the earth, the gravitational force is equal to the product of the mass of the object and the gravitational acceleration g.

$$\vec{F}_{grav} = G\frac{M_E}{R^2}m\hat{r} = m\vec{g}$$

- By measuring $\vec{g}$ we can determine for example the mass of the earth (assuming we know G).



http://www.csr.utexas.edu/grace/

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Changes in the gravitational acceleration.

FINDINGS

Before the '04 Tsunami, an Earthquake So Violent It Even Shook Gravity

The giant earthquake that set off a devastating tsunami across the Indian Ocean in December 2004 disrupted the earth enough to change gravity and to deflect satellites passing hundreds of miles above.

Two identical satellites, collectively known as the Gravity Recovery and Climate Experiment, or Grace, travel one behind the other in a polar orbit separated by about 130 miles.

By recording small changes in the distance between them when their orbits are deflected, the satellites provide data used to calculate variations in the earth's gravitational field.

In a report in the current issue of the journal Science, scientists at Ohio State University and the University of California, Santa Barbara, report that in the aftermath of the magnitude 9.1 earthquake, the largest in four decades, Grace recorded a sudden drop in gravity near the quake's epicenter off Sumatra.

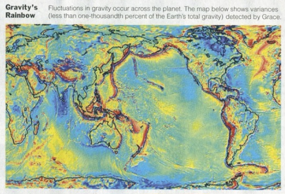
The rupture raised thousands of square miles of the seafloor, reducing the density of rocks in the earth's crust and diluting their gravitational pull. The data, combined with models of the earth's interior, indicate that the density changes extend hundreds of miles.

"It really gives an insight of the earth's interior down to the mantle area," said Shin-Chan Han, an Ohio State research scientist and an author of the Science paper. It was the first time that the gravitational effect of an earthquake had been observed.

The gravity at the earth's surface decreased by as much as about 0.0000015 percent, meaning that a 150-pound person would experience a weight loss of about one-25,000th of an ounce. In other places, where the force of the earthquake compressed rocks, gravity increased by a similar amount.

The force of gravity is changing in other areas of the earth, too. In Hudson Bay, Canada, which was crushed downward by the weight of ice during the last ice age, the ground is still rebounding upward. That change adds about one-400,000th of an ounce to the weight of a 150-pound person every year. KENNETH CHANG

Gravity's Rainbow Fluctuations in gravity occur across the planet. The map below shows variances (less than one-thousandth percent of the Earth's total gravity) detected by Grace.



New York Times, August 2006

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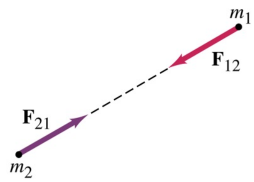
Implications of Newton's third law.

- The gravitational force comes in pairs: the force exerted by mass m_1 on mass m_2 has the same magnitude as the force exerted by mass m_2 on mass m_1, but it is pointing in the opposite direction (**Newton's Third Law**).
- This implies that the gravitational force you exert on the earth has the same magnitude as the gravitational force the earth exerts on you. Sounds weird?



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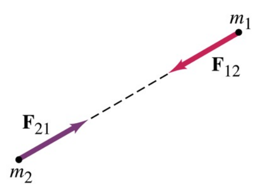
Implications of Newton's third law.

- The magnitude of the change in the linear momentum of mass m_1 is thus the same as the magnitude of the change in the linear momentum of mass m_2.
- But …… the change in the magnitude of the velocity of the two masses may be very different. For example, in the non-relativistic limit we expect that:

$$|\Delta\vec{v}_1| = \frac{m_2}{m_1}|\Delta\vec{v}_2|$$



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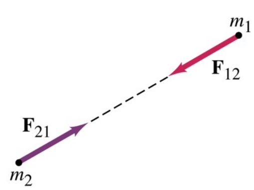
Implications of Newton's third law.

- If we consider the two masses together, the net force is zero.
- The momentum principle thus implies that there is no change in the linear momentum of the system:

$$\Delta\vec{p} = \vec{F}_{net}\Delta t$$

- Linear momentum is thus conserved if no external forces act on the system.
- Note: this applies to all possible forces (not just gravitational).



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2 Minute 39 Second Intermission

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 2 minute 39 second intermission.
- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Go asleep, as long as you wake up in 2 minutes and 39 seconds.

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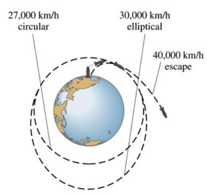
Orbital motion.

- Consider an object of mass *m* moving in a circular orbit of radius *r* around the earth.
- In order for this motion to be possible, a net force must be acting on this object with a magnitude of mv^2/r, directed towards the center of the earth.
- The only force that acts in this direction is the gravitational force and we must thus require that

$$G\frac{mM_{earth}}{r^2} = \frac{mv^2}{r} \quad \Rightarrow$$

$$v^2 = G\frac{M_{earth}}{r}$$



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Orbital motion.

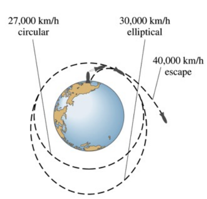
- The orbital velocity is related to the period of motion:

$$v = \frac{2\pi r}{T}$$

and the relation between *v* and *r* can be rewritten as a relation between *T* and *r*:

$$r^3 = G\frac{M_{earth}}{4\pi^2}T^2$$

- This relation shows that based on the orbital properties of the moon we can determine the mass of the earth.



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Orbital motion.

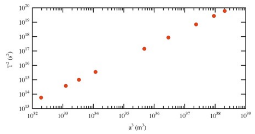
- The relation between orbit size and period can also be applied to our solar system and be used to determine the mass of the sun:

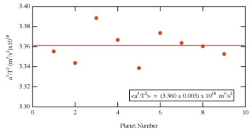
$$r^3 = G\frac{M_{sun}}{4\pi^2}T^2$$

- Using the orbital information of the planets in our solar system we find that

$$G\frac{M_{sun}}{4\pi^2} = (3.360 \pm 0.005)\times 10^{18}\ \mathrm{m}^3/\mathrm{s}^2$$

$$M_{sun} = (1.989 \pm 0.003)\times 10^{30}\ \mathrm{kg}$$





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Numerical studies.

- The properties of the circular orbit just discussed can be determined analytically.
- In order for a planet to carry out such a circular orbit, its velocity and position must be exactly right. Any small deviation from these perfect conditions will produce an elliptical orbit.
- The properties of these elliptical orbits are best studied numerically using tools such as VPython.

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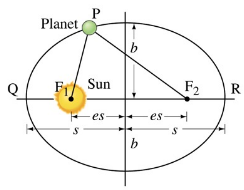
Planetary motion: Orbital shapes.

- Stable planetary motion does not require a perfect circular orbit.
- The shape of the orbit of a planet is described by an ellipse (note: a circle is a special type of ellipse). The ellipse is determined by specifying its semimajor axis s and its semiminor axis b.
- The foci of an ellipse are special points for which the sum of the distance F_1 to P and the distance F_2 to P is the same for every point on the ellipse.



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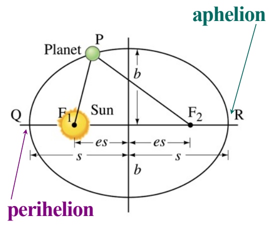
Planetary motion:
Kepler's first law.

- Note: for a circle $s = b$ and $F_1 = F_2$.
- The sun is located at one focus on the ellipse.
- The eccentricity e of the defined such that es is the distance from the center of the ellipse to either focus. Note: for a circle $e = 0$ m.
- The properties of the shape of the orbit of the planets and the location of the sun are part of what we call **Kepler's First Law**.



Frank L. H. Wolfs Department of Physics and Astronomy, University of Rochester, Lecture 05, Page 25

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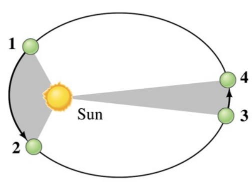
Kepler's second law.

- Kepler's Second Law states:

  "Each planet moves so that an imaginary line drawn from the Sun to the planet sweeps out equal areas in equal periods of time."

- Important consequences of Kepler's Second Law:
  - The velocity of the planet will increase the closer the planet is to the Sun (e.g. $v_{12} > v_{34}$).
  - The details of the orbit provide information about the mass of the sun.



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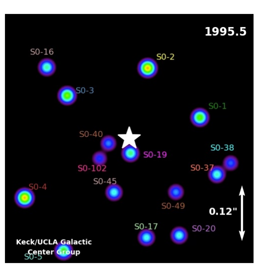
Kepler's second law.

- Kepler's Second Law can also be used to describe the motion of stars around black holes.
- The study of the motion of the nearby stars can be used to determine the mass of the black hole.
- A good example is the determination of the mass of the black hole at the center of our galaxy. Based on the motion of the star S2 we have determined that the mass of the black hole is 2,600,000 times the mass of the sun.



https://galacticcenter.astro.ucla.edu/animation.html

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Mass and weight. Two very different parameters.

- Before continuing, I want to make sure we do not confuse mass and weight:
  - **Mass** is an intrinsic property of an object. When we specify the mass of an object, we will always specify its mass when it is at rest. We know that the apparent mass of the object is velocity dependent (although this will only be noticeable at velocities close to the speed of light) and the apparent mass is thus not an intrinsic property of this object. The unit of mass is the kilogram (kg).
  - The **weight** of an object is a measure of the gravitational force acting on it. It is thus dependent on its location (e.g. the weight of an object will be smaller on the surface of the moon compared to its weight on the surface of the earth). The unit of weight is the Newton (N).

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Weightlessness. Do not get confused!

- One of the most confusing aspects of space travel is the concept of weightlessness. It appears as of the astronauts in the space station do not have any weight.
- Frequently people interpret this as implying the absence of the gravitational force.
- Certainly, this can not be the case since the gravitational force scales as $1/r^2$ and is thus not that different from the force we feel on the surface on the earth.

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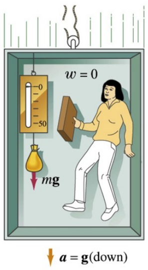
Weightlessness. Do not get confused!

- We experience apparent weightlessness anytime we fall with the same acceleration as our surroundings.
- Consider a falling elevator. Every object in the elevator will fall with the same acceleration, and the elevator will not need to exert any additional forces, such as the normal force, on those inside it.
- It appears as if the objects in the elevator are weightless (in reality, they of course are not).



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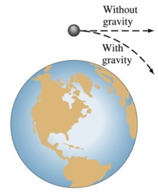
Weightlessness.
Do not get confused!

- Weightlessness in space is based on the same principle:
  - Both astronaut and spaceship "fall" with the same acceleration towards the earth.
  - Since both the astronaut and the spaceship fall in the same way (gravitational acceleration only depends on the mass of the earth, not on the mass of the spaceship or the astronaut) the astronaut appears to be weightless.



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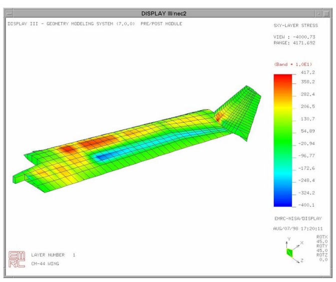
Enough stress for today!
Next week: start Chapter 4.



http://www.emrc.com/webpages/composite/comp_6.htm

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