Physics 121.
Lecture 07.

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Physics 121.
Lecture 07.

- Topics:
  - Course announcements.
  - Quiz
  - Gravitation:
    - The force of gravity
    - Motion of satellites
    - Dark matter

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When the wind speed is at least 30 mph …..

https://www.youtube.com/watch?v=VMinwf-kRlA

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Physics 121.
Course announcements.

- The solutions of homework set # 2 are now available on the web.
- Homework set # 3 is due on Saturday morning, February 14, at 8.30 am.
- The most effective way to work on the assignment is to tackle 1 or 2 problems a day.
- If you run into problems, please attend our office hours and/or ask questions during workshop. Do not wait until the last moment to try to resolve homework related issues.

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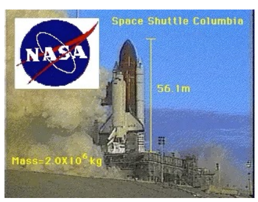
Preview of homework set # 4.

- On set # 4 you will be asked to carry out our first video analysis.
- You will study the launch of the space shuttle. The main question are:
  - what is the acceleration of the space shuttle?
  - what is the force generated by the engines?
- You will need to use loggerPro for this analysis. You can download the software from the Physics 121 website.



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Quiz.

- Let's practice what we learned (and read).

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Concept Test.

- Let's practice what we learned (and read).

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The gravitational force. It keeps us together.

- The motion of the planets of our solar system is completely governed by the gravitational force between the components of the solar system.
- The law of universal gravitation was developed by Newton based on simple observations of the motion of the moon around the earth.

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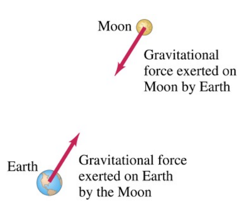
The gravitational force.

- The force of gravity is the weakest force we know …… but it is the main force responsible for the motion of the components of our solar system and beyond.
- This is a consequence of the fact that the gravitational force is always attractive. The other forces can be attractive, repulsive, or zero.



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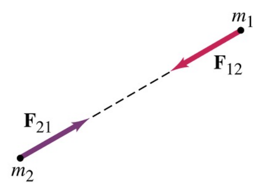
The gravitational force.

- The gravitational force has the following properties:
  - It is always attractive.
  - It is proportional to the product of the masses between which it acts (proportional to $m_1 m_2$).
  - It is inversely proportional to the square of the distance between the masses (proportional to $1/r_{12}^2$).
  - It is directed along the line connecting the two masses.

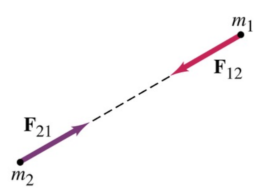


The gravitational force.

- The magnitude of the gravitational force is given by the following relation:

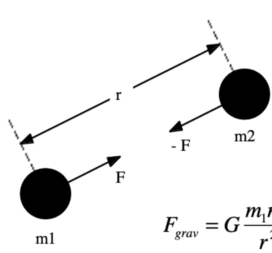
$$\vec{F}_{grav} = G\frac{m_1 m_2}{r^2}\hat{r}$$

- The constant G is the gravitational constant which is equal to 6.67×10^{-11} N m^2/kg^2.



The gravitational force.
The shell theorem (Appendix E).

- 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 object, 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.

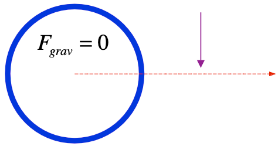


$$F_{grav} = G\frac{m_1 m_2}{r^2}$$

The gravitational force. The shell theorem (Appendix D).

- Consider a shell of material of mass m_1 and radius R.
- In the region outside the shell, the gravitational force 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.

$$F_{grav} = G\frac{m_1 m_2}{r^2}$$



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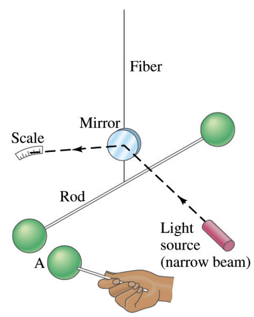
The gravitational force. Measuring G.

- The gravitational constant G can be measured using the Cavendish apparatus.
- The Cavendish apparatus relies on the attraction between small mass mounted on a rod and larger masses located nearby.
- Let's have a look at this experiment ……..



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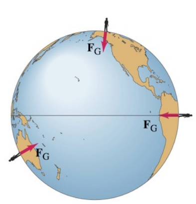
The gravitational force. The mass of the Earth.

- Using Newton's gravitational law and the measured gravitational acceleration on the surface of the earth, we can determine the mass of the earth:
  - $F_{grav} = GmM_{earth}/R_{earth}^2$
  - $F_{grav} = mg$
  - By combining these two expressions for the gravitational force we find that
    $M_{earth} = gR_{earth}^2/G$
    or
    $M_{earth} = 5.98 \times 10^{24}$ kg



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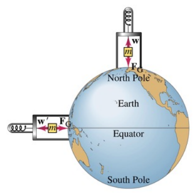
The gravitational force. Variations in the gravitational force.

- The gravitational force on the surface of the earth is not uniform for a number of reasons:
  - The effect of the rotation of the earth.
  - The earth is not a perfect sphere.
  - The mass is not distributed uniformly, and significant variations in density can be found (in fact using variations in the gravitational force is one way to discover oil fields).



3 Minute 1 Second Intermission

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 3 minute 1 second intermission.
- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Solve a WeBWork problem.
  - Go asleep, as long as you wake up in 3 minutes and 1 second.

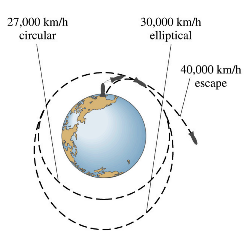
Orbital motion.

- 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

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

or

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



Orbital motion.

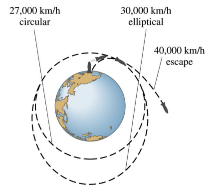
- The orbital velocity is related to the period of motion:

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

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

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

- 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 and weightlessness.

- One of the most confusing aspects of orbital motion is the concept of weightlessness.
- Frequently people interpret this as implying the absence of the gravitational force.
- Certainly, this can not 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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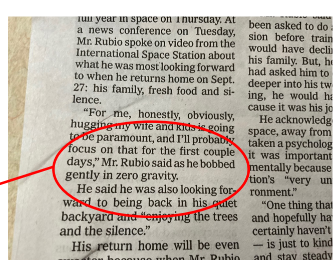
New York Times 9/21/2023.
I directed the author to lecture 5.


full year in space on Thursday. At a news conference on Tuesday, Mr. Rubio spoke on video from the International Space Station about what he was most looking forward to when he returns home on Sept. 27: his family, fresh food and silence.

"For me, honestly, obviously, hugging my wife and kids is going to be paramount, and I'll probably focus on that for the first couple days," Mr. Rubio said as he bobbed gently in zero gravity.

He said he was also looking forward to being back in his quiet backyard and "enjoying the trees and the silence."

His return home will be even

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tion's "very un
ronment."

"One thing that
and hopefully ha
certainly haven't
— is just to kind
and stay steady

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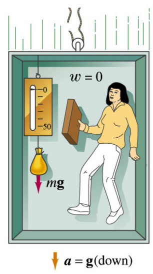
Orbital motion and weightlessness.

- 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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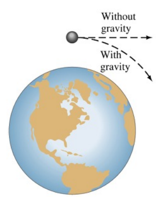
Orbital motion and weightlessness.

- Weightlessness in space is based on the same principle:
  - Both astronaut and spaceship "fall" with the same acceleration towards the earth.
  - Since both of them 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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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:

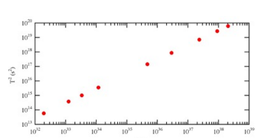
$$r^3 = GM_{sun}\frac{T^2}{4\pi^2}$$

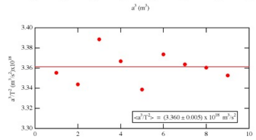
- Using the orbital information of the planets in our solar system we find that

$$\frac{GM_{sun}}{4\pi^2} = (3.360 \pm 0.005)\times 10^{18}\,\frac{\text{m}^3}{\text{s}^2}$$

or

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





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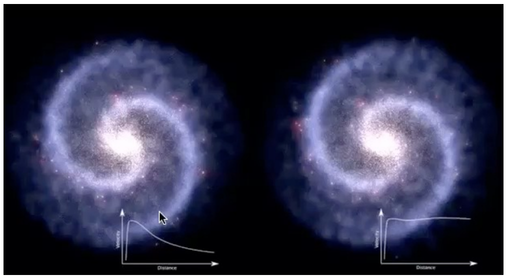
Rotation Curves



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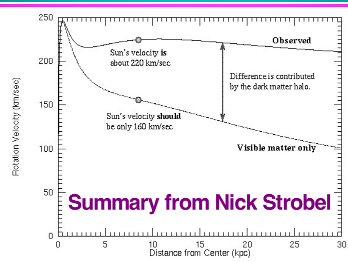
Our sun is moving too fast! We are moving through a sea of dark matter.



The gravity of the visible matter in the Galaxy is not enough to explain the high orbital speeds of stars in the Galaxy. For example, the Sun is moving about 60 km/sec too fast. The part of the rotation curve contributed by the visible matter only is the bottom curve. The discrepancy between the two curves is evidence for a **dark matter halo.**

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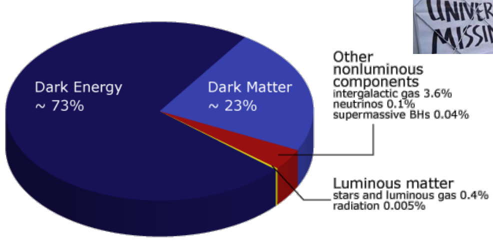
Help! 96% of the universe is missing!



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Looking for dark matter in a goldmine in Lead, South Dakota.

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Going down, 4850' below the surface.

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Building the infrastructure to detect dark matter in South Dakota.

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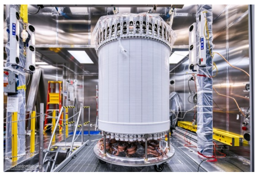
LZ: The most sensitive dark-matter detector in the world.



Read about our latest result.

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Made possible in part by the Rochester group.

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That's all! Review of Exam # 1 on Thursday.

Opportunity's Horizon Credit:
Mars Exploration Rover Mission, JPL, **NASA**

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