Astromechanics: gravity

Astronomy 101
Syracuse University, Fall 2022
Walter Freeman

October 6, 2022

Announcements

- Homework quiz 4 is Tuesday at the end of class Tuesday. Please make sure you have finished your homework so you can ask questions at the beginning of class.
- We'll be doing makeup/retake quizzes next Tuesday in addition to during office hours. I'll send out a signup tomorrow morning.

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  - ... and you'll also get five extra credit points for the exam!

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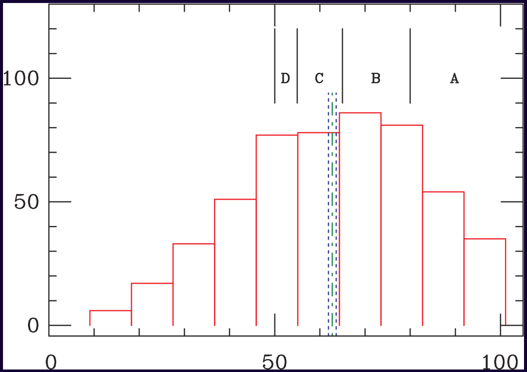
Prelabs for next week are available in the Physics Clinic and online.

Next week's lab and prelab involve an online orbit simulator available on the website.

Exam 1 retrospective



- Median grade: C+
- More A's and B's than D's and F's

This is a new format this year (post-pandemic) and people generally did quite well!

- If you did well, congratulations – you worked hard and it showed.
- If you didn't do as well as you had hoped, then we have plenty of semester left!
- People's semester grades are generally a good bit higher than their exam average
- ... and the first exam is the hardest.

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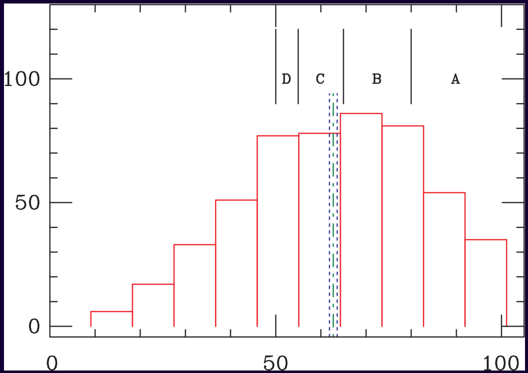

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- You will have another opportunity to show us that you've mastered this material on the final.
- You can *absolutely* pass the class regardless of your Exam 1 grade.
- Advice for now: look forward, don't look back too much
- Review the solution video for Exam 1 once I make it

The law of gravity

Newton showed mathematically what Kepler suspected: that "there is a force in the Earth that causes the Moon to move".

That thing, of course, is gravity.

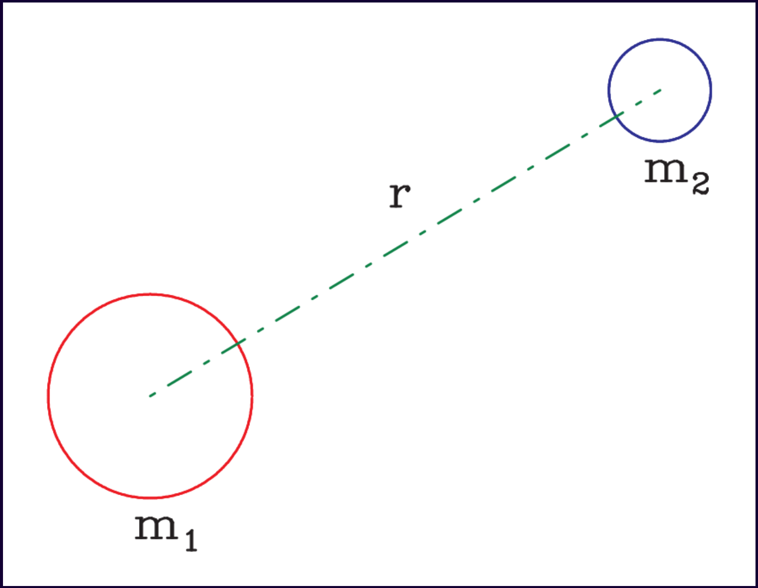
Newton discovered:

All objects attract all other objects with a force that is:

- Proportional to the product of their masses
- Inversely proportional to the distance between their centers, squared

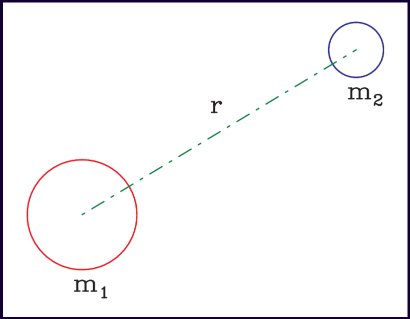
In symbols:

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



The gravitational force between these two planets is

$$F_g = \frac{Gm_1m_2}{r^2}.$$



Here's the same diagram again. Suppose m_1 is a planet and m_2 its moon. As before the force on the moon is

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

Suppose we make the planet twice as massive. How does the gravitational force on the moon change?

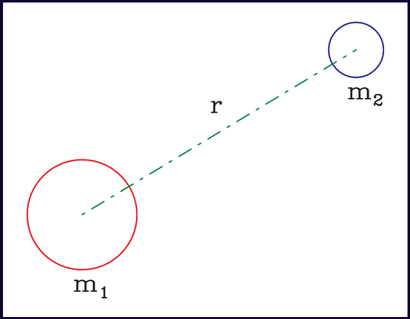
A: It doesn't change

B: It becomes twice as strong

C: It becomes four times as strong

D: It becomes half as strong

E: It becomes one-quarter as strong



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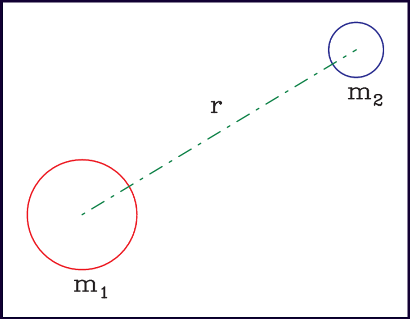

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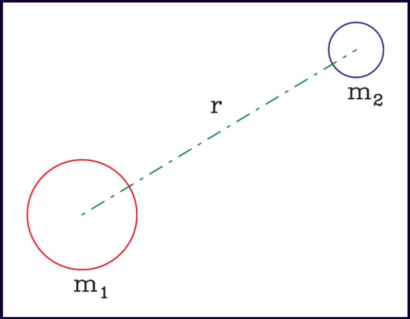

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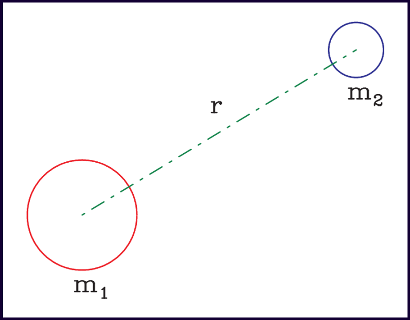
$$F_g = 2\frac{Gm_1 m_2}{r^2}$$



Again, m_1 is a planet and m_2 its moon. As before the force on the moon is

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

Suppose we move the moon twice as far away from the planet. How does the gravitational force on the moon change?

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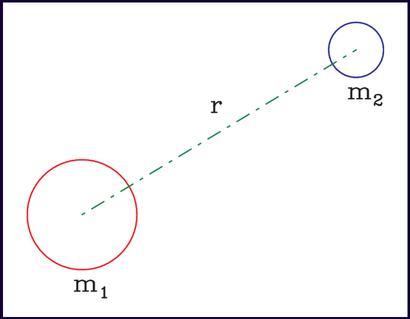

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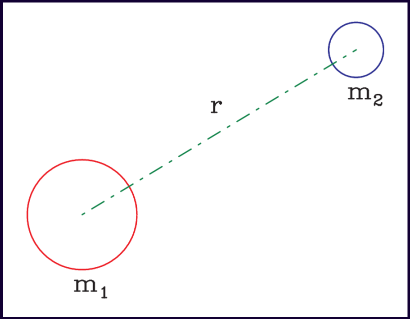

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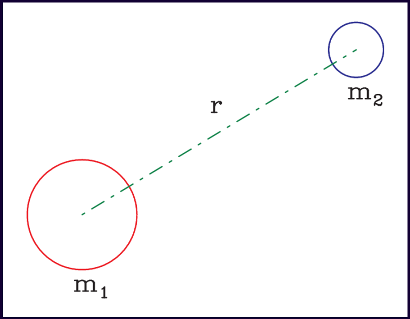
$$F_g = \frac{Gm_1m_2}{(2r)^2}$$



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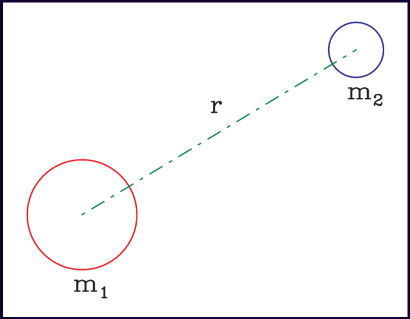
$$F_g = \frac{G m_1 m_2}{4r^2}$$



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Suppose we move the moon twice as far away from the planet. How does the gravitational force on the moon change?

A: It doesn't change

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D: It becomes half as strong

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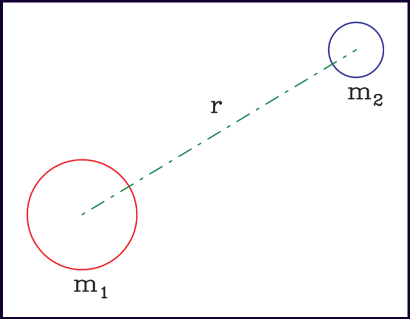
$$F_g = \frac{1}{4}\frac{Gm_1 m_2}{r^2}$$

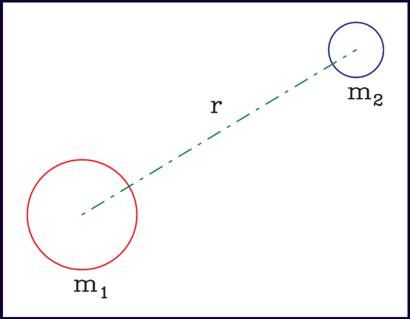


Here's the same diagram again. Suppose m_1 is a planet and m_2 its moon, and m_1 is twice as big as m_2. As before the force that the planet applies to the moon is

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

How does the force that the moon applies on the planet compare to the force the planet applies to the moon?

A: The force on the planet is twice as large as the force on the moon
B: The force on the planet is four times as large as the force on the moon
C: The force on the planet is half as large as the force on the moon
D:The force on the planet is one-quarter as large as the force on the moon
E: Both planets pull on one another with the same force.



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D:The force on the planet is one-quarter as large as the force on the moon
E: Both planets pull on one another with the same force.

$$F_g = \frac{Gm_1m_2}{r^2}$$

The law of gravity

All objects attract all other objects with a force that is:

- Proportional to the product of their masses
- Inversely proportional to the distance between them squared

In symbols:

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

Notice I didn't say which mass was which. It doesn't matter!

Suppose two asteroids are floating out in space, 20 miles apart. Asteroid A is twice as massive as asteroid B, and the force of A's gravity on B is ten tons.

Suppose I now move the two asteroids closer, so they're only 10 miles apart. What will the force of A's gravity on B be now?

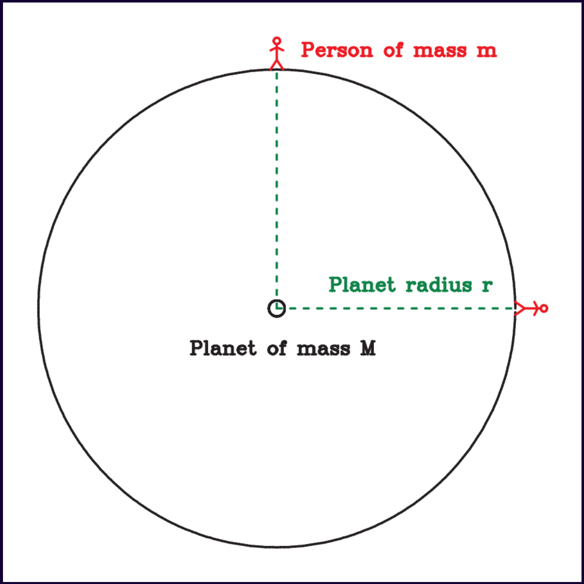
A: 5 tons

B: 10 tons

C: 20 tons

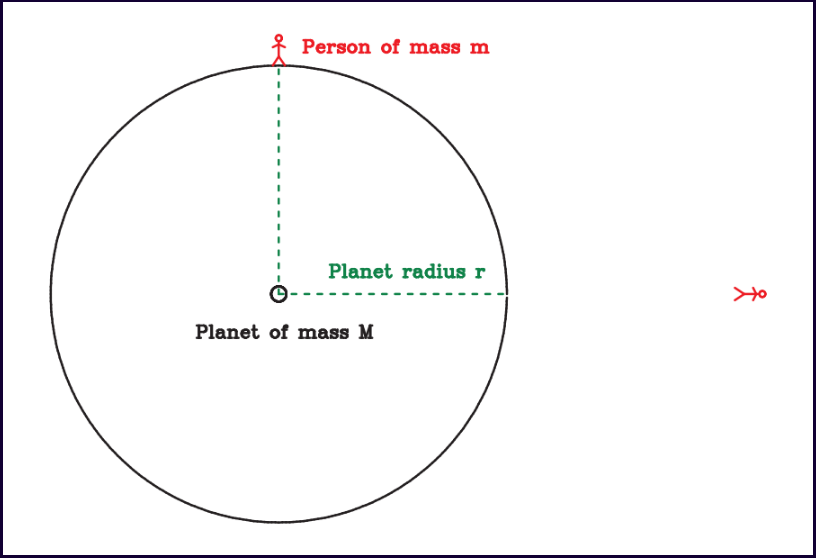
D: 40 tons

The distance is measured between the *centers* of the objects.



This lets you calculate the force of a planet's gravity on people on its surface!

Earth has a radius of about 6,000 km. If we move this person 6,000 km away from Earth's surface, how does the strength of Earth's gravity change?



A: It stays the same

B: It becomes twice as strong

C: It becomes half as strong

D: It becomes one-quarter as strong

E: There's no gravity in space, so it goes away totally

The ball and the feather

We still haven't figured out why this happens:

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So far we have talked only about the *force* of gravity.

The missing piece: **how do forces make things move?**

"Forces cause objects to accelerate"

$$F = ma$$

$$F/m = a$$

"The strength of a force, divided by the mass of the thing it acts on, gives that thing's acceleration"

Let's apply this to the hammer and the feather and see what happens.

(on document camera)

Newton's biggest idea

Surprising result: this means that *all objects*, regardless of their mass, move in response to gravity in the same way!