The beginnings of physics

Astronomy 101
Syracuse University, Fall 2018
Walter Freeman

October 9, 2018

Announcements

- No office hours this week (I've been invited to give a seminar in DC)
- I fixed a bunch of grade issues (ODS people; SUID errors)
- Grades for makeup exams still pending (sorry)

Exam 2 approaches

Exam 2 is next Tuesday. Reminders:

- You may bring a single-sided page of notes, as before
- You won't need your globes (nor will they help)
- I'll be holding an extra review on Monday from 2PM-5PM
- The study guide for Exam 2 is posted

On the papers

We've started to grade your papers.

Issue 1: Don't just list facts, tell why they are important and how they work!

The Jewish calendar has 12 months in a year. Each month has 29 or 30 days. Every few years there is a thirteenth month added; this is called an intercalary month.

... compared with ...

The Jewish calendar has 12 months in a year. These months are exactly based on the phases of the moon, unlike the months in our calendar, which are only approximate. But 12 lunar cycles is about ten days short of a full year. This means that around every third year, a 13th month must be added to the calendar, so that the New Year happens in the same season each time.

On the papers

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Issue 2: If you don't understand something (words, ideas), ask about it, rather than glossing over it!

The ancient Egyptian year begins with the heliacal rising of Sirius.

... compared with ...

Since the sidereal day and solar day are not equal, stars rise at different hours of the day in different parts of the year. When the Sun has already risen, you can't see the stars. This means that during part of the year, we won't see Sirius rise. However, since Sirius will rise earlier and earlier each day, eventually it will come up before the Sun has risen, and you'll see Sirius rise again. This event marked the ancient Egyptian new year.

On the papers

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Issue 3: Fluff

The Flubowilli calendar is very interesting! It's very different from our own Gregorian calendar!

... compared with ...

The Flubowilli people live on a planet near two stars that orbit each other. This gives them the ability to tell time by the motion of their suns, which is the basis of their calendar.

Newton's three ideas, one at a time

1. Objects move in a straight line at a constant speed unless a force acts on them; hoverpuck demo
2. Forces cause their velocities to change size and direction (accelerate); cart demo
3. Gravity is such a force!

Newton's first law

What happens to a ship at sea whose engines die?

A: It comes to a stop

B: It keeps going forward until it hits something

Newton's first law

What happens to a spacecraft whose engines die?

A: It comes to a stop
B: It keeps going forward until it hits something

Newton's first law

No motive force is required to keep things moving. They do that on their own.

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On Earth things come to rest only because of the forces of friction. (Aristotle was wrong!)

In space we don't have these, so things "coast" forever without another force to change their motion.

Newton’s biggest idea: the second law of motion

“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”

Acceleration

Acceleration has a direction; it can increase, decrease, or redirect an object's velocity:

- Apply engine power to a car going East: force to the East $\rightarrow$ it goes East faster
- Apply brakes to a car going East: force to the West $\rightarrow$ it goes East more slowly
- Turn steering wheel left: force to the North $\rightarrow$ car starts traveling Northeast

The force of gravity

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$$F_{\text{grav}} = \frac{G \times (\text{mass of object A}) \times (\text{mass of object B})}{(\text{distance between them})^2}$$

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G is just a number telling how strong gravity is: about a ten-billionth of the weight of an apple for two kilogram objects a meter apart.

Suppose two asteroids are floating out in space. Asteroid A is twice as massive as asteroid B.

If the force of A's gravity on B is ten tons, the force of B's gravity on A will be...

A: 5 tons

B: 10 tons

C: 20 tons

D: 40 tons

The solution

Let's look at that expression again:

$$F_{\text{grav}} = \frac{Gm_1m_2}{r^2}.$$

(Remember, r is the distance between the objects)

Notice that switching m_1 (one asteroid) and m_2 (the other) in this expression doesn't affect the result!

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"For every action there is an equal and opposite reaction": if the Earth's gravity pulls me down with a force of 160 pounds, I pull *up on the Earth* with the same force of 160 pounds.

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 20 tons.

Suppose I now move the two asteroids further apart, so they're 40 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

E: 80 tons

The solution

Recall:

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

If I increase the distance between the asteroids by a factor of 2, then I increase the denominator of this fraction by a factor of __________, which will __________ the whole fraction by a factor of __________.

Complete *Lecture Tutorials pp. 29-32.*

We will do something else after this.

Suppose I have two satellites next to each other orbiting the Earth at a distance r. The small one has a mass m_A; the big one has mass m_B; the Earth has mass m_E.

What is the force of gravity ("weight") on satellite A from the Earth?

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Suppose I have two satellites next to each other orbiting the Earth at a distance r. The small one has a mass m_A; the big one has mass m_B; the Earth has mass m_E.

What is the force of gravity ("weight") on satellite B from the Earth?

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The *force* that they feel depends on their own masses. How does this change how they move?

Suppose I have two satellites next to each other orbiting the Earth at a distance r. The small one has a mass m_A; the big one has mass m_B; the Earth has mass m_E.

What is the acceleration of satellite A because of the Earth's gravity?

Newton's second law: $F = ma \rightarrow a = F/m$

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The mass of the satellite cancels from the equation!

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The mass of the satellite *doesn't affect* how Earth's gravity makes it move!

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Yes, this makes sense because since $a = F/m$ is an inverse relationship, if the force were to double due to the mass increase, when it is divided by the new doubled mass, the acceleration will be the same due to the inverse relationship. If both are doubled and then divided, the acceleration would stay the same...

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Force, which equals ma, is equal to GMm/r^2. The m from both sides cancels.

–Yihong

Student A: “Kepler’s laws say that the planets orbit around the Sun in elliptical orbits, with the Sun fixed at one focus of the ellipse. The Sun doesn’t move.

Student B: “But the laws of gravitation say that if the Sun pulls on the planets, which it must in order to hold them in their orbits, the planets must pull back on the Sun. This pull makes the Sun accelerate, so it has to wobble a bit.”

Who’s right?

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A: The gravitational forces from all the planets on the Sun cancel each other out

B: The planets are so far away that the force they exert on the Sun is small

C: The Sun’s mass is so big that this amount of force doesn’t affect it that much

D: We *do* see this wobble, if we look closely enough

Someone else might see it, too...

How does this create circular motion?

Without a force, things travel in straight lines at constant speeds (Newton's first law).

It requires a force *directed toward the center* to hold something in circular motion.

Let's demonstrate and watch this.

What about elliptical orbits?

For gravity, the force depends on the distance from the center, as you know.

The particular mathematics that produces ellipses is beyond the scope of this class. But we can understand the principles!

To make all the simulations for this class, all I did was program $F = \frac{GMm}{r^2}$ and $F = ma$ into my computer and make it do the math for me! (This is next week's homework in my other class!)

How far can we take this?

https://www.youtube.com/watch?v=W-csPZKAQc8

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The only difference between this and what I've done on my own computer is the number of objects!