The beginnings of physics

Astronomy 101
Syracuse University, Fall 2019
Walter Freeman

October 1, 2020

"What, then, is the meaning of it all? ... I think that we must frankly admit that *we do not know.*

This is not a new idea; this is the idea of the age of reason. This is the philosophy that guided the men who made the democracy that we live under. The idea that no one really knew how to run a government led to the idea that we should arrange a system by which new ideas could be developed, tried out, tossed out, more new ideas brought in; a trial and error system. This method was a result of the fact that science was already showing itself to be a successful venture at the end of the 18th century. Even then it was clear to socially-minded people that the openness of the possibilities was an opportunity, and that doubt and discussion were essential to progress into the unknown. If we want to solve a problem that we have never solved before, we must leave the door to the unknown ajar.

We are at the very beginning of time for the human race. It is not unreasonable that we grapple with problems.... Our responsibility is to do what we can, learn what we can, improve the solutions and pass them on. It is our responsibility to leave the men *(sic)* of the future a free hand. In the impetuous youth of humanity, we can make grave errors that can stunt our growth for a long time. This we will do if we say we have the answers now, so young and ignorant; if we suppress all discussion, all criticism, saying, "This is it, boys, man is saved!" and thus doom man for a long time to the chains of authority, confined to the limits of our present imagination. It has been done so many times before.

It is our responsibility as scientists, knowing the great progress and great value of a satisfactory philosophy of ignorance, the great progress that is the fruit of freedom of thought, to proclaim the value of this freedom, to teach how doubt is not to be feared but welcomed and discussed, and to demand this freedom as our duty to all coming generations.

–Richard Feynman (American physicist and philosopher), *The Value of Science* (1955)

Announcements: papers

- Lots of people have been sending me drafts – way more than I can read. I am going to see if I can get an all-hands-on-deck effort from our teaching staff today and tomorrow to help provide additional feedback to you.
- I've not been able to reply to all "extension requests" – if you've requested an extension on your draft, assume that it is okay
- If you sent your draft for feedback to another student and don't receive any, don't worry about your grade
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  Your final version is due by the end of the day next Monday. When you are done, email it to `suast101projects@gmail.com` with the subject "Paper 1".

Announcements: other stuff

- Lab 4 (on-your-own) should be done by the end of the day Sunday
  - Someone told me there was a typo in the Word document link; it's fixed now
- Lab 5 will be back to your usual groups and times
- **If your would rather do your lab online, that is okay!** – just go to Blackboard Collaborate at the chosen time
- Project 3 will be assigned Friday/Saturday

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

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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. This means that the Egyptian year was the sidereal *year, not the* seasonal *year.*

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If you don't understand something (words, ideas), ask us about it or research it, rather than glossing over it!

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Don't waste time and space on "fluff" or BS. Make your words count!

The story so far

Kepler realized that all the planets moved in elliptical orbits, and described their properties.

He didn't know *why* they moved like that, only that they did.

Isaac Newton uncovered fundamental laws that (when combined with mathematics) explained *why* they move in ellipses.

Today, we will:

- Explore a little more of the physical science of motion
- Talk about how Newton's laws of motion connect to astronomy
- See why the mass of a planet doesn't matter for its motion

Newton's four ideas

1. The law of gravity: all objects attract each other
2. The first law of motion: without a force, objects keep moving with the same velocity
3. The second law of motion: forces make objects accelerate (change their velocity)
4. The third law of motion: forces come in pairs

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Two of these are more important to us than the others...

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The force of gravity

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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.

Newton's first law

What happens to a ship at sea whose engines die?

Newton's first law

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Does it keep going?

Does it come to a stop?

Why?

Newton's first law, puppo edition

This is Chester. Chester is the goodest boi – I believe he is Jared Welch's dog. He doesn't actually have lights shining out of his eyes. (Why does that happen? What's with the little streaks?)

Chester's got fuzzy socks on his feet.

Every dog owner is familiar with this story:

You're cooking dinner in the kitchen, with a smooth wooden floor. You drop a bit of food on the floor.

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You're cooking dinner in the kitchen, with a smooth wooden floor. You drop a bit of food on the floor.

Chester – with his fuzzy socks – sees this from another room and comes running as fast as he can into the kitchen.

What happens to Chester once he gets onto the wooden floor?

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Does it keep going?

Does it come to a stop?

Why?

What's different between the spaceship and the ship-ship?

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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"

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Why?

Remember:

- The law of gravity lets us figure out the force that a mass M (like the Sun) exerts on another mass m (like a planet)
- Newton's second law lets us figure out how that force causes that mass m to accelerate.

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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$$F = \frac{G \times m_E \times m_A}{r^2}$$

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?

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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!

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

Let's see this on the blackboard.

What does acceleration do?

Acceleration causes changes in an object's velocity.

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Acceleration causes changes in an object's velocity.

Velocity causes changes in an object's position.

Using the mathematics of changes (calculus), you can work out *everything* about how an object moves this way!

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:

$$F_{\text{grav}} = \frac{Gm_1 m_2}{r^2}.$$

(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.

Newton's third law of motion

Newton's third law says that if object A exerts a force on object B, object B exerts the same force back on A.

This is easily apparent from the form of the gravitational law:

$$F_g = \frac{G m_A m_B}{r^2}$$

The math doesn't distinguish between "the object pulling" and "the object being pulled": the force is the same on both ends.

Consider the gravity between the Earth and the Moon:

- The gravitational force is the same on both objects

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- The gravitational force is the same on both objects
- ... but this force causes a greater acceleration on the Moon, because its mass is smaller

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 animate 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 too hard for our pencils. But our computers can do it!

To make our simulator, all I did was program $F = \frac{GMm}{r^2}$ and $F = ma$ into my computer and make it do the math for me!

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 you will do in lab is the number of objects!

Gravitation

"What forces does gravity produce?"

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

- All objects attract all other objects
- The force is proportional to the product of the masses...
- ... divided by the squared distance between their centers.

Second law of motion

"How do forces make things move?"

$$a = F/m$$

- Forces make objects accelerate
- The acceleration is in the direction of that force...
- ... and is equal to the size of the force divided by that thing's mass.

Gravity tells us the forces on all objects in space; the second law of motion tells us how that causes them to move. From this, and a little math, you can predict everything about their motion.