Kepler's laws

Astronomy 101
Syracuse University, Fall 2016
Walter Freeman

October 11, 2016

”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 sociallyminded 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 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.

–Feynman, *The Value of Science* (1955)

"If there is any fixed star in our constitutional constellation, it is that no offical, high or petty, can prescribe what shall be orthodox in politics, nationalism, religion, or other matters of opinion or force citizens to confess by word or act their faith therein."

–Supreme Court Justice Robert Jackson, for the majority,
West Virginia State Board of Education v. Barnette (1943)

Announcements

- Exam prep schedule:
  - Tuesday night: Help session 4:30-6:30 (clinic back room). I'll catch up on answering emails (some regarding *Mastering Astronomy*) tonight.
  - Wednesday: I'll be writing your exam and a study guide, which I will send you. In my office most of the afternoon; stop by!
  - Thursday: Class as usual, with a mini-review and time for questions
  - Friday: Help session Friday morning and afternoon (afternoon 1:30-3:30)
  - Sunday morning/afternoon: Review session, times announced Thursday
  - Monday: Available all day for questions.
- If you had problems with *Mastering Astronomy* and emailed me, I will answer your email tonight. Don't worry.
- Remember, there are astronomy coaches and/or physics PhD students in the Clinic all the time to help you!

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?

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

The force of gravity

Newton discovered:

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

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

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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:

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

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 ________.

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.”

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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...

Complete *Lecture Tutorials pp. 29-31.*

We will do something else after this.

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!

What about elliptical orbits?

"If we imagine a line connecting a comet and the sun, we can see that when a comet is closer to the sun, the line is smaller and when the comet is further, the line is longer. Newton's law of gravity says that the shorter the line gets, the stronger the connection (gravity) is between the sun and the comet. Conversely, the longer the line gets, the weaker the connection (gravity) is between the comet and the sun."

–Ariana