General announcements

- Lab to be announced!

- **Today:** Asteroids; Preamble, Newton’s Laws and the Island Series

So Asteroids:

What was needed to change the ship's motion?

You needed to fire its thrusters, which is to say you needed to apply a force.

What causes an object to change its motion in general?

A force . . .

What is involved when an object is made to move in a circular path?

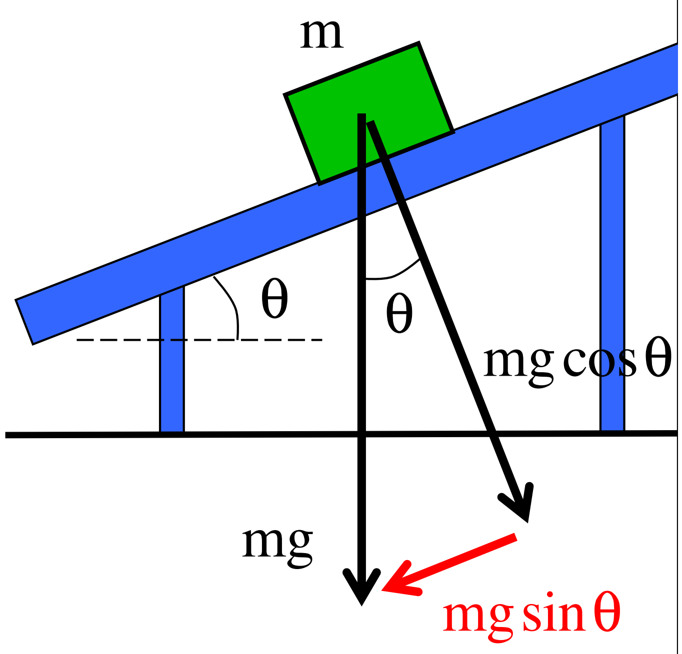
Need a force to be applied to push the body out of straight-line motion.

The Island Series:

You have been kidnapped by a crazed physics nerd and left on an island with twenty-four hours to solve the following problem. Solve the problem and you get to leave. Don't solve the problem and you don't.

The problem: You are given an incline plane, a protractor, a calculator and a cart with frictionless wheels on it. Determine the acceleration of the cart as it rolls freely down the incline.

Solution to Island Problem:



According to Newton, a net force in a particular direction will generate an acceleration in that direction with the net force equaling the *mass times that acceleration*. The only force acting on the cart along the line of the motion is the component of gravity along that line, which means

$$\cancel{m}g\sin\theta = \cancel{m}a$$

In other words, all you need to determine the acceleration is a *protractor* to determine the angle of the incline.

Newton's Second Law is a very powerful tool in analyzing systems. It is the approach with which this section is concerned.

CHAPTER 5:
Newton's Laws

You are horribly spoiled . . . a quick excursion into the history of the computer.

Life hasn't always been the bowl of cherries it is today, at least for scientists . . . A quick history of the evolution of science . . .

The photos have been lifted from Mr. White's lecture notes:

The Greek philosopher & metaphysicist Aristotle (384-322 B.C.), teacher of Alexander the Great and student of Plato (who was, in turn, the student of Socrates), was the first western scientist (at least that we know about) in the sense that he looked at the world and tried to find "laws" that governed its existence.

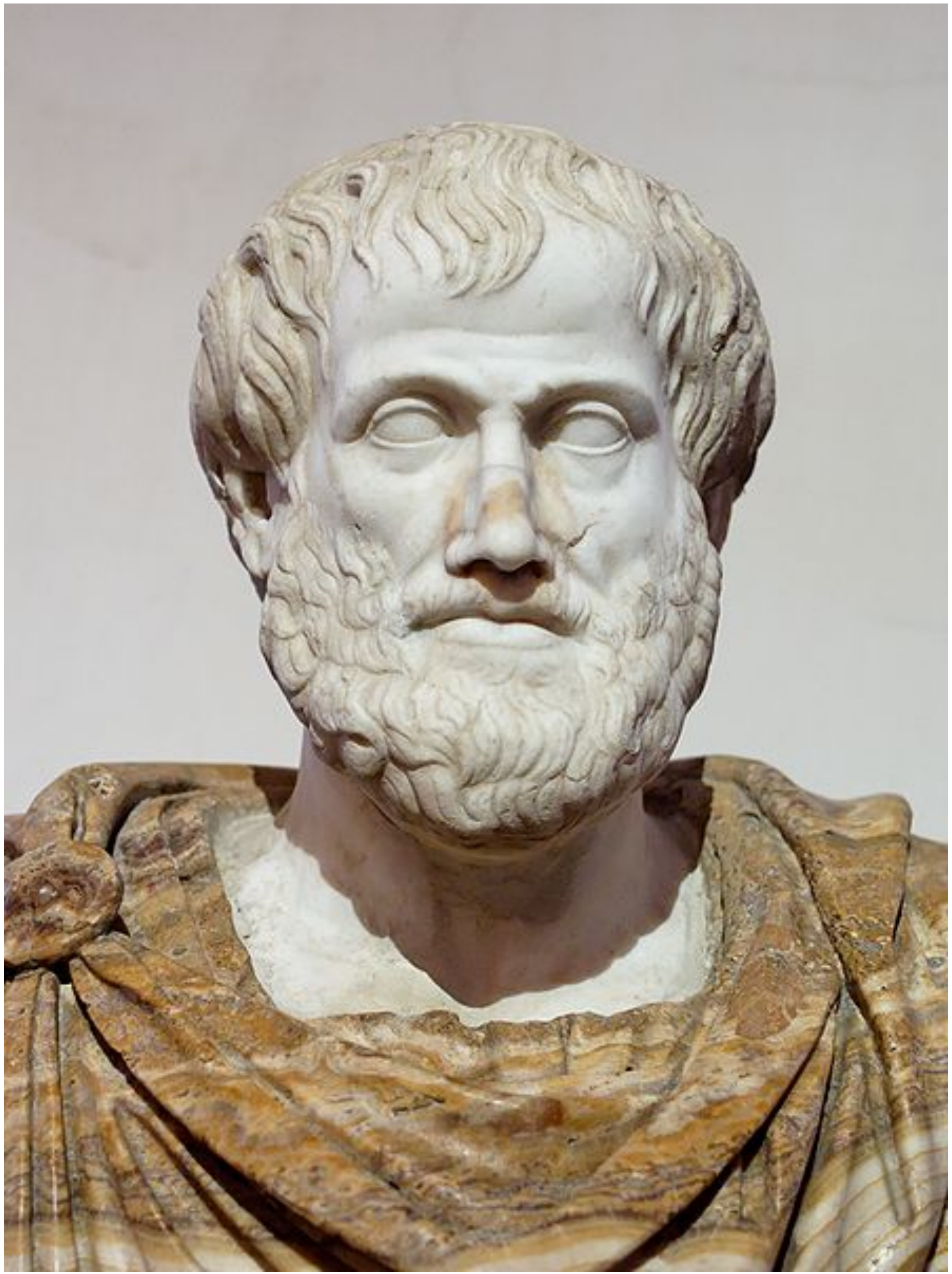
"Heavier objects fall faster in proportion to their weight;"

"The sun orbits the earth;"

"For an object to move with a constant velocity, a force is required;"

"Objects come to rest while in motion because it is their natural state to be at rest, and object tend to their natural state."

All incorrect, but all following logically from everyday observation.



The rub:

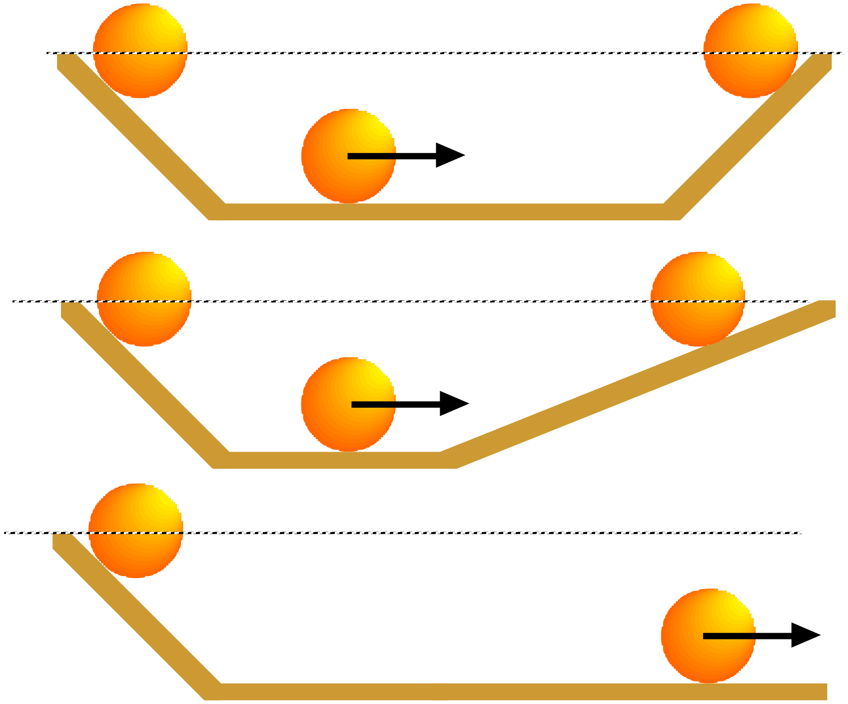
Religion in Italy in the 1500 and 1600's was dominated by the Catholic church, located at the Vatican, and church doctrine at the time was quite vehement about several points.

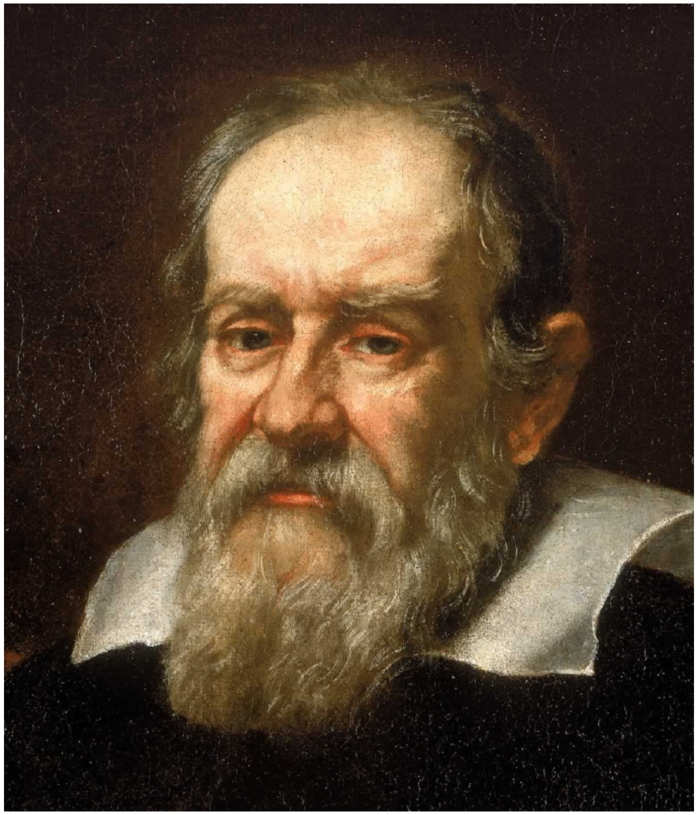
1.) Man was the center of God's creation;
2.) Only through the church could one get to God;
3.) The church was infallible.

In addition, the church endorsed the "findings" of Aristotle, especially liking the notion that the Sun and, essentially, all else, rotated around the earth, this rather naturally fitting into the idea that man was the center of God's creation. What's more, individuals who did not agree with the church were deemed heretics and, if they did not recant their view, were often burned at the stake (this action being necessary to "save their souls").

Enter Galileo Galilei (1564-1642): Galileo started out by using the recently invented telescope to impress the Doge of Venice, thereby receiving a stipend for life to "go out and be scientific." He then used the device to view the sun (a thoroughly bad idea—he was blind by the time he died), seeing sun spots moving on its surface, and he viewed the planet Jupiter along with the four moons (now called *the Galilean moons*) that clearly orbited, not the earth, but Jupiter itself (an observation Aristotle wouldn't have liked).

Galileo also messed with Aristotle directly. He concocted a series of demonstrations, shown below in a rather nice graphic created by the good Mr. White)





in which he showed that objects tend to roll almost up to their starting level when released on a ramp, the consequence being that if they were never given the opportunity to get back up to that original level (assuming whatever retarding force that kept them from getting *all the way back up* was eliminated), the objects would *never* stop, thereby contradicting Aristotle's claim that objects "come to rest because it is their natural state to do so."

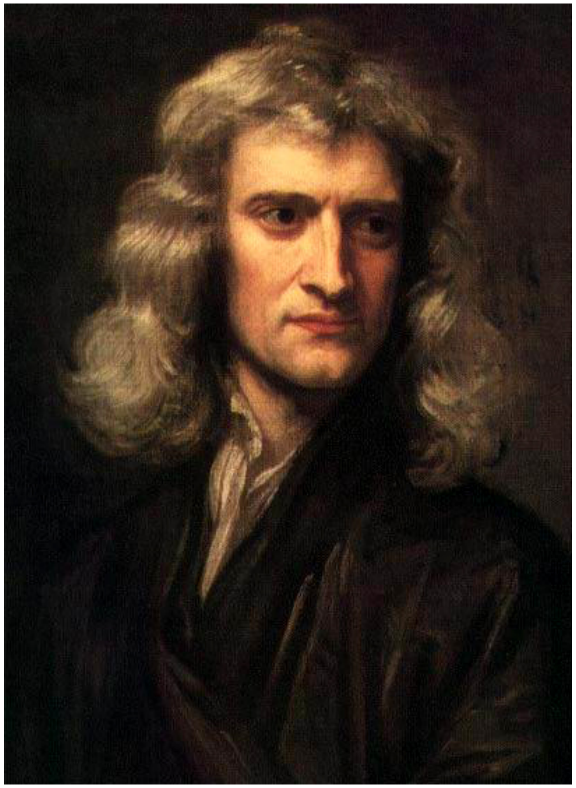
The Vatican, with Aristotle being their man and ever mindful of their doctrine of infallibility (you can’t very well tell people what to do under the mantle of infallibility if you are shown to be fallible), was not amused when Galileo published his findings, not in Latin (which was something very few could read) but in Italian. The consequence was two summonses during his lifetime. During the first, he took his telescope to show the moons of Jupiter, thinking that when they saw that not *everything* rotated around the earth, they’d be surprised but intellectually fascinated. They weren’t. They apparently told him he might be right, but talking about it would just confuse the common folks. It was best that he not continue publishing.

When he didn’t comply, a second summons was sent out, this one with a heresy charge attached (in fact, it wasn’t until the 1950’s that the Vatican formally acknowledged that it had been wrong about him). He was given the choice of recanting or being burned at the stake as a heretic. He recanted (who wouldn’t?).

Put under house arrest, he died nine years later.

The year after Galileo died, Isaac Newton was born (1642-1726/7). In 1665, Cambridge University closed due to "the Great Plague," Newton had his supposed *apple on the head* experience and the idea of gravity emerged.

What was, maybe, more significantly in a cosmic sense was by that time, the Vatican had realized it was not going to be able to stifle scientific exploration, and that Aristotle wasn't the end-all, be-all. Their solution? They made an agreement with the scientific community that said, *As long as you, the scientific community, don't delve into "metaphysical topics" (i.e., topics "beyond the physical"—talking about God or what happens after death), you can do anything you wanted in the way of scientific research.* In other words, you could do research without fear of being burned for it.



This change allowed Newton to be Newton. He was brilliant (not very pleasant to be around, but brilliant). When he didn't have the math required to justify an assumption he wanted to make about how the bits and pieces of stuff making up the whole of the earth gravitationally affect a single body on the earth's surface, he *made up* the math out of whole cloth. Today, we call it *Calculus*. (Leibnitz independently paralleled him—it's Leibnitz's notation we actually use today, but that hardly diminishes the feat.) In 1687, he wrote the definitive work, his Principia Mathematica, on classical mechanics, which included his *analysis of motion*. The ideas therein are what you will spend the first semester studying.

Newton's Three Laws

NEWTON'S FIRST LAW: *In an inertial frame of reference,* objects in motion stay in motion with a constant velocity (i.e., in a straight line), and object at rest stay at rest, unless impinged upon by a net force. This is sometimes called the Law of Inertia.

NEWTON'S SECOND LAW: *The net force* acting on an object is *proportional to* the acceleration of the object, with the proportionality constant being the object's mass. In short, $\vec{F}_{net} = m\vec{a}$.

NEWTON'S THIRD LAW: *For every action* there is an *equal and opposite action* somewhere in the universe.

Newton's First Law

Wait a minute: *Called "the law of inertia,"* *Newton's First Law* starts out with:

In an *inertial frame of reference,*

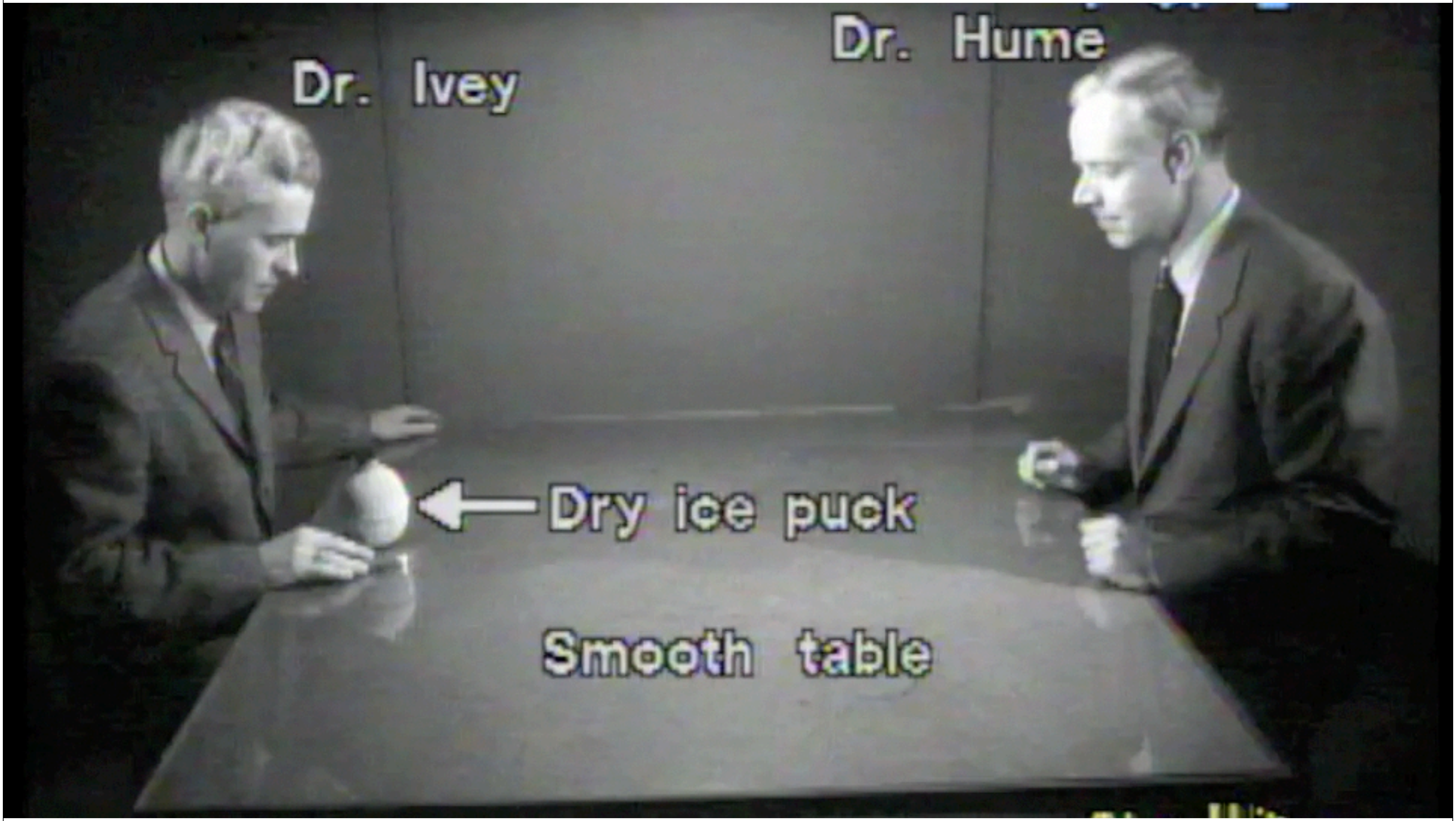
What *is* that?

An *inertial frame of reference* is an UNACCELERATED frame of reference. That is, a *non-inertial frame of reference* is a frame that IS accelerated.

Newton's Laws and his laws of motion are predicated on having a frame of reference that is *NOT ACCELERATED*.

What happens when you view motion from an accelerated frame?

Non-inertial frame: https://youtu.be/zqYHaulHzLI start at 16:45, go to 18:40



So back at the ranch:

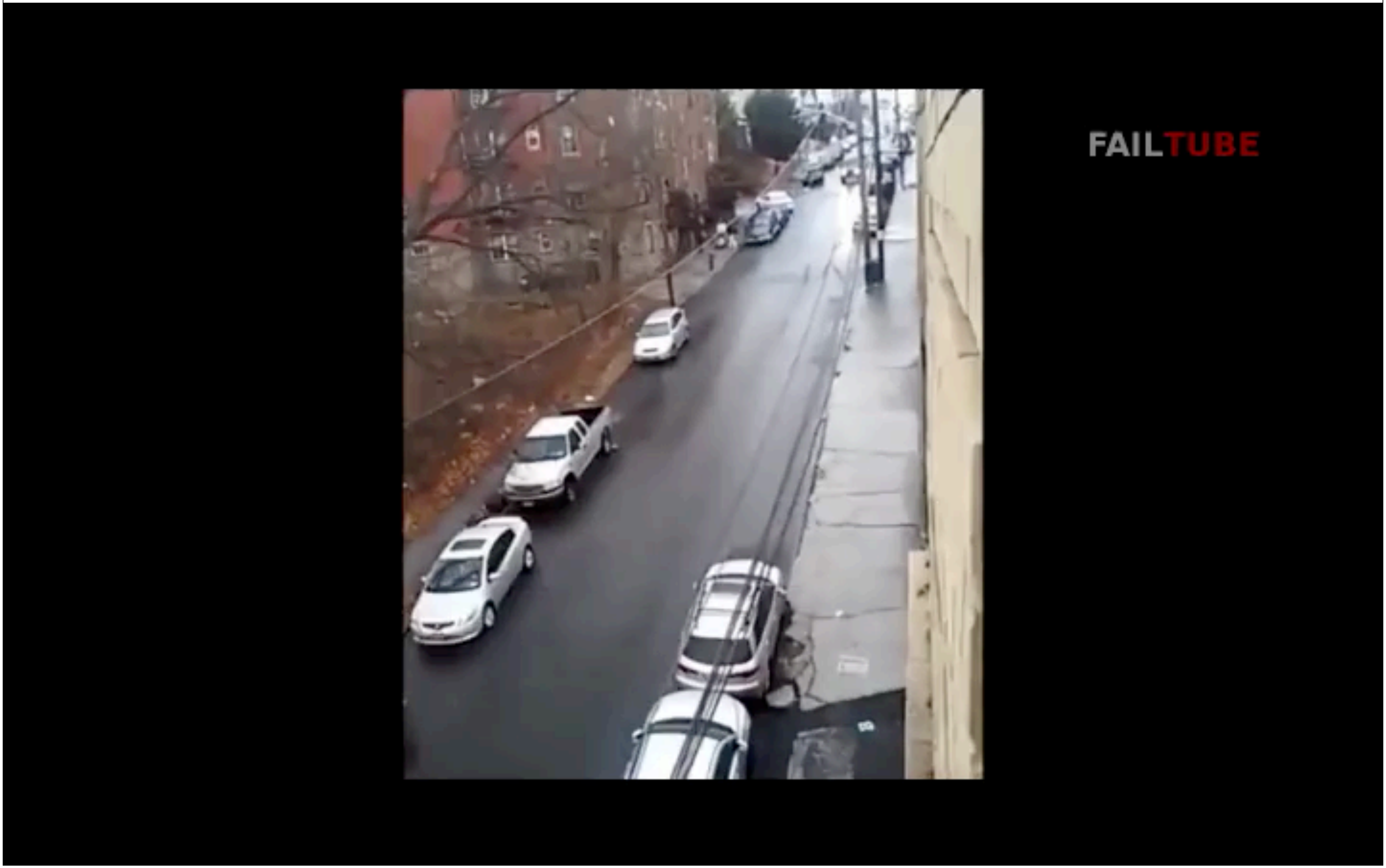
Examples of Newton’s First, the Law of Inertia:

What's going on here?

This is an example of Newton's First Law, the law of inertia.

Objects in motion stay in motion unless impinged upon by a force,

https://youtu.be/DrOO_HcQngg start 0:48 to 1:03



and objects at rest stay at rest unless impinged upon by a force.

https://youtu.be/mfEMW0sXwiw https://youtu.be/1hDv5pib89s

and more objects at rest stay at rest unless impinged upon by a force.

https://media.giphy.com/media/loHlOOGrVZEEhojAI/giphy.gif

So what's wrong with this picture?

https://youtu.be/b6DNlshrrVY (this YouTube version cuts out the crucial 3 second part at the end . . .)

Minor Point--MASS

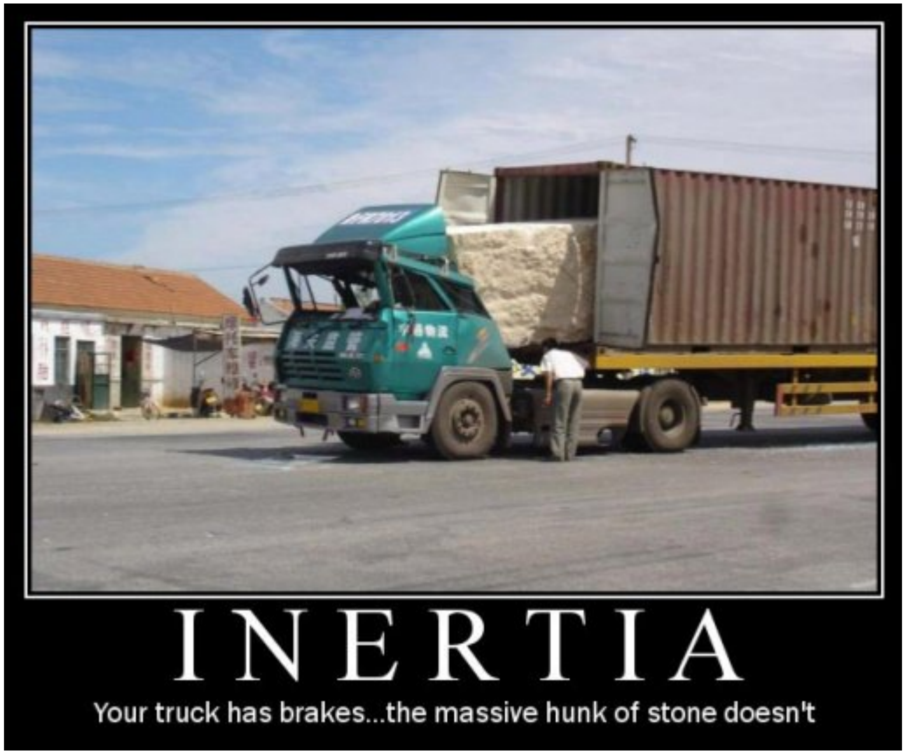
So what is mass?

Mass is a relative measure (relative to what? . . . to a standard found at the Bureau of Weights and Measures in Paris, France . . . though this has recently changed . . .) of a body's *resistance to changing its motion* (i.e., its inertia).

This is called the body's inertial mass.

Example: A Volkswagen sitting out in space is going to be inherently more difficult to move (or change the motion of) than will be a box of Kleenex. Why? Because the Volkswagen has more *inertia*, more mass.

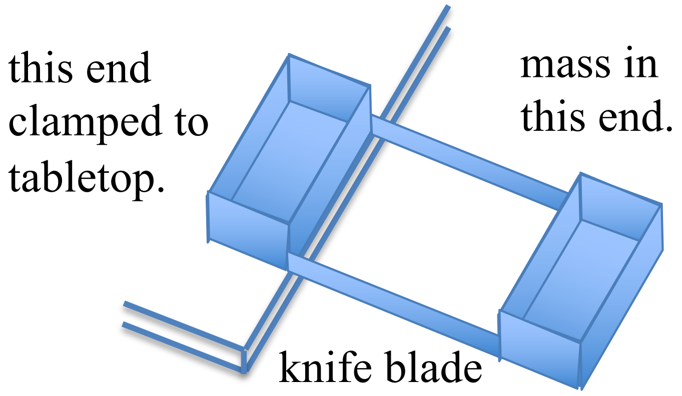
Fun fact: the word *inertia* is Latin meaning *lazy*.



To change a body's motion, you need a force. No force, no change of motion.

So what kind of mass are we dealing with when we use F = ma?

We are talking about forces needed to overcome an object's resistance to changing its motion, so we are talking about *inertial mass*.



And how, technically, should we measure *inertial mass* in the lab?

With an inertial balance . . . which is a tray at the end of a pair of knife-blades, clamped to a tabletop, in which an unknown mass can be put. The vibrational frequency of the tray will be proportional to the unknown mass.

Argh!

Enter gravitational mass, a *relative measure* of a body's *willingness to be attracted to other bodies*, and another measurement relative to a STANDARD (just like inertial mass).

Example: Place an object on a scale and the body's attraction to the earth is what provides the force that depresses the scale effecting the measurement. This is a measure of the body's attraction to another body, in this case the earth. The scale is measuring *gravitational mass*.

So here's the deal. When the standard for inertial mass was housed in Paris, being defined as having *1 kilogram of inertial mass,* an interesting observation was made. If the SAME STANDARD was used to define gravitational mass (denoted as *1 kilogram of gravitational mass*), a mass determined to be twice as inert as the standard (hence, 2 kg of inertial mass) was found to have twice the willingness to be attracted to other objects (hence, 2 kg of gravitational mass). The two mass values were the same. THERE IS NO GOOD REASON (at least within the Newtonian model) for this to be the case . . . but it is.

That means, if you want the *inertial mass* of an object, which is the kind of mass you need in $\vec{F}_{net} = m\vec{a}$, you don't have to use an *inertial balance* to measure it. All you have to do is put the body on a scale and measure it's gravitation mass. Knowing that will give you its inertial mass because they will be numerically the same.

Consequence: Nobody delineates between the two masses, they just refer to a body's *mass*.

So if we ignore friction, why do all objects fall at the same rate no matter their weight?

> That is, if you have body 1 with twice the weight of body 2, why will the heavier body fall at the same rate as the lighter one even though the heavier one is . . . well . . . Heavier (and again, we are assuming we can ignore air friction as the two free fall).

Answer: The gravitational mass of body 1 is twice that of body 2, so its weight will be twice as much. But that means its inertial mass will also be twice as much , so it will have twice the *resistance to changing its motion* as will body 2. As such, those two qualities will cancel one another out and both objects will fall at the same rate.

Newton's Second Law

A net force applied to a body will accelerate the body in proportion to the force. The proportionality constant between the two will be the body's inertial mass.

More succinctly, and in a considerably more useful form:

$$\vec{F}_{net} = m\vec{a}$$

Note that there are really *three equations* here, and we will be saying a LOT more about this shortly . . . it's the real work horse of Newton's Laws.

So according to Newton's Second, apply a net force, get an acceleration!

https://youtu.be/_AW0qGGcfbI

Newton's Third Law

For every action there is an equal and opposite action somewhere in the universe. These action/action pairs ALWAYS EXIST.

In other words, *there will always be a force of response when a force of action occurs.*

Example: You push on the wall; the wall pushes with equal and opposite force back on you.

Example: The earth exerts a gravitational force on the moon; the moon exerts a gravitational force back on the earth.

Example: The earth exerts a gravitational force on *you*; *you* exert an EQUAL AND OPPOSITE gravitational force back on the earth.

Example: While standing on a table, the table exerts an upward "normal" force on you; you exert an equal, downward force on the table.

The trick: The *same* language used in identifying the *action* should be used to identify the *response*, but with the objects reversed. *You* apply a force to *it*; *it* applies a force to *you*, etc.

The hand feels a force; the face feels a force. *SAME FORCE MAGNITUDE!*

https://youtu.be/YZSRszXGo80

This is important: (you should be able to pick the right one)

A bug runs into the windshield of a car that is traveling at 60 mph.

a.) The bug experiences a greater force and acceleration than the car.

b.) The bug experiences a greater force but lesser acceleration than the car.

c.) The bug experiences a greater force but same acceleration as the car.

d.) The bug experiences a lesser force and lesser acceleration than the car.

e.) The bug experiences a lesser force but same acceleration as the car.

f.) The bug experiences a lesser force but greater acceleration than the car.

g.) The bug experiences the same force and same acceleration as the car.

h.) The bug experiences the same force but greater acceleration as the car.

i.) The bug experiences the same force but lesser acceleration than the car.