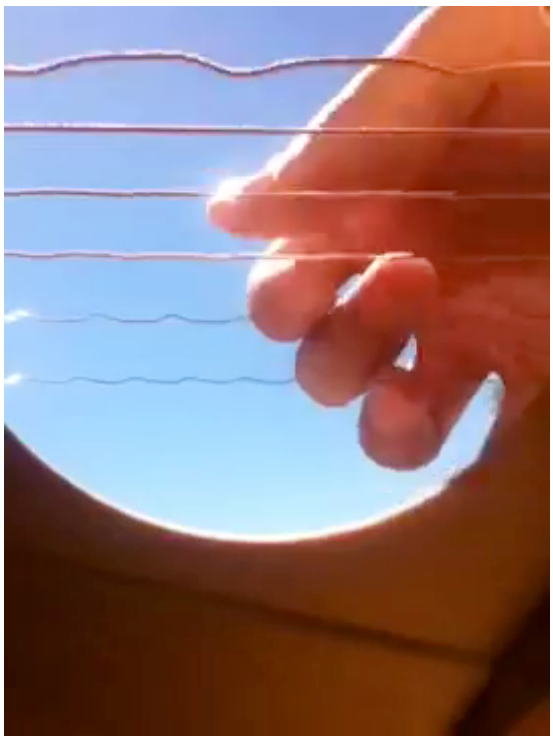
Oscillations and Waves



Aristotle

Some concepts involved in Aristotle's physics are:

1. **Teleology**: Aristotle observes that natural things tend toward definite goals or ends insofar as they are natural. Regularities manifest a rudimentary kind of teleology.
2. **Natural motion**: Terrestrial objects tend toward a different part of the universe according to their composition of the four elements. For example, earth, the heaviest element, tends toward the center of the universe—hence the reason for the Earth being at the center. At the opposite extreme the lightest element, fire, tends upward, away from the center.

Galileo & Newton

Lex I: Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum illum mutare.

Translated to English, this reads:

Law I: Every body persists in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by force impressed.

A force does not create a *velocity*, but only an *acceleration* (a change in velocity)

Velocity and acceleration

Velocity is the rate of change of position:
100 km/hour means your position changes by 100km every hour

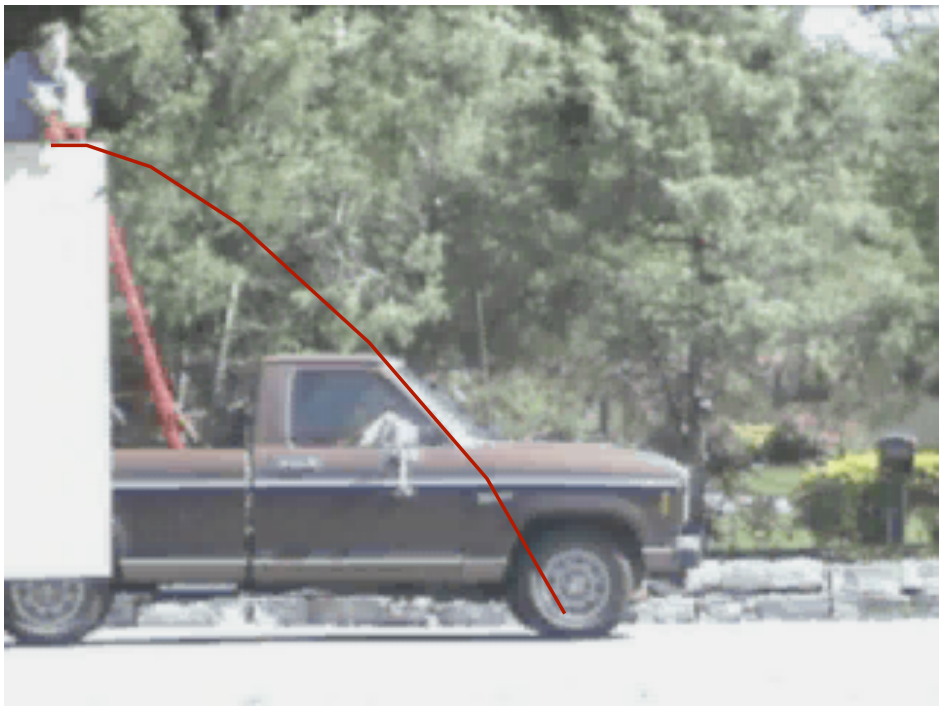
Acceleration is the rate of change ("derivative") of velocity:
From 0 to 100 km/hour in 10s means (100km/hr)/10s = 10 (km/h/s)

9.8 m/s^2 means (9.8 m/s) / s: from 0 to 9.8 m/s in 1 s;
from 0 to 19.6 m/s in 2 s; ...

Falling under gravity

Why doesn’t it move left or right?

How do you know you're at rest?



Who discovered the principle of relativity?

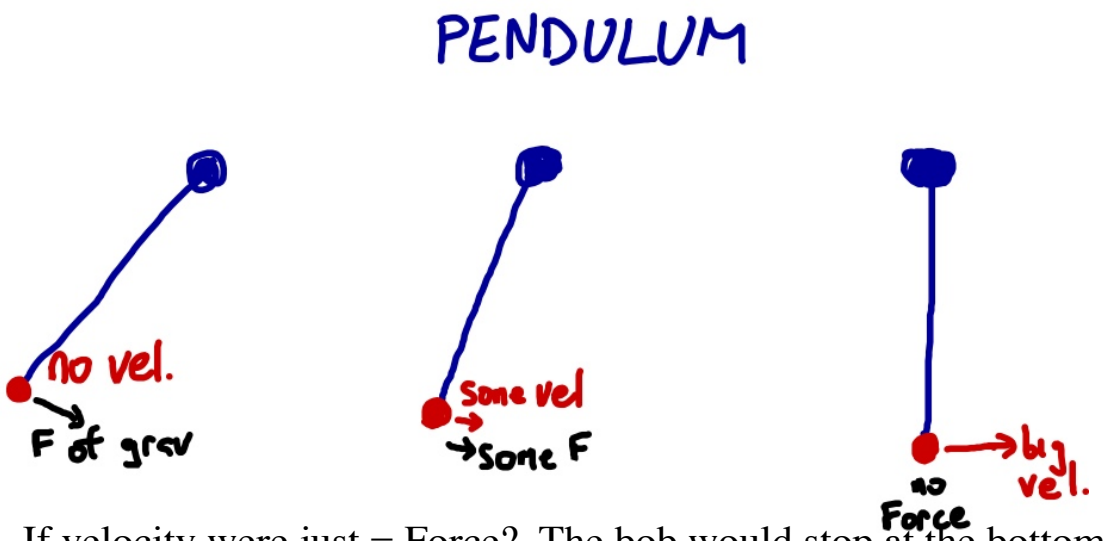
Galileo in 1632, thinking about objects falling on a ship.

(Arguing against the argument that "the earth can't be rotating, or when we dropped things, we'd see them fly to the West.")

"Absolutely at rest" or "absolutely in motion" means nothing; only your velocity *relative* to other objects matters to the laws of physics.
(If you test all the laws of physics and are on a spaceship moving half the speed of light, you will see no difference from what someone sitting still observes -> if there is no *observable* difference, then there is no real difference.)

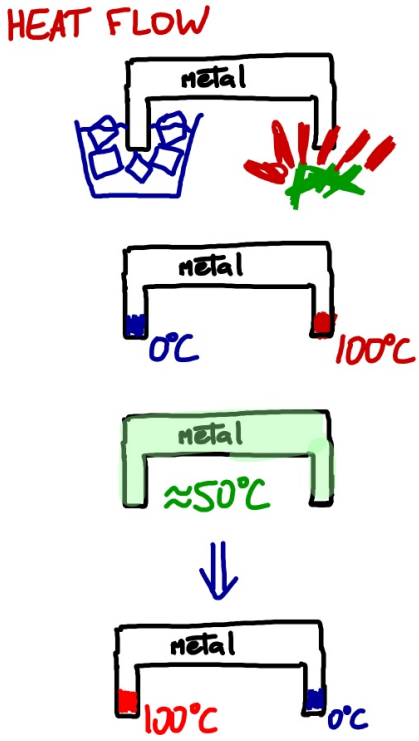
Two steps ("second derivative")

- Force changes velocity
- Velocity changes position



If velocity were just = Force? The bob would stop at the bottom.
Galileo: If no force, the bob keeps moving at constant velocity.
As it climbs, the force starts pushing it back -> oscillations.

Consequences of such "2-step" evolution



Heat flow is *not* like this!
Unlike position, which keeps changing at a constant velocity until there's a force, temperature *only* changes when there's a "force" (something hotter or colder nearby).
-> no oscillations.

What are waves?

"Waves are things which obey a wave equation"

Anything (height of water surface, pressure of air, displacement of guitar string, ... "field") which oscillates both in space & time.

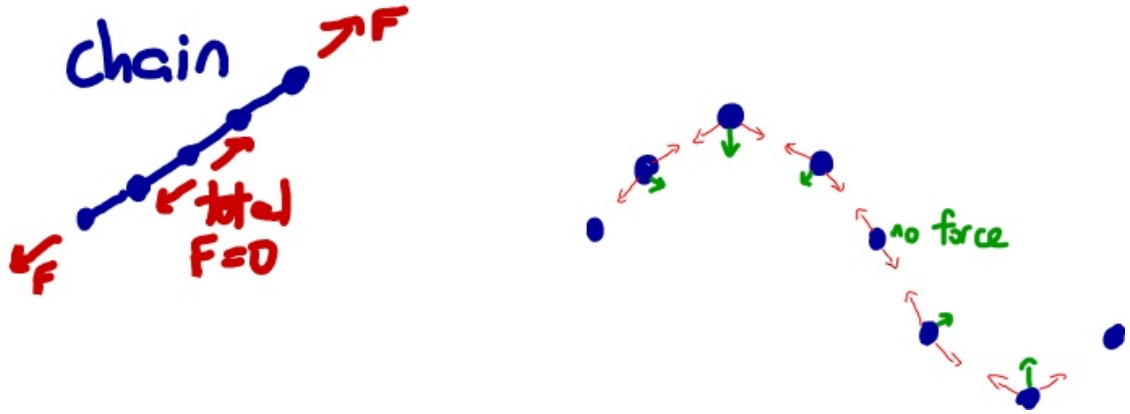
They occur because of this oscillatory tendency to overshoot like a pendulum, but specifically
when the force is due to interaction with the "neighborhood."

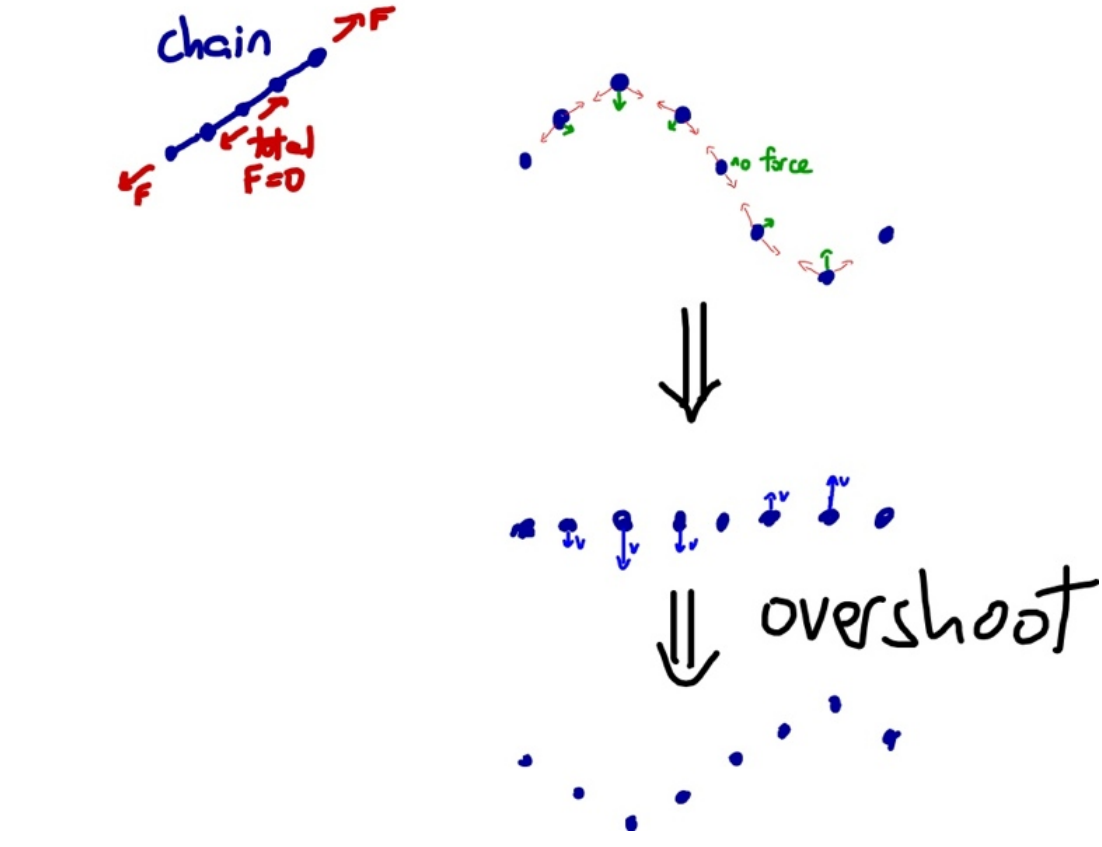
Wave equation

"Acceleration" (rate of change *of rate of change*)
of some quantity, at some place

is proportional to

How different that quantity is nearby





Linearity

Approximation: if I pull something twice as hard, it moves twice as far (turns out to be a *good approximation* if I don't pull "too hard," but bad otherwise – like most of physics, never exact.)

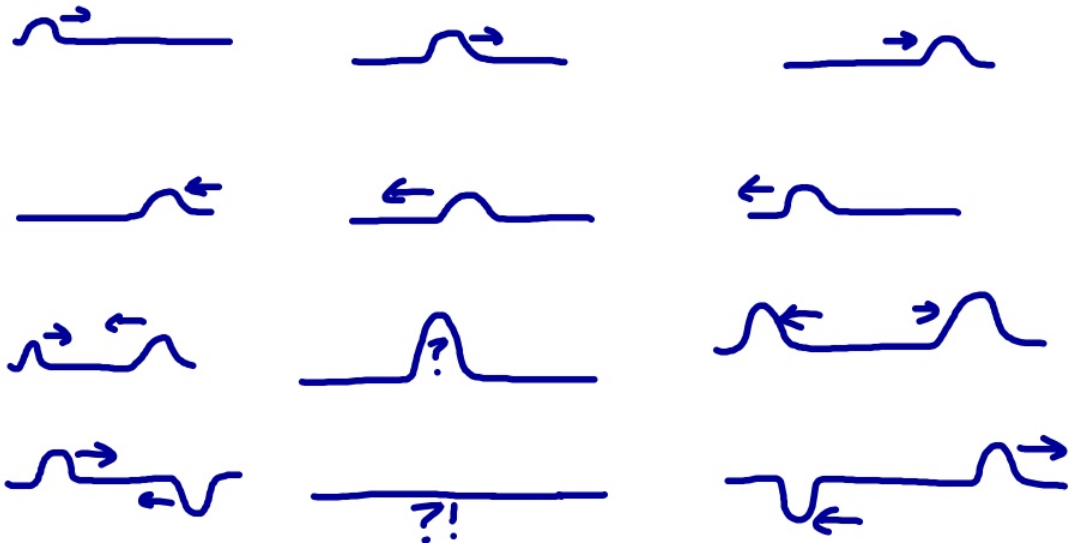
Nonlinearity: equations get much more complicated;
life gets much more interesting;
but most of us don't know how to solve the problems!
(will come back to this later in the term.)

Linearity -> Superposition

If one wave W_1 "is a solution of the wave equation"
("obeys the law" / "is allowed")
and so does some other wave W_2,
then either W_1 or W_2 *could happen*...

If the equation is linear, it turns out
$W_3 = W_1 + W_2$ *could also happen*...

Waves pass through each other



But they also "interfere" -- not in the normal sense!

Interference is the signature property of waves

When you "combine" ("superpose") two waves, they get bigger in some places, but smaller in others....

(But once they pass through each other, they keep going -- neither one "interferes" with the other's propagation in the normal English sense)