



## University Physics 226N/231N Old Dominion University

### More on Newton and Forces



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 Happy Birthday to Heike Kamerlingh Onnes (Nobel 1913), Donald Glaser (Nobel 1960), Faith Hill, and Bill Murray!  
Happy Miniature Golf Day, Pecan Cookie Day, and Get Out Of Town Today Day!

# Reiteration of Kinematics

- So far, everything we've done has followed from a few ideas
  - Position, velocity, and acceleration are **vectors**,  $\vec{v} = \frac{d\vec{x}}{dt}$   $\vec{a} = \frac{d\vec{v}}{dt}$
  - We can describe all motion with **constant acceleration** (including zero)
  - For each problem, **draw a picture** (including labeling axes, vectors, distances, and angles)
  - Figure out what's **known and unknown**
  - Break vectors down into **components**
- Then in each dimension of motion (e.g. horizontal/vertical) we have **two basic equations** to describe the motion in time

$$x - x_0 = v_0 t + \frac{1}{2} a t^2 \quad v = v_0 + a t$$

- For **projectile motion** the horizontal acceleration is zero (which makes the equations easier) and the vertical acceleration is the acceleration of gravity (where we need to use the full equations)



# Galileo and Newton

- Aristotle vs Galileo and Newton
- **Forces do not cause velocity**
- **Forces instead cause changes in velocity**
  - Hey, wait, this is just acceleration
- Yes, **forces are vectors** that are directly related to **acceleration**

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

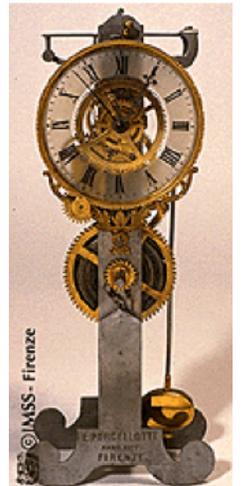
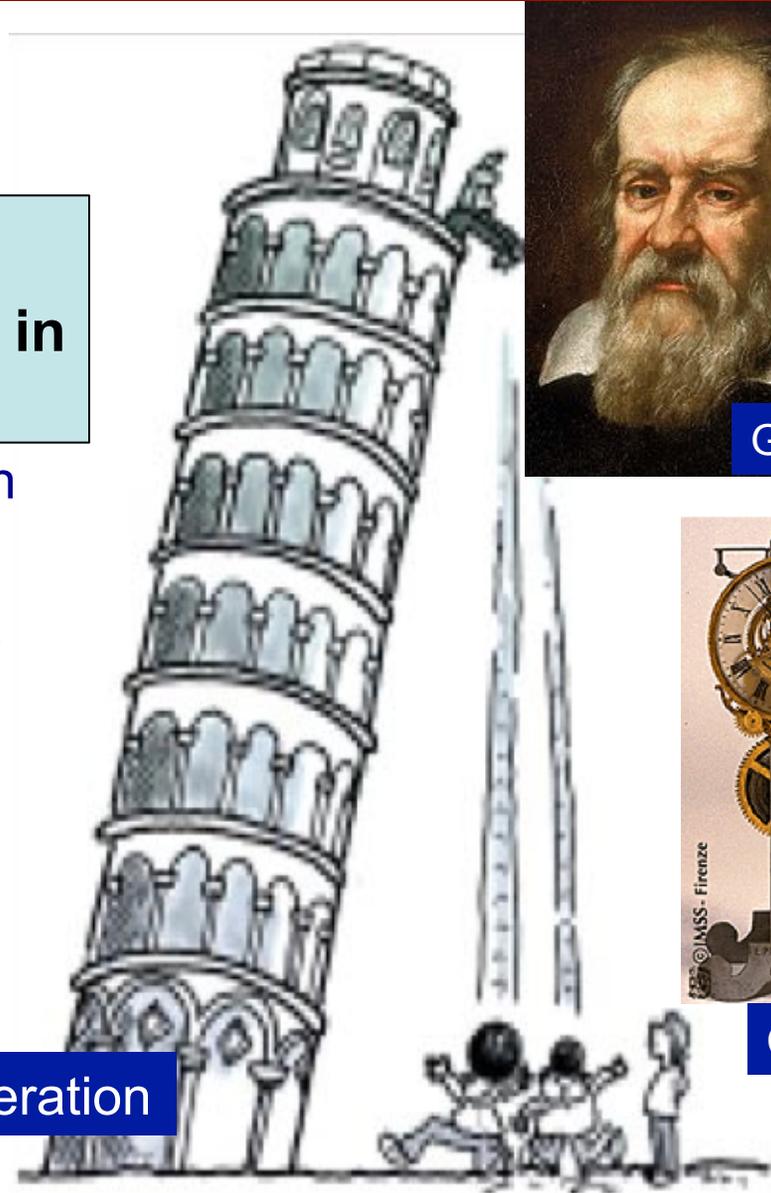
Net Force

Mass or Inertia

Acceleration



Galileo



Clock!



# Use the Force, Newt!

Newton's three "laws" of motion (1687)

## Newton's First Law

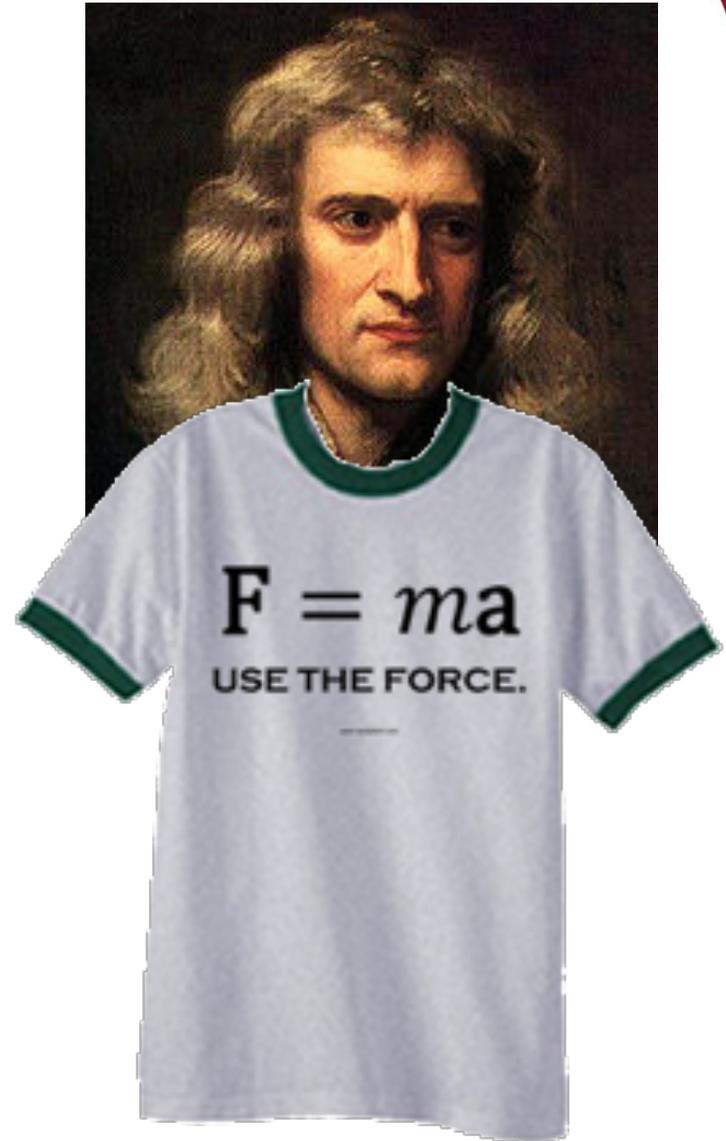
A body in uniform motion remains in uniform motion, and a body at rest remains at rest, unless acted on by a nonzero net force.

## Newton's Second Law

- This was basically  $\vec{F}_{\text{net}} = m\vec{a}$

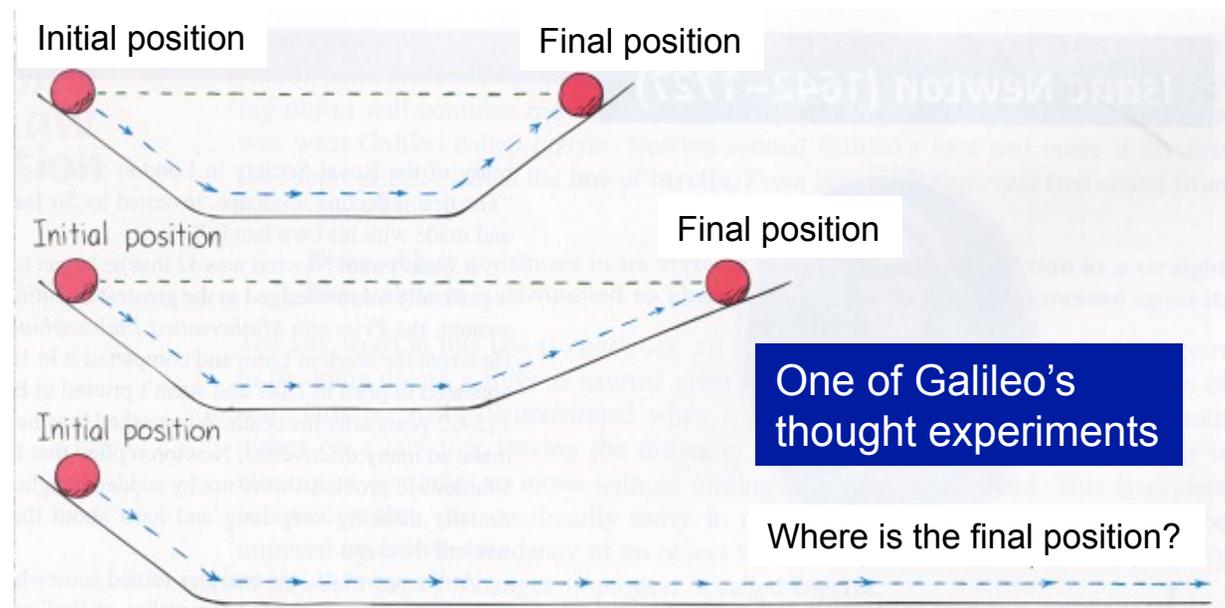
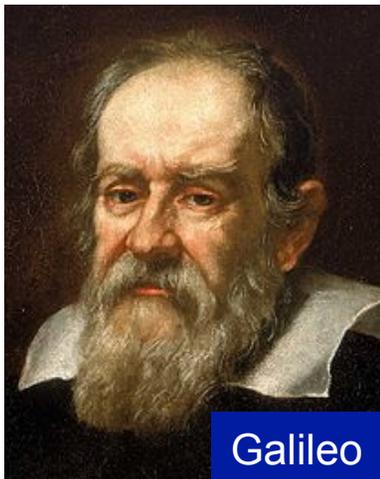
## Newton's Third Law

If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.



# Newton's First Law

- Newton's first law is a special case of the second law, when there's no net force acting on an object, that is, when  $\vec{F}_{\text{net}} = 0$ 
  - With no net forces, an object's motion (velocity) doesn't change.
  - If at rest it remains at rest. If in motion, it remains in uniform motion.
    - Uniform motion is motion at constant velocity in a straight line.
    - Thus the first law shows that uniform velocity is a natural state, requiring no explanation.



# Newton's Second Law

- The second law tells quantitatively how force causes changes in an object's "quantity of motion."
  - Newton defined "quantity of motion," now called **momentum**, as the product of an object's mass and velocity:

$$\vec{p} = m\vec{v}$$

Definition of momentum

- Newton's second law equates the rate of change of momentum to the net force on an object:

$$\vec{F} = \frac{\Delta\vec{p}}{\Delta t} = \frac{d\vec{p}}{dt}$$

Yes, that's a derivative

- When mass is constant, Newton's second law becomes

$$\vec{F} = \frac{d(m\vec{v})}{dt} = m \frac{d\vec{v}}{dt} = m\vec{a}$$

- The force required to accelerate a 1-kg mass at the rate of 1 m/s<sup>2</sup> is defined to be 1 **Newton (N)**.



# Momentum

- You have everyday experience with momentum

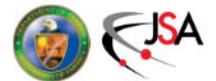
$$\vec{p} = m\vec{v}$$

If both are moving with same speed...



... the more massive object has higher momentum: which inflicts more damage in a crash?

- Later we'll get into **conservation laws**
  - Conservation of momentum** seems to be a **fundamental law**
  - Conservation of energy** also seems to be a **fundamental law**
- Newton's second law lets us figure out motion even when mass changes
  - What happens when things fall apart or stick together when moving?



# Mass, Inertia and Force

- If we solve the second law for the acceleration we find that

$$\vec{a} = \frac{\vec{F}}{m}$$

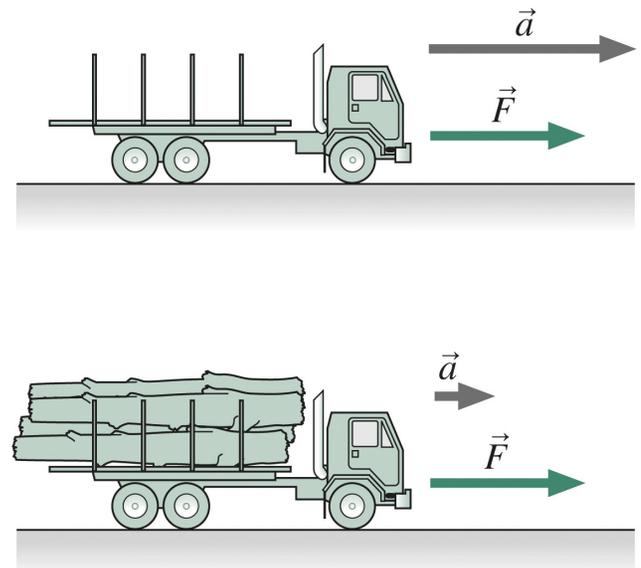
showing that a given force is less effective in changing the motion of a more massive object.

- The mass  $m$  that appears in Newton's laws is thus a measure of an object's **inertia** and determines the object's response to a given force.
- From Newton's second law for a force of magnitude  $F$ ,

$$\vec{F} = m_{\text{known}} \vec{a}_{\text{known}}, \quad \vec{F} = m_{\text{unknown}} \vec{a}_{\text{unknown}}$$

we get

$$\frac{m_{\text{unknown}}}{m_{\text{known}}} = \frac{a_{\text{known}}}{a_{\text{unknown}}}$$



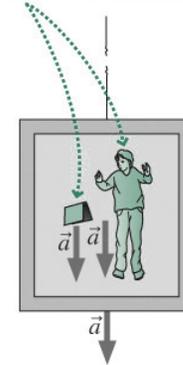
# Mass, Weight, and Gravity

- **Weight** is the force of gravity on an object:

$$w = mg$$

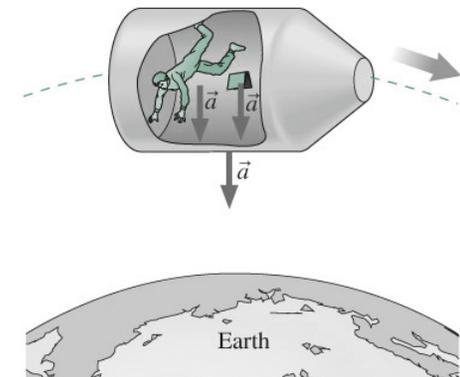
- Mass doesn't depend on the strength of gravity.
- Weight depends on gravity, so varies with location:
  - Weight is different on different planets.
  - Near Earth's surface,  $\vec{g}$  has magnitude 9.8 m/s<sup>2</sup> or 9.8 N/kg, and is directed downward.
- All objects experience the same gravitational acceleration, regardless of mass.
  - Therefore objects in **free fall** with an observer (under the gravity alone) appear **weightless (not massless)** because they share a common accelerated motion.
  - This effect is noticeable in orbiting spacecraft
    - because the absence of air resistance means gravity is the only force acting.
    - because the apparent weightlessness continues indefinitely, as the orbit never intersects Earth.

In a freely falling elevator you and your book seem weightless because both fall with the same acceleration as the elevator.



Earth  
(a)

Like the elevator in (a), an orbiting spacecraft is falling toward Earth, and because its occupants also fall with the same acceleration, they experience apparent weightlessness.



(b)

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# Newton's Second Law: Example

- A 740-kg elevator accelerates upward at  $1.1 \text{ m/s}^2$ , pulled by a cable of negligible mass. Find the tension force in the cable.
  - The object of interest is the elevator; the forces are gravity and the cable tension.

- Newton's second law reads

$$\vec{F}_{\text{net}} = \vec{T} + \vec{F}_g = m\vec{a}$$

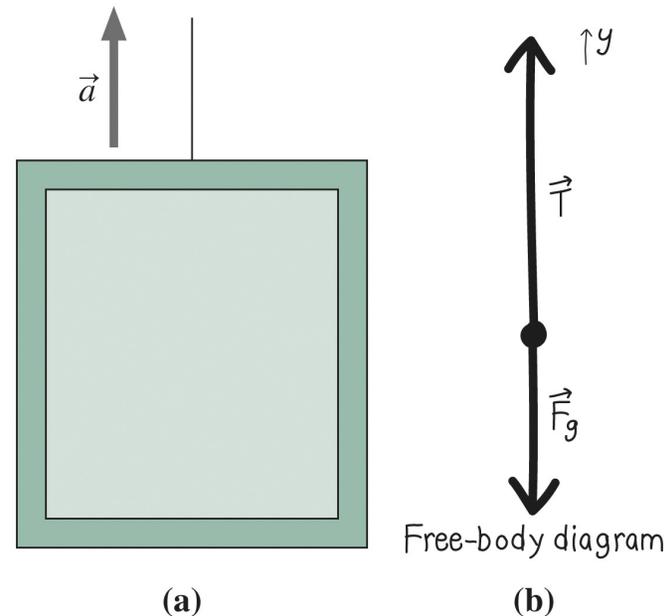
- In a coordinate system with  $y$ -axis upward, Newton's Second Law is

$$T_y + F_{gy} = ma_y$$

Solving gives

$$T_y = m(a_y + g) = 8.1 \text{ kN}$$

- Does this make sense? Let's look at some cases:
  - When  $a = 0$ ,  $T = mg$  and the cable tension balances gravity.
  - When  $T = 0$ ,  $a = -g$ , and the elevator falls freely.



# Pseudo-Ponderable

- A non-zero net force acts on an object. Does that mean the object necessarily is moving in the same direction as the net force?

A. Yes

B. No



# Pseudo-Ponderable

- A non-zero net force acts on an object. Does that mean the object necessarily is moving in the same direction as the net force?

A. Yes

B. No

- The English term for this is “deceleration”
- A net force (and thus an acceleration) can be in the opposite direction (or **any** direction) of the object’s motion (or velocity)
- Examples include
  - An elevator slowing down as it reaches a top or bottom floor
  - Braking in a moving vehicle
  - Circular motion (where the net force is towards the center of the circle, but velocity is around the circle)



## End-of-Class Ponderable

- Someone is holding a Slinky by one end and letting the other end dangle down near the ground
- At this point the Slinky is in equilibrium – all forces balance, the net force is zero, and the Slinky does not accelerate
- So... **What happens when he lets the Slinky go? How does the overall slinky move?**

See a movie at

[http://www.jokeroo.com/s\\_ho8k](http://www.jokeroo.com/s_ho8k)

Read about it at

<http://n.pr/QhyxTT>

