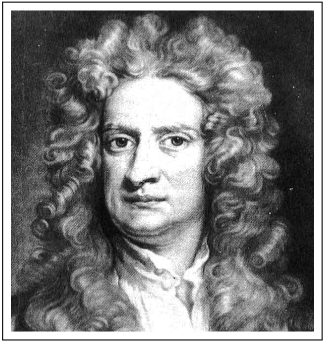
Chapter 5 - Force and Motion



"I know not what I appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell, whilst the great ocean of truth lay all undiscovered before me."

- Sir Isaac Newton
1643 - 1727
(84 years old!)

David J. Starling
Penn State Hazleton
PHYS 211

Introduction

- We know that the position of a body can be described by the following equation:
  - $\mathbf{r}(t) = \mathbf{r}_0 + \mathbf{v}_0 t + \frac{1}{2}\mathbf{a}t^2$

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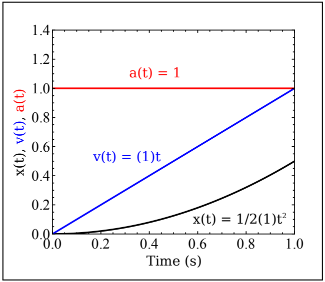

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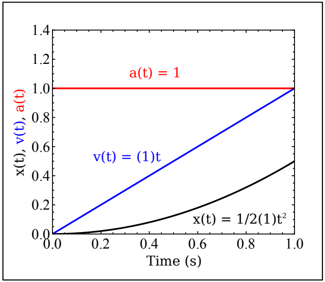

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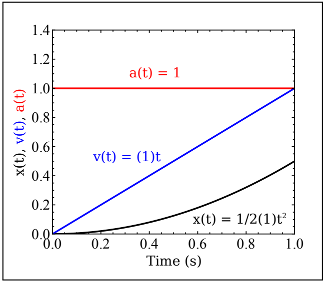

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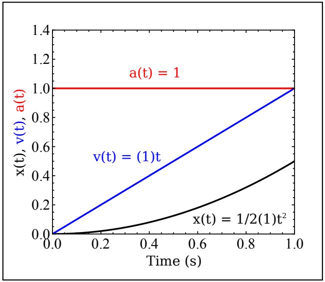

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  - This is called *dynamics*
  - Dynamics are described by Newton's Laws

Introduction

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$\approx 4,500$ years ago

≈ 2000 years ago

$\approx 4,400$ years ago

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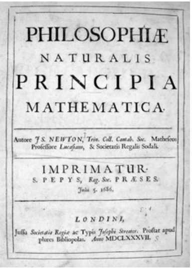


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore J S. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

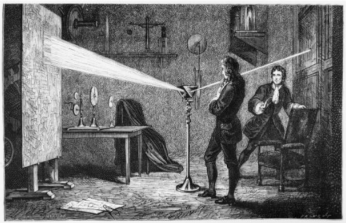
LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

325 years ago!

Introduction

Sir Isaac Newton's scientific contributions

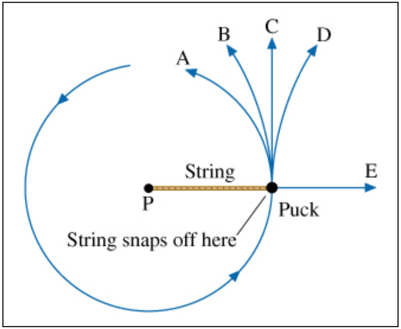
- Mathematics
- Kinematics
- Dynamics
- Gravitation
- Optics



NEWTON DÉCOMPOSE LA LUMIÈRE AU MOYEN DU PRISME

Newton's First Law

Consider the following diagram:



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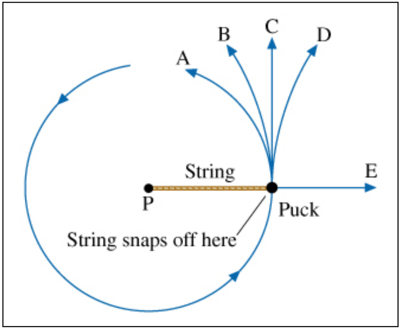
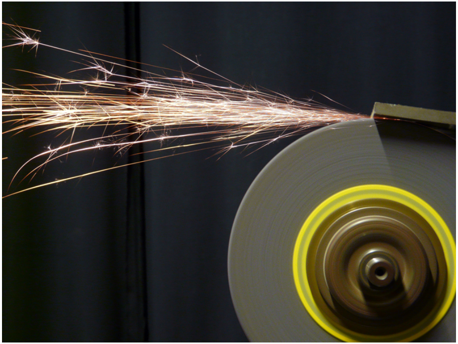


If the string suddenly snaps when the puck is in the position shown, which path best represents the puck’s subsequent motion?

Newton’s First Law

Interesting Example



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(The Law of Inertia)

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Examples:

- A puck or hockey player on ice
- A paper weight on your desk
- What else?

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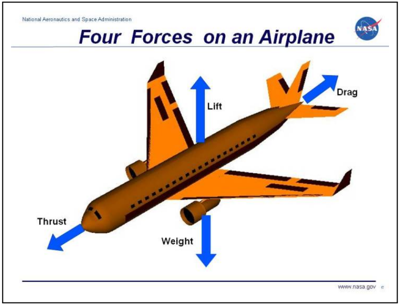
But what is a force?

Newton's First Law

But what is a force?

Types of forces:

- Tension
- Contact
- Friction
- Force at a distance
- Normal



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$$\sum_i \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ... = \vec{F}_{net}$$

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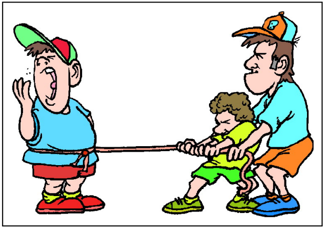
- An object with balancing forces



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$$\begin{aligned} \mathbf{v}(t) &= v_x(t)\hat{i} + v_y(t)\hat{j} + v_z(t)\hat{k} \\ \frac{d}{dt}\mathbf{v} &= \left(\frac{d}{dt}v_x(t)\right)\hat{i} + \left(\frac{d}{dt}v_y(t)\right)\hat{j} + \left(\frac{d}{dt}v_z(t)\right)\hat{k} = \vec{0} \end{aligned}$$

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\frac{d}{dt}v_x(t) &= \frac{d}{dt}v_y(t) = \frac{d}{dt}v_z(t) = 0
\end{aligned}$$

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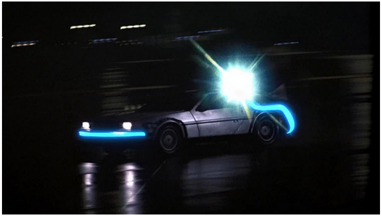

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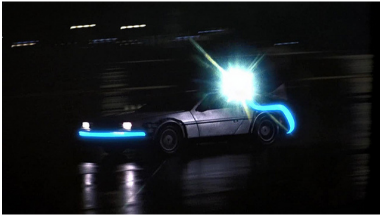

- Change the direction of $\vec{v}$

Newton's First Law

Lecture Question 5.1
When you drive your car down a straight highway at a constant velocity, the net force on your car is zero.

(a) True

(b) False, because of air drag.

(c) False, because of friction from the road.

(d) False because of air drag and friction from the road.

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An object acted upon by a net force accelerates according to

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

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- Force is in newtons (N) [$4.45\ \text{N} \approx 1\ \text{lb}$]

$$F = 100\ \text{lb} = 100\ \text{lb} \times 4.45 \frac{\text{N}}{\text{lb}} = 445\ \text{N}.$$

Lecture Question 5.2

A car of mass m is moving at a speed $3v$ in the left lane on a highway. In the right lane, a truck of mass $3m$ is moving at a speed v. As the car is passing the truck, both drivers apply the brakes to stop ahead at a red light. What is the ratio of the force required to stop the truck to that required to stop the car? Assume each vehicle stops with a constant deceleration and stops in the same distance x.

(a) 1/9

(b) 1/3

(c) 1

(d) 3

(e) 9

Newton’s Third Law

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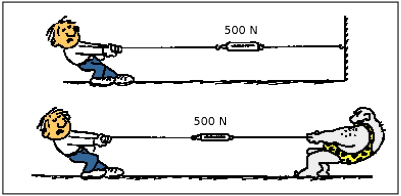
The mutual forces between two bodies are equal and opposite.



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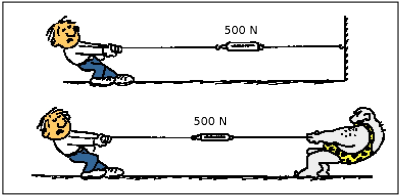
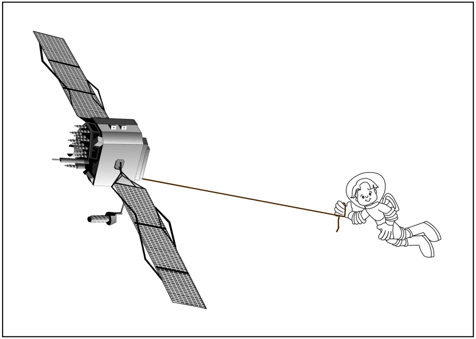


Other examples:

- Tug of war!
- Opening a door
- Jumping on a trampoline

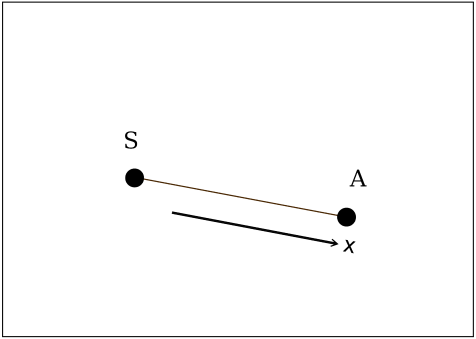
Newton's Third Law

Example: An astronaut ($m_a = 80$ kg) is tethered to a satellite ($m_s = 800$ kg) in a remote region of space. The astronaut pulls on the tether with 40 N of force. What happens?



Newton's Third Law

First, let's simplify this picture:



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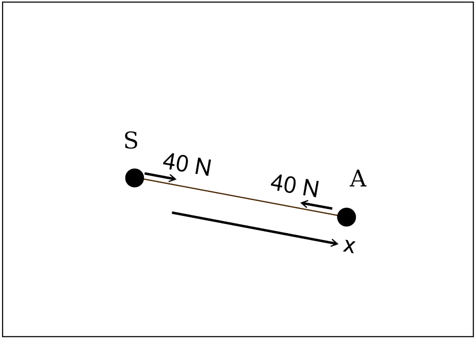
What are the forces on each object?



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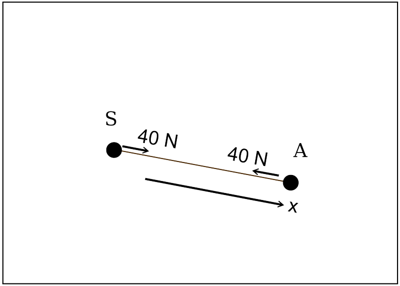

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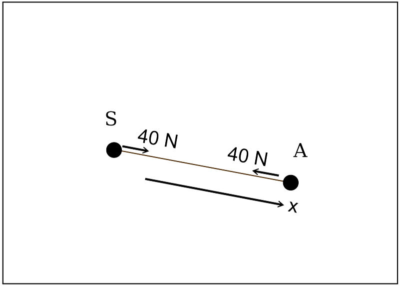

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- $\vec{F}_{net} = 40\hat{i} = m_s\vec{a}_s = 800\vec{a}_s$

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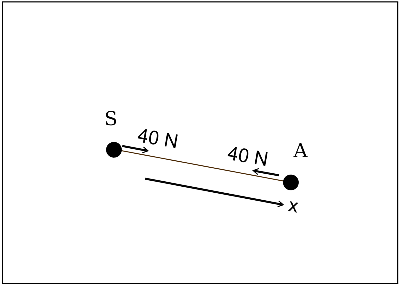

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- $\vec{F}_{net} = 40\hat{i} = m_s\vec{a}_s = 800\vec{a}_s$
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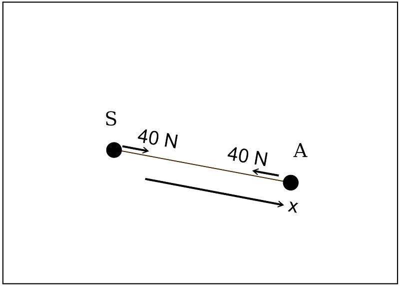

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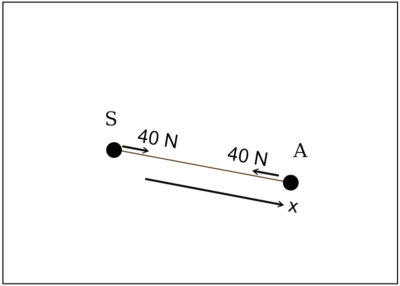

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- 3: The mutual forces between two bodies are equal and opposite.

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Problem Solving Techniques

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- Step 2: Draw each force on object(s)
- Step 3: Draw a set of axes and separate forces into components along them
- Step 4: Sum the forces (head to tail)
- Step 5: Set equal to $m\vec{a}$ and solve

Lecture Question 5.3

When a satellite travels around the Earth in a circular orbit, it moves at a (roughly) constant *speed*. Does Newton's first law apply in this situation?

(a) Yes

(b) No, because the satellite's position is changing

(c) No, because the satellite is also pulled by the sun

(d) No, because the satellite changes direction

(e) No, because the satellite's orbit eventually decays