Newton's Law of Motion

Physics 211
Syracuse University, Physics 211 Spring 2019
Walter Freeman

February 11, 2019

Announcements

- Homework 3 due Friday
- Office hours this week as before:
  - Wednesday 2-6
  - Thursday 1:45-3:45
- You will get new groups in recitation tomorrow

Forces

Rational mechanics must be the science of the motions which result from any forces, and of the forces which are required for any motions, accurately propounded and demonstrated. For many things induce me to suspect, that all natural phenomena may depend upon some forces by which the particles of bodies are either drawn towards each other, and cohere, or repel and recede from each other: and these forces being hitherto unknown, philosophers have pursued their researches in vain. And I hope that the principles expounded in this work will afford some light, either to this mode of philosophizing, or to some mode which is more true.

-Isaac Newton, *Philosophiae Naturalis Principia Mathematica* (1687), translated from the Latin by Whewell (1837)

Forces

*Mechanics involves figuring out how things move from knowing the forces that act on them, and figuring out what forces act on them if we know how they move. I suspect that all physical things involve things exerting forces on each other, and since people have not known what forces these are, nobody's been able to figure much out. Hopefully someone will read this book and figure this stuff out, either following my suspicion that it's all forces under the hood (***classical physics!***), or with some deeper understanding of nature (***quantum physics!***)*

-Isaac Newton, *Philosophiae Naturalis Principia Mathematica*, in modern English

Summary from last time

- Forces: anything that pushes or pulls
- Forces cause accelerations: $\sum \vec{F} = m\vec{a}$
  - If $\sum \vec{F} = 0$, $\vec{a} = 0$: motion at a constant velocity
- Forces come in pairs: if A pushes on B, B pushes back on A
- It's the vector sum $\sum \vec{F}$ that matters
- Draw force diagrams to keep all of this straight

What is a force?

A force is anything that pushes or pulls something:

- Gravity: $F = mg$, so $mg = ma \rightarrow a = g$
  - Gravity pulls down on everything (on Earth) with a force mg, called its weight
  - If something isn't accelerating downward, some other force must balance its weight

What is a force?

A force is anything that pushes or pulls something:

- Gravity: $F = mg$, so $mg = ma \rightarrow a = g$
- "Normal force": stops things from moving through each other
- Tension: ropes pull on both sides equally
  - What are the forces in a contest of tug-of-war?

What is a force?

A force is anything that pushes or pulls something:

- Gravity: $F = mg$, so $mg = ma \rightarrow a = g$
- "Normal force": stops things from moving through each other
- Tension: ropes pull on both sides equally
  - What are the forces in a contest of tug-of-war?
  - What about the forces on the people?
- Friction: a force opposes things sliding against each other

What is a force?

A force is anything that pushes or pulls something:

- Gravity: $F = mg$, so $mg = ma \rightarrow a = g$
- "Normal force": stops things from moving through each other
- Tension: ropes pull on both sides equally
  - What are the forces in a contest of tug-of-war?
  - What about the forces on the people?
- Friction: a force opposes things sliding against each other
- Electromagnetic forces, nuclear forces, radiation pressure...

What is a force?

A force is anything that pushes or pulls something:

- Gravity: $F = mg$, so $mg = ma \rightarrow a = g$
- "Normal force": stops things from moving through each other
- Tension: ropes pull on both sides equally
  - What are the forces in a contest of tug-of-war?
  - What about the forces on the people?
- Friction: a force opposes things sliding against each other
- Electromagnetic forces, nuclear forces, radiation pressure...
- Acceleration is not a force!
- ... it's the *result* of forces

Ask a physicist: time near black holes

Ask a physicist: time near black holes

... want a really amazing tombstone?

Suppose an object is moving in a straight line at a constant speed. Which number of forces could *not* be acting on it?

- A: Zero
- B: One
- C: Two
- D: Three
- E: Four

Suppose an object is moving in a straight line at a constant speed. Which number of forces could *not* be acting on it?

- A: Zero
- B: One
- C: Two
- D: Three
- E: Four

Suppose an object is moving in a circle at a constant speed. Which number of forces could *not* be acting on it? (Hint: what is the definition of velocity? Of acceleration?)

- A: Zero
- B: One
- C: Two
- D: Three
- E: Four

Forces in 2D (and 3D)

Force is a vector; handle it like any other

One copy of Newton's second law in each direction (per object)

$$\vec{F} = m\vec{a} \rightarrow \begin{pmatrix} F_x = ma_x \\ F_y = ma_y \end{pmatrix}$$

Forces in 2D (and 3D)

Force is a vector; handle it like any other

One copy of Newton's second law in each direction (per object)

$$\vec{F} = m\vec{a} \rightarrow \begin{pmatrix} F_x = ma_x \\ F_y = ma_y \end{pmatrix}$$

Important: When dealing with inclines, choose your axes to align with the incline! (That way you know $a_y = 0$!)

A problem-solving recipe (remember this!)

- Accounting: Draw force diagrams for every object
  - Pick a coordinate system for each object
  - Label each force with the algebraic symbol you'll use for it
  - Work out components (trigonometry) of vectors in funny directions – no need for numbers

A problem-solving recipe (remember this!)

- Accounting: Draw force diagrams for every object
  - Pick a coordinate system for each object
  - Label each force with the algebraic symbol you'll use for it
  - Work out components (trigonometry) of vectors in funny directions – no need for numbers
- Physics: Write down $\sum F = ma$ in each dimension, for each object
  - If any forces aren't aligned with your coordinates, that's fine – you did the components a bit ago, right?
  - Often motion is *constrained* – you know some components of $\vec{a}$ are zero

A problem-solving recipe (remember this!)

- Accounting: Draw force diagrams for every object
  - Pick a coordinate system for each object
  - Label each force with the algebraic symbol you'll use for it
  - Work out components (trigonometry) of vectors in funny directions – no need for numbers
- Physics: Write down $\sum F = ma$ in each dimension, for each object
  - If any forces aren't aligned with your coordinates, that's fine – you did the components a bit ago, right?
  - Often motion is *constrained* – you know some components of $\vec{a}$ are zero
- Math: Put in the stuff you know, solve for the stuff you don't
  - This will usually involve a system of equations
  - Solve this system by *substitution*, not other tricks (they often are hard/don't work)
  - Remember: normal forces and tensions are usually things you have to *solve for*

A problem-solving recipe (remember this!)

- Accounting: Draw force diagrams for every object
  - Pick a coordinate system for each object
  - Label each force with the algebraic symbol you'll use for it
  - Work out components (trigonometry) of vectors in funny directions – no need for numbers
- Physics: Write down $\sum F = ma$ in each dimension, for each object
  - If any forces aren't aligned with your coordinates, that's fine – you did the components a bit ago, right?
  - Often motion is *constrained* – you know some components of $\vec{a}$ are zero
- Math: Put in the stuff you know, solve for the stuff you don't
  - This will usually involve a system of equations
  - Solve this system by *substitution*, not other tricks (they often are hard/don't work)
  - Remember: normal forces and tensions are usually things you have to *solve for*
- Kinematics: Connect acceleration to motion

A problem-solving recipe (remember this!)

- Accounting: Draw force diagrams for every object
  - Pick a coordinate system for each object
  - Label each force with the algebraic symbol you'll use for it
  - Work out components (trigonometry) of vectors in funny directions – no need for numbers
- Physics: Write down $\sum F = ma$ in each dimension, for each object
  - If any forces aren't aligned with your coordinates, that's fine – you did the components a bit ago, right?
  - Often motion is *constrained* – you know some components of $\vec{a}$ are zero
- Math: Put in the stuff you know, solve for the stuff you don't
  - This will usually involve a system of equations
  - Solve this system by *substitution*, not other tricks (they often are hard/don't work)
  - Remember: normal forces and tensions are usually things you have to *solve for*
- Kinematics: Connect acceleration to motion

It really is this easy; I promise!

A problem-solving recipe (remember this!)

- Accounting: Draw force diagrams for every object
  - Pick a coordinate system for each object
  - Label each force with the algebraic symbol you'll use for it
  - Work out components (trigonometry) of vectors in funny directions – no need for numbers
- Physics: Write down $\sum F = ma$ in each dimension, for each object
  - If any forces aren't aligned with your coordinates, that's fine – you did the components a bit ago, right?
  - Often motion is *constrained* – you know some components of $\vec{a}$ are zero
- Math: Put in the stuff you know, solve for the stuff you don't
  - This will usually involve a system of equations
  - Solve this system by *substitution*, not other tricks (they often are hard/don't work)
  - Remember: normal forces and tensions are usually things you have to *solve for*
- Kinematics: Connect acceleration to motion

It really is this easy; I promise!
"Ask physics the question, don't tell it the answer"

Sample questions: dealing with two dimensions

A stone hangs from the roof of a car by a string; the car accelerates forward at 3 $\mathrm{m/s^2}$.

- What happens to the string?

Sample questions: dealing with two dimensions

A stone hangs from the roof of a car by a string; the car accelerates forward at 3 $\mathrm{m/s^2}$.

- What happens to the string?
- What angle does the string make with the vertical?

Sample questions: dealing with two dimensions

A stone hangs from the roof of a car by a string; the car accelerates forward at 3 m/s^2.

- What happens to the string?
- What angle does the string make with the vertical?
- What is the tension in the string?

Sample questions: dealing with two dimensions

A cart slides down a frictionless track elevated at angle θ; what is its acceleration?

Sample questions: dealing with two dimensions

A cart on a frictionless track is connected to a string running over the side; what is its acceleration?

Sample questions: dealing with multiple objects

Two masses of m_1 and m_2 kg hang from a massless pulley on either side. How do they move?

Summary

- Forces: anything that pushes or pulls
- Forces cause accelerations: $\sum \vec{F} = m\vec{a}$
  - If $\sum \vec{F} = 0$, $\vec{a} = 0$: motion at a constant velocity
- Forces come in pairs: if A pushes on B, B pushes back on A
- It's the vector sum $\sum \vec{F}$ that matters
- Draw force diagrams to keep all of this straight