Newton's Law of Motion

Physics 211
Syracuse University, Physics 211 Spring 2023
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Announcements

- Homework 3 due next Wednesday (will be posted today; shorter than HW2)
- You will get new groups in recitation Friday or Wednesday
- Exam 1 is mostly graded; you will get your grades back in recitation this week or next

Newton's laws

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

- Forces on an object cause it to accelerate
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- The larger the mass, the smaller the acceleration
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- The larger the mass, the smaller the acceleration
- You intuitively know this already
- No forces $\rightarrow$ no acceleration: not necessarily no motion!

- Forces come in pairs (Newton's third law)
  - "If A pushes on B, B pushes back on A"
  - Very important to be clear about what forces you're talking about

Newtons

We need a new unit for force: the newton

$$\vec{F} = m\vec{a} \rightarrow \text{Force has dimensions kg m/s}^2$$

- 1 N = 1 kg m/s^2: about the weight of an apple
- 4 N is about a pound
- 9.8 N is the weight of a kilogram

Force is a vector

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

- Force is a *vector*
- Multiple forces on an object add like vectors do
- Really, we should write

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

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
  - We are now switching the way we think about gravity!
    - Before: gravity makes objects in free fall accelerate downward at g
    - Now: gravity is just one of *many* forces that can act on objects

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  - Are there normal forces on me right now?
  - However big it needs to be to stop objects from sliding through each other
  - The normal force is usually an unknown you will need to solve for, not a thing you know
  - Directed "normal" (perpendicular) to the surface
  - Really caused by electric force/Pauli exclusion principle

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- Electromagnetic forces, nuclear forces, radiation pressure...
- Acceleration is not a force!
- ... it's the *result* of forces

One particular force: gravity

Gravity exerts a downward force on all objects (on Earth), with a magnitude of mg.

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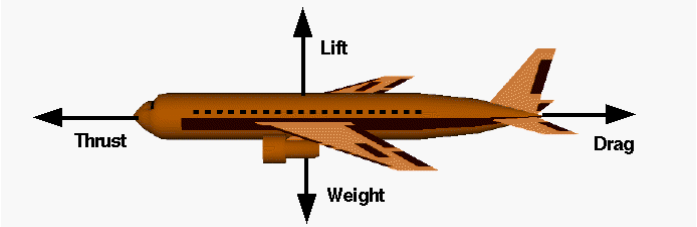
Why is the acceleration of a falling object g downward?

- A: Because g is the acceleration of all objects within Earth's gravitational field
- B: Solve Newton's law: $\vec{F} = m\vec{a} \rightarrow mg(-\hat{j}) = m\vec{a} \rightarrow \vec{a} = -g\hat{j}$
- C: Because the definition of g is the acceleration that a falling object undergoes
- D: It's only g if there are no other forces besides gravity acting on it

Force diagrams

- Lots of forces, easy to get confused
- Draw a picture!



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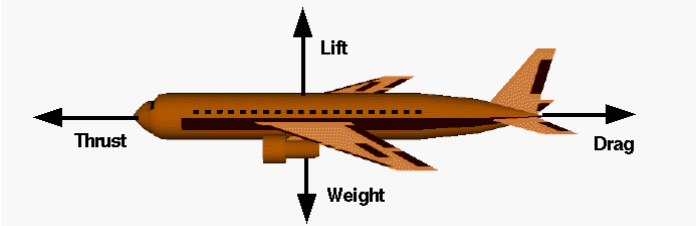

- Each object feeling forces gets a separate diagram
- Label each force and its direction
- These are also called “free body diagrams”

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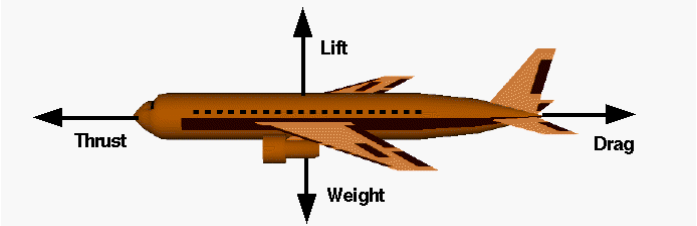

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(Examples on document camera)

An example

(Use 10 m/s^2 for g, please!)

An aircraft at an air show has a mass of 10,000 kg and its engine produces a maximum thrust of 130 kN.

If it is using its engine at full power to take off (on the ground), what is its acceleration?

(Neglect air resistance for now – this only matters once it is moving quickly)

- A: 10 m/s^2 downward
- B: 13 m/s^2 forward
- C: 23 m/s^2 forward
- D: 3 m/s^2 forward

An example

The pilot wants to show off for the crowd, so they point the aircraft straight upward once it is in the air.

(Again, it has a mass of 10,000 kg and its engine has a thrust of 130 kN.)

What is its acceleration now?

- A: 10 m/s^2 downward
- B: 3 m/s^2 downward
- C: 13 m/s^2 upward
- D: 3 m/s^2 upward
- E: 23 m/s^2 upward

An example

Suppose the pilot then dives straight down at high speed, using their engines to push them downward faster.

Since they are going so fast, there is substantial air resistance.

If the plane's acceleration is 8 m/s^2 downward, what is the force of air resistance? (Again, the aircraft has a mass of 10,000 kg and its engine has a thrust of 130 kN.)

- A: 100 kN downward
- B: 100 kN upward
- C: 150 kN upward
- D: 80 kN downward
- E: 230 kN upward

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
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- D: Three
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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

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(Use $\vec{F} = m\vec{a}$ to connect force to acceleration, and then kinematics to connect acceleration to motion)

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- Acceleration is not a force
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- If two things don't touch, or interact by gravity, electricity, etc., they don't exchange forces
- "A force is something that can send you to the doctor"

A sample problem

A stack of two books sits on a table. Each book weighs 10 newtons. Draw a force diagram for each one, and calculate the size of all the forces.

(Your answer should match what you know about how this works!)

Which of the following is/are *not* an example of Newton's third law?

- A: a subway car accelerates forward; you are thrown back
- B: the propeller on an airplane pushes the air backwards; the air pushes the airplane forwards
- C: an elevator accelerates upward; passengers are pushed downward
- D: the Earth's gravity pulls downward on me; my gravity pulls upward on the Earth
- E: a rocket pushes downward on its exhaust; the exhaust pushes upward on the rocket

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