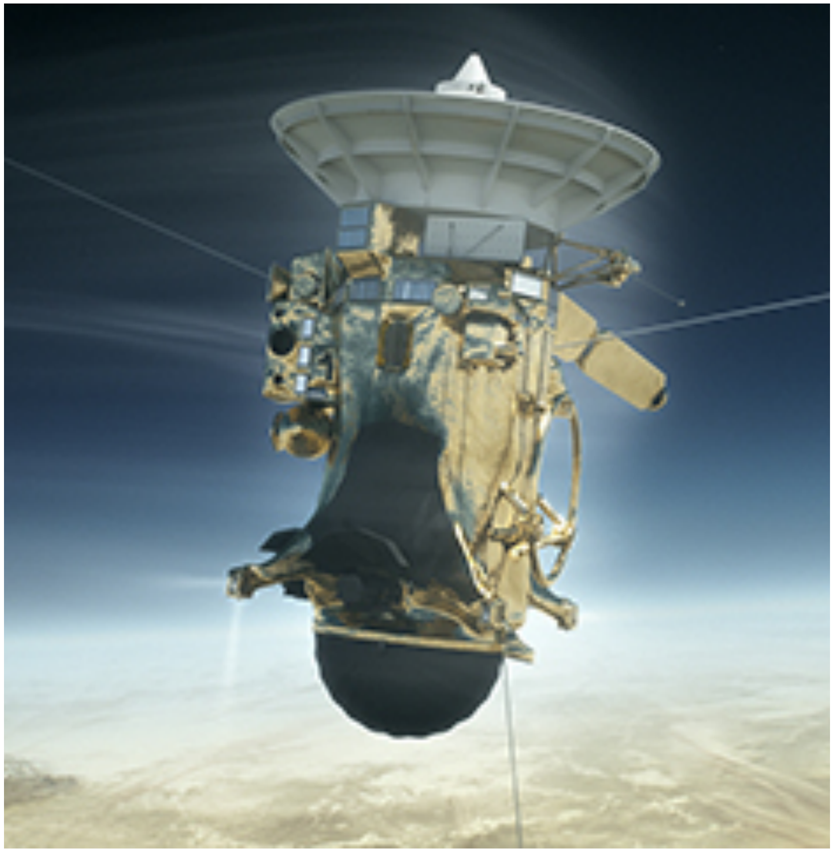
[06] Laws of Motion (9/14/17)

Upcoming Items

1. Homework #3 due next class.
2. Read Ch. 4.3–4.4 by next class and do the self-study quizzes.

Thanks for all you've taught us!

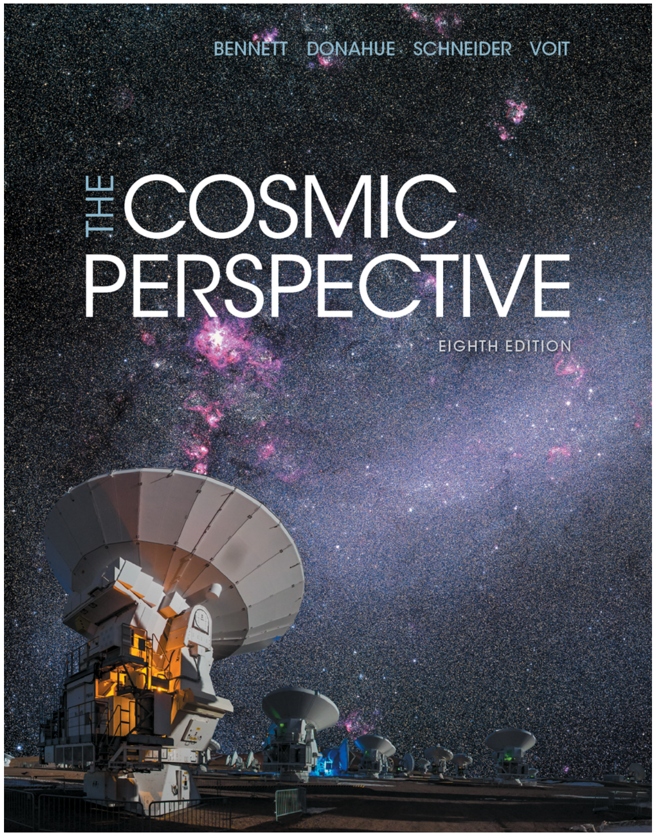


LEARNING GOALS

Chapters 4.1–4.2

For this class, you should be able to…

- … *distinguish between speed, velocity, and acceleration, and be able to determine whether a net force is acting on an object based on its motion;*
- … *explain the relationship between mass, apparent weight, and net force.*
- … *apply Newton's laws of motion to astrophysical situations.*



Reminder

- Please fill out your pre-discussion question by tonight!

Any astro questions?

In-class quiz!

1. Suppose you throw a ball directly upward. Which of the following statements best describes how Newton's 2nd Law accounts for the motion of the ball when it reaches its maximum height?

A. The ball has a velocity that is zero and an acceleration that is zero.
B. The ball has a velocity that is upward and an acceleration that is downward.
C. The ball has a net force that is downward and an acceleration that is downward.
D. The ball has a net force that is downward and a velocity that is downward.
E. The ball has a net force that is downward and an acceleration that is zero.

2. Which of the following is impossible?

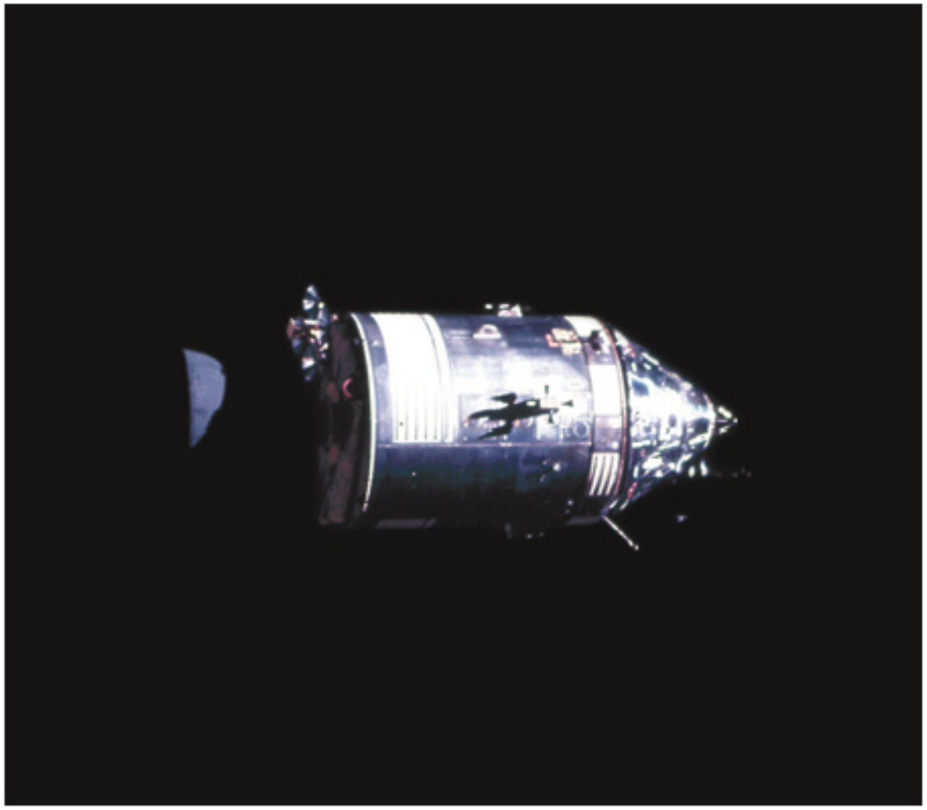
A. An object having zero velocity and non-zero acceleration.
B. An object having non-zero velocity and zero acceleration.
C. An object whose acceleration is northward and velocity is southward.
D. An object with constant velocity and constant acceleration.
E. An object with constant velocity and changing acceleration.

The preliminaries: describing motion

- As indicated in the last class, vectors are really useful!
  A vector has both magnitude and direction
- Suppose we have an object at a position **r** (we have defined an origin of our coordinates somewhere)
  Note that we use boldface to denote a vector
  You can also put an arrow over the symbol
- Then the rate of change of the position is the velocity, or:
  d**r**/dt=**v** Momentum is mass times velocity: **p**=m**v.**
- The rate of change of the velocity is the acceleration, or:
  d**v**/dt=**a**.
- Please keep these definitions in mind!
- Any questions at this stage? Important to ask!

Newton's First Law of Motion

- An object moves at constant velocity unless a net force acts to change its speed or direction.



Newton's Second Law of Motion

- Force = mass × acceleration. **F=ma**

In more detail...

- Note that Newton's first and second laws can be combined nicely
- Newton 2: "**F**=m**a**"
  Equivalently, "Force is the rate of change of momentum"
  Or, **F**=d**p**/dt
- Why equivalent? Momentum is mass times velocity, and in Newtonian physics the mass of an object is constant: **p**=m**v**
  As a result, d**p**/dt=d(m**v**)/dt=**v**dm/dt+md**v**/dt=md**v**/dt=m**a**
- m=const=>changing momentum means changing velocity
- If there is no force, there is no change in velocity
- Thus Newton's first law follows!
- **F**=d**p**/dt is more general (holds in relativity too)

Newton’s Third Law of Motion

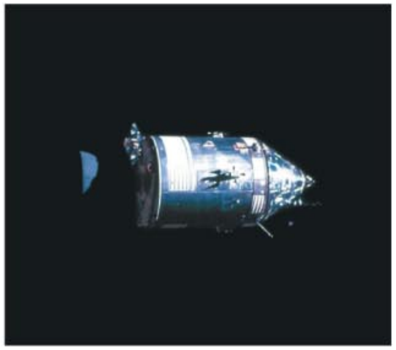
- For every force, there is always an *equal and opposite* reaction force.

Newton 3 in vectors

- Suppose we have two objects, A and B
- Let the force of A on B be $\mathbf{F}_{AB}$, and the force of B on A be $\mathbf{F}_{BA}$
- Then Newton's third law tells us that:
  $\mathbf{F}_{AB} = -\mathbf{F}_{BA}$
  Equal magnitude, but opposite direction (that's the minus)
- Note the amazing generality of this; it doesn't matter what the force is!
  Could be gravity, could be electromagnetism, could be nuclear forces, could be some weird force not yet discovered
- Has implications for which quantities are conserved, as we'll see next time

Newton's Laws

Newton's first law of motion:
An object moves at constant velocity unless a net force acts to change its speed or direction.



Example: *A spaceship needs no fuel to keep moving in space.*

Newton's second law of motion:
Force = mass × acceleration

Example: *A baseball accelerates as the pitcher applies a force by moving his arm. (Once the ball is released, the force from the pitcher's arm ceases, and the ball's path changes only because of the forces of gravity and air resistance.)*

Newton's third law of motion:
For any force, there is always an equal and opposite reaction force.

Example: *A rocket is propelled upward by a force equal and opposite to the force with which gas is expelled out its back.*

Angular Momentum

- What we normally call "momentum" is more precisely *linear* momentum, usually represented by **p**
- The rotational equivalent is *angular* momentum; unfortunately the notation isn't universal, but we'll use **L**
- Linear momentum is given by **p**=m**v**
- For angular momentum, you need to define a point around which you calculate the angular momentum of your object
- For example, suppose that your object is **r** away from that point
- Then **L**=**r**x**p** (vector cross product)

Change in Angular Momentum

- Just as **p** can change if there is a force (**F**=d**p**/dt), L can change if there is a torque (often represented as **N**): **N**=d**L**/dt=d(**r**x**p**)/dt=**r**x(d**p**/dt)+(d**r**/dt)x**p**
- But we can simplify this. Remember that **p**=m**v**, and that d**r**/dt=**v**.
- Thus (d**r**/dt)x**p**=**v**x(m**v**)=m(**v**x**v**)=0 (the cross product of a vector with itself is zero)
- Also d**p**/dt=**F**, from Newton's second law
- Therefore, the torque is **N**=d**L**/dt=**r**x**F**
- Just as linear momentum is constant if there is not an external force, angular momentum is constant if there is not an external torque, or if **F** is parallel to **r** (as in a central force)

Thought Question

How does the force the Earth exerts on you compare with the force you exert on it?

A. Earth exerts a larger force on you.

B. You exert a larger force on Earth.

C. **Earth and you exert equal and opposite forces on each other.**

Group Exercise

1. The OSIRIS-REx spacecraft needed to achieve a speed relative to Earth of at least 11 km/s to escape into space. What *constant* acceleration would the rockets need to provide to get to that speed in 1 hour? Express your answer in units of g (9.8 m s^{-2}).
2. What average force was exerted (in N), if the spacecraft mass was 1,000 kg?

NOTE: this is all approximate, because the spacecraft jettisoned a lot of mass during flight and did not do a constant burn.

You're aboard the International Space Station and are enjoying a feeling of "weightlessness" as you float around. What can you say about your weight and the forces acting on you?

A. Your true weight is zero, and no force is acting on you.
B. Your true weight is zero, and a force is acting on you.
C. Your apparent weight is zero, and no force is acting on you.
D. **Your apparent weight is zero, and a force is acting on you.**

ClassAction: Renaissance Astronomy

- G11: Applying Newton's Laws 1
- G23: Forces and Motion
- D3: Applying Newton's Laws 2

Gravity Clip!