Making Sense of the Universe (Chapter 4)

Why does the Earth go around the Sun?

Part, but not all, of Chapter 4

Based on part of Chapter 4

- This material will be useful for understanding Chapters 8 and 11 on “Formation of the solar system” and “Jovian planet systems”
- Chapters 2 and 3 on “The structure and size of the universe” and “Years, seasons, and months” will be useful for understanding this chapter

Goals for Learning

- What is Newton’s Law of Gravity?
- What causes tides?
- What are speed, velocity, and acceleration?
- What are Newton’s Laws of Motion?

Why does the Earth go around the Sun?

- Kepler’s Laws are just a description of HOW planets move
- They don’t say WHY the planets move like that

- 70 years after Kepler discovered HOW, Isaac Newton discovered WHY

Isaac Newton

Isaac Newton (1642-1727)

- Born in the year of Galileo’s death, Newton worked at a time when Copernicus’s idea of Earth orbiting the Sun and Kepler’s Laws were commonly accepted

- Newton was the first person to propose laws of physics that applied both on Earth and in the heavens

Gravity

- Things fall down, fall towards the centre of the Earth.
- Why don’t the Sun, Moon, planets, and stars fall down as well?

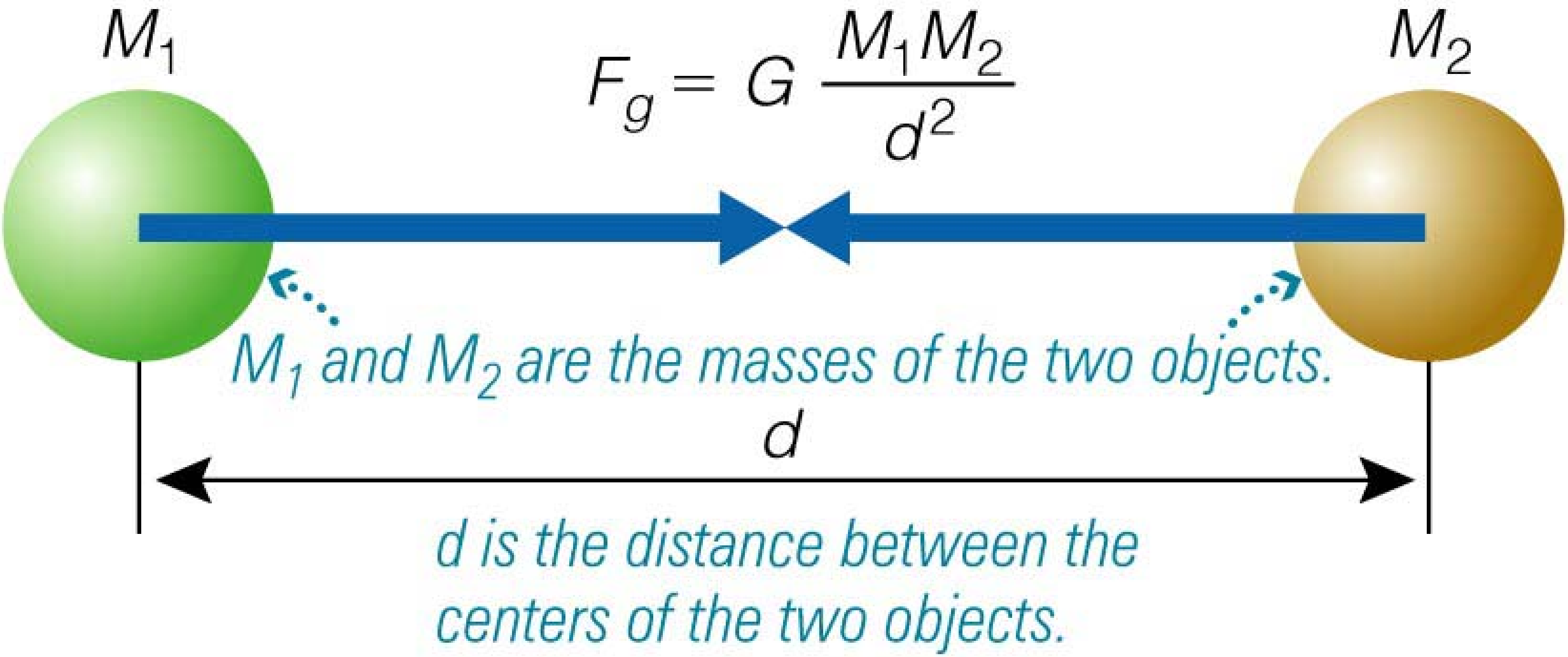
- This question was answered with Newton’s law of gravity

Newton’s Law of Gravity

- Every mass attracts every other mass through the force called gravity

- Applies to every object in the universe
- Always an attractive force, never a repulsive force

The ***universal law of gravitation*** *tells us the strength of the gravitational attraction between the two objects.*



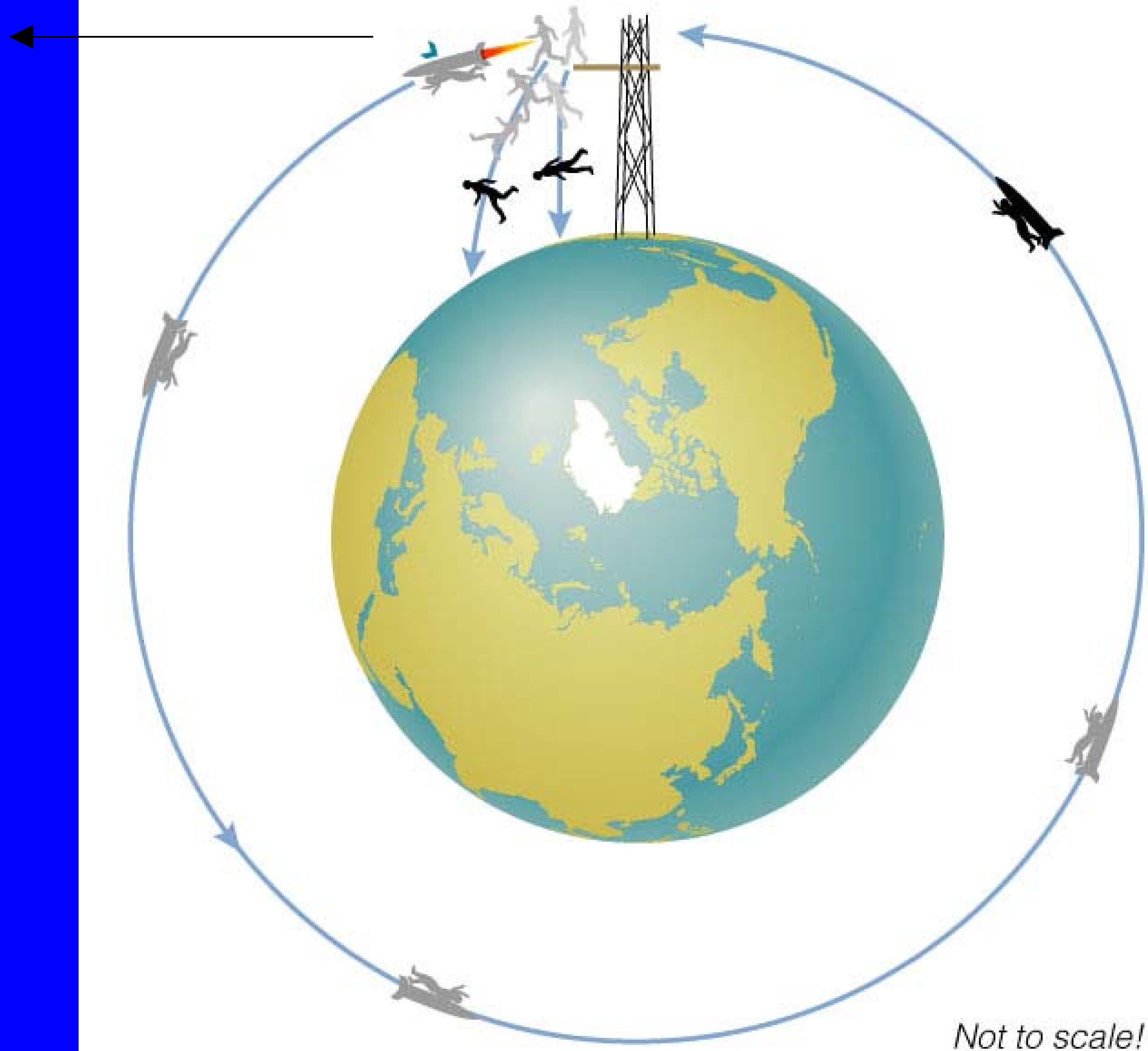
$$F_g = G\frac{M_1 M_2}{d^2}$$

G = gravitational constant = $6.67 \times 10^{-11}\ m^3 / (kg \times s^2)$

What does a force do?

- Forces cause acceleration, a change in the speed and direction of an object’s motion
- An object with a large mass is accelerated more by a fixed force than an object with a small mass is

- Why does $F = GM_1M_2/d^2$ lead to orbits?



Interactive Figure 4.22 Cannonballs

Planets orbit the Sun (Copernicus)

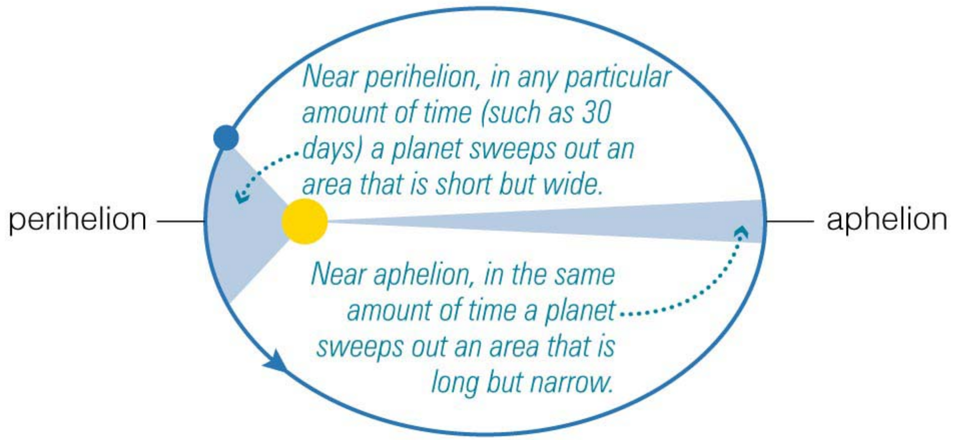
- The Sun is much heavier than any of the planets
- Since the Moon orbits the Earth, the Earth is much heavier than the Moon

Orbits are Ellipses (Kepler 1)

- Newton's law of gravity plus lots of math explains why planets must orbit the Sun in circles or ellipses, rather than any other kind of shape

- Bonus – Newton's Law also makes predictions for shape of comet orbits, which Kepler's Laws do not

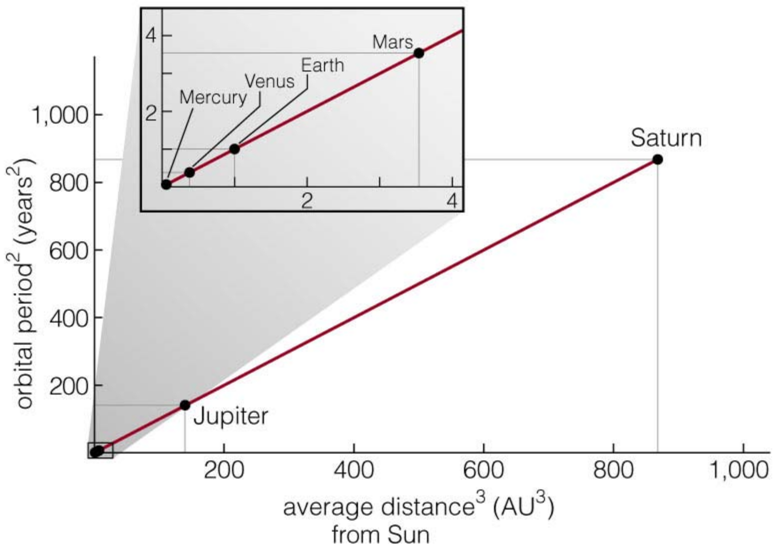
Planets go fastest when close to the Sun (Kepler 2)



The areas swept out in 30-day periods are all equal.

- $F = G\, M_1 M_2 / d^2$
- The gravitational force on the planet due to the Sun is stronger at perihelion than at aphelion
- The planet is accelerated more at perihelion than at aphelion
- The planet goes faster at perihelion than at aphelion

$(p/years)^2 = (a/AU)^3$ (Kepler 3)

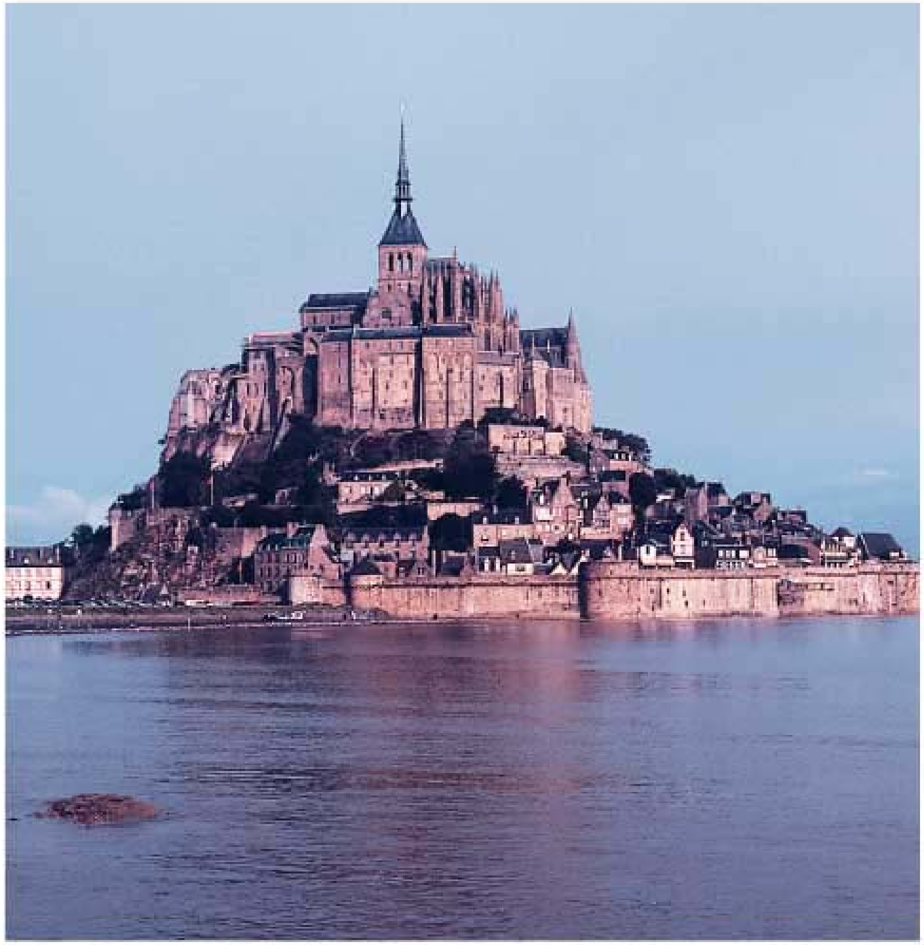


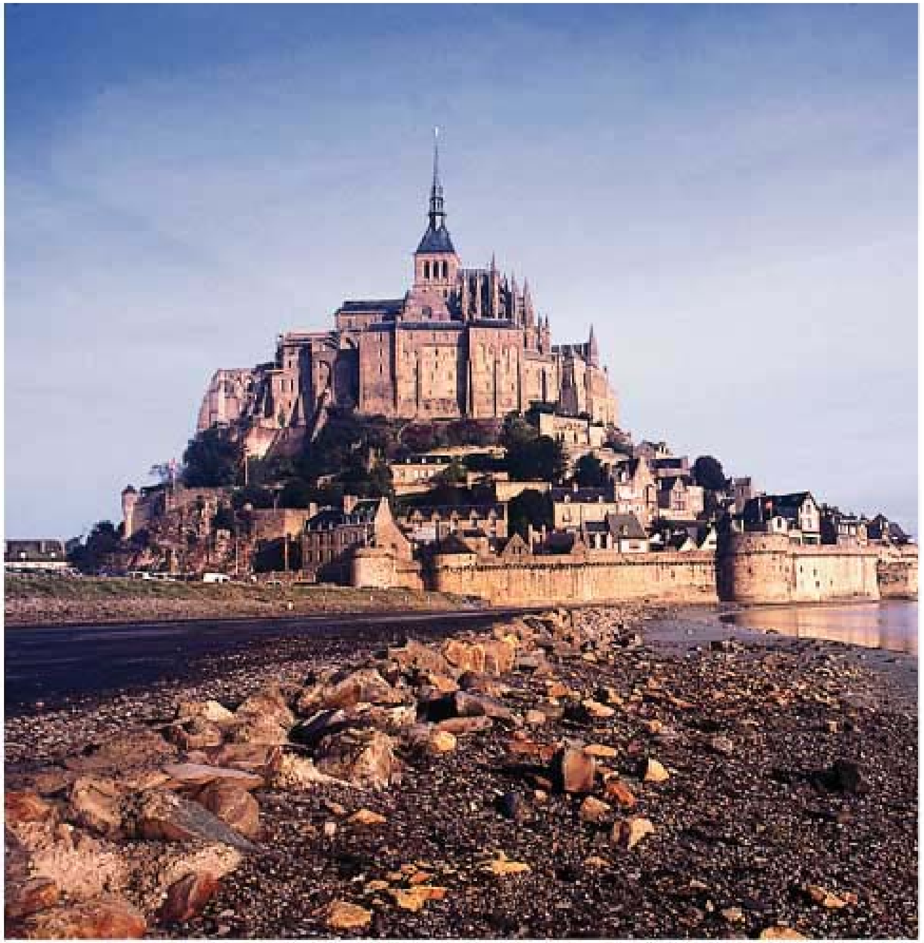
- $F = G M_1 M_2 / d^2$ plus lots of math leads to
- $p^2 = a^3 \times 4\pi^2 / (G M_{Sun})$
- Period depends only on the mass of the Sun.
- All planets orbit the same Sun

Summary

- $F = G M_1 M_2 / d^2$ explains
- Planets go around Sun, not Earth
- All three of Kepler's Laws
- Orbits of comets
- Plus it allows us to determine masses of objects

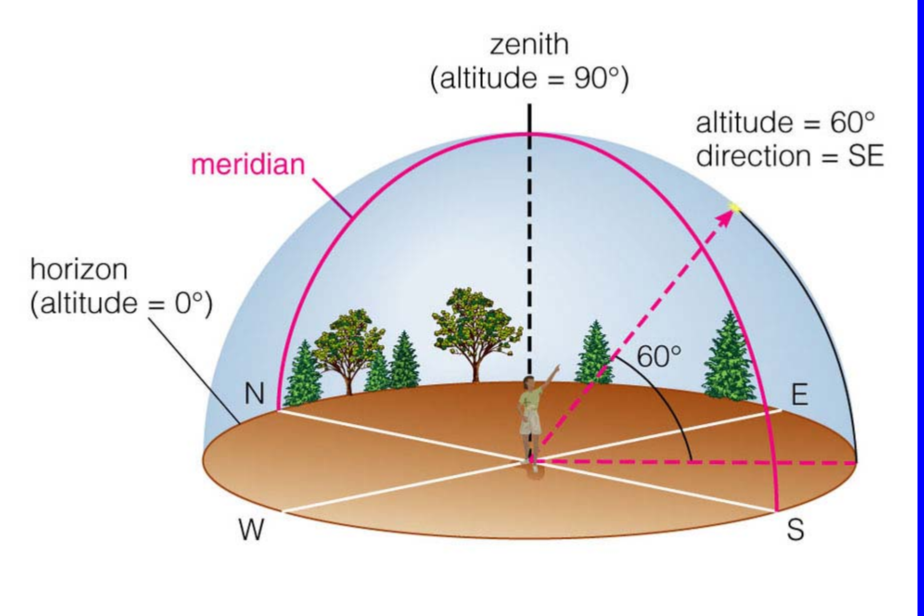
Tides

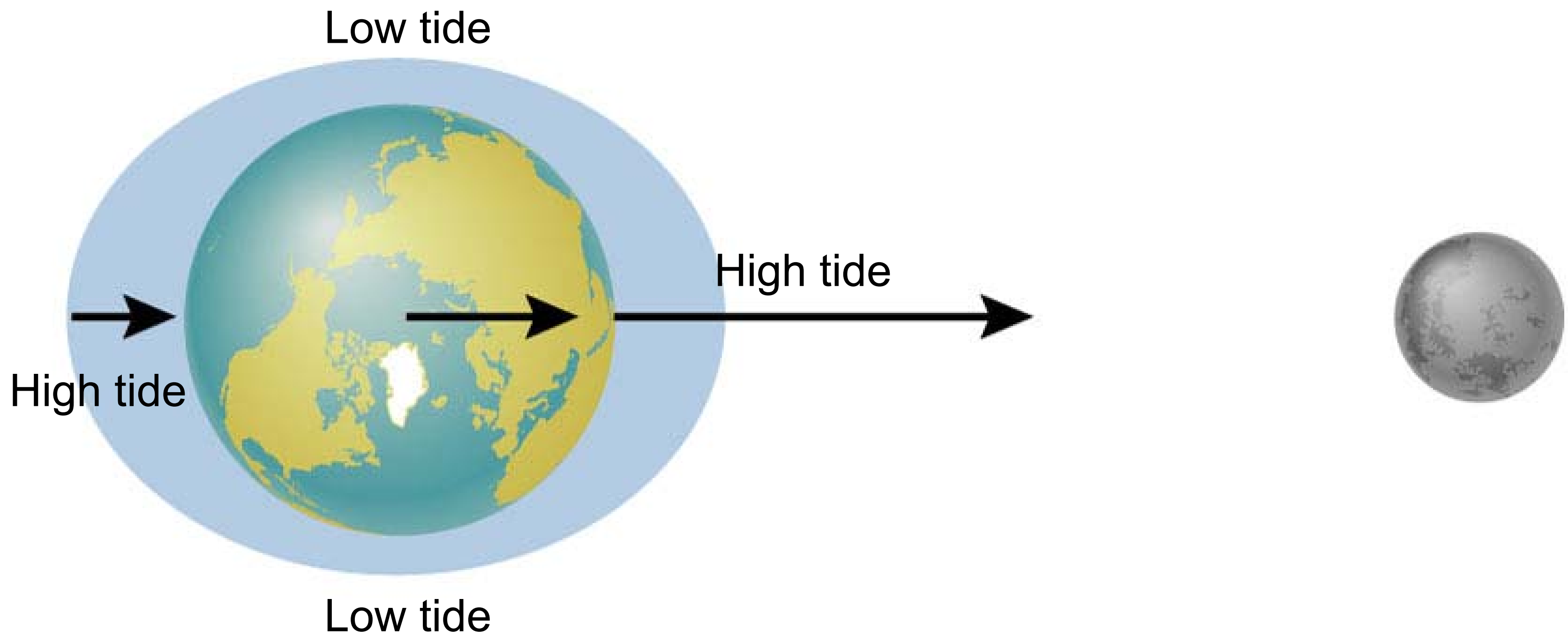




Observations of Tides

- Two high tides and two low tides every 25 hours (just longer than one day)
- The Moon crosses the meridian in the sky every 25 hours.
- One high tide occurs when the Moon crosses the meridian in the sky
- The other high tide occurs halfway between these meridian crossings





Tides are not due to the Moon pulling all of Earth's oceans over to one side of Earth

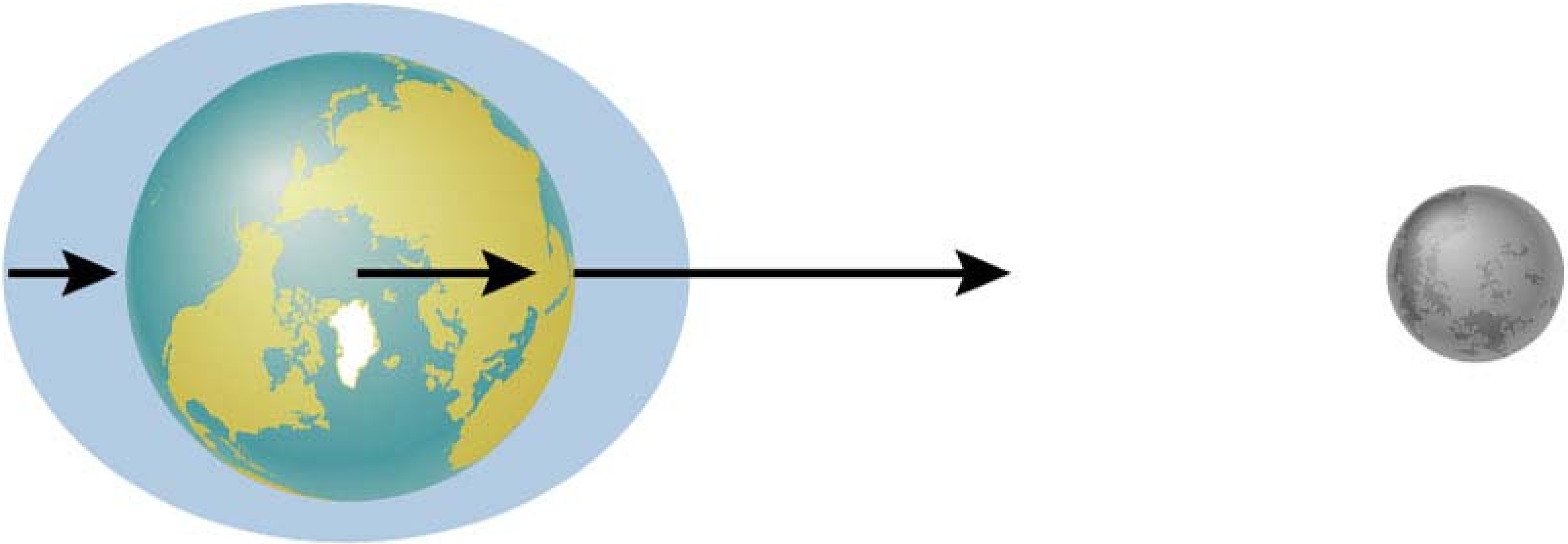
Far from land, the oceans rise and fall by about 2 m

Not to scale!

The rise and fall of the water level is more complicated close to land

The Cause of Tides

- Every part of the Earth is attracted to the Moon due to gravity
- One side of Earth is closer to the Moon than the other side of the Earth is. The closer side is more strongly attracted towards the Moon than the more distant side is
- The Earth is being stretched by the difference in the gravitational attraction of the Moon from one side of Earth to the other side of Earth



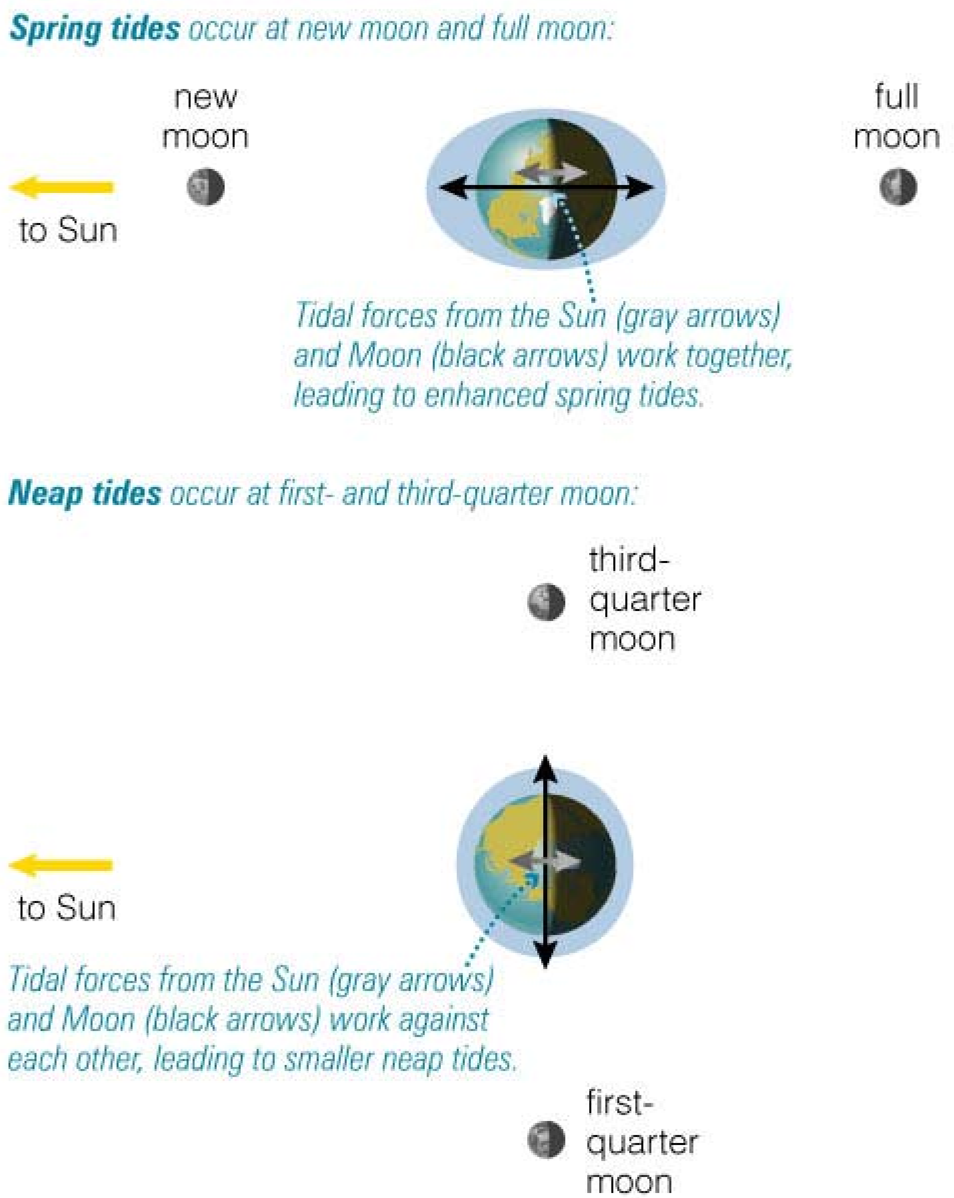
The bulge in the oceans stays in a fixed alignment with the Moon

Meanwhile, the land we live on rotates around once per day

Not to scale!

The Sun and the Moon

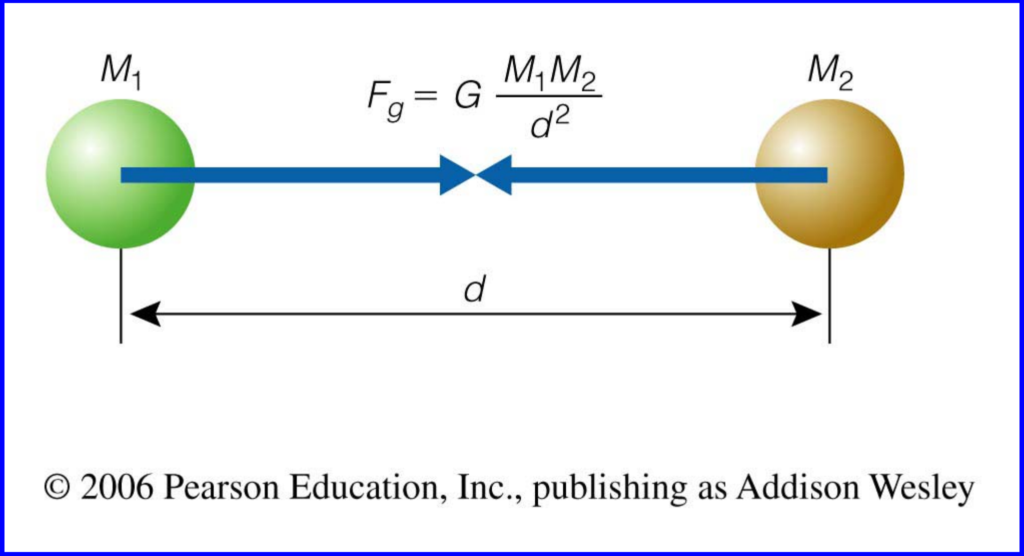
- The gravitational force between Earth and the Sun is **stronger** than the gravitational force between Earth and the Moon
- The Sun is **further away** from Earth than the Moon is
- The change in the Sun's gravitational force from one side of Earth to the other is quite **small**
- The change in the Moon's gravitational force from one side of the Earth to the other is quite **large**
  - Tides on the Earth due to the Sun are much weaker than those due to the Moon

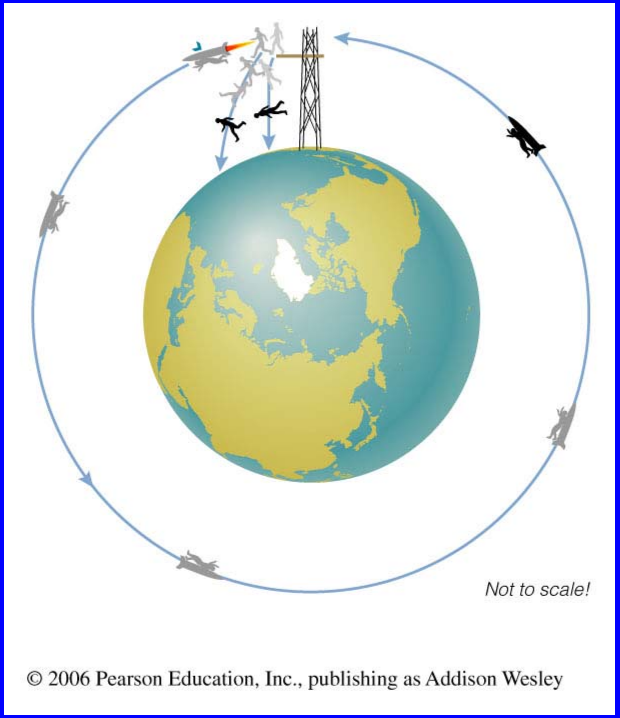

Spring tides occur at new moon and full moon:
new moon
full moon
to Sun
Tidal forces from the Sun (gray arrows) and Moon (black arrows) work together, leading to enhanced spring tides.
Neap tides occur at first- and third-quarter moon:
third-quarter moon
to Sun
Tidal forces from the Sun (gray arrows) and Moon (black arrows) work against each other, leading to smaller neap tides.
first-quarter moon

Tide Summary

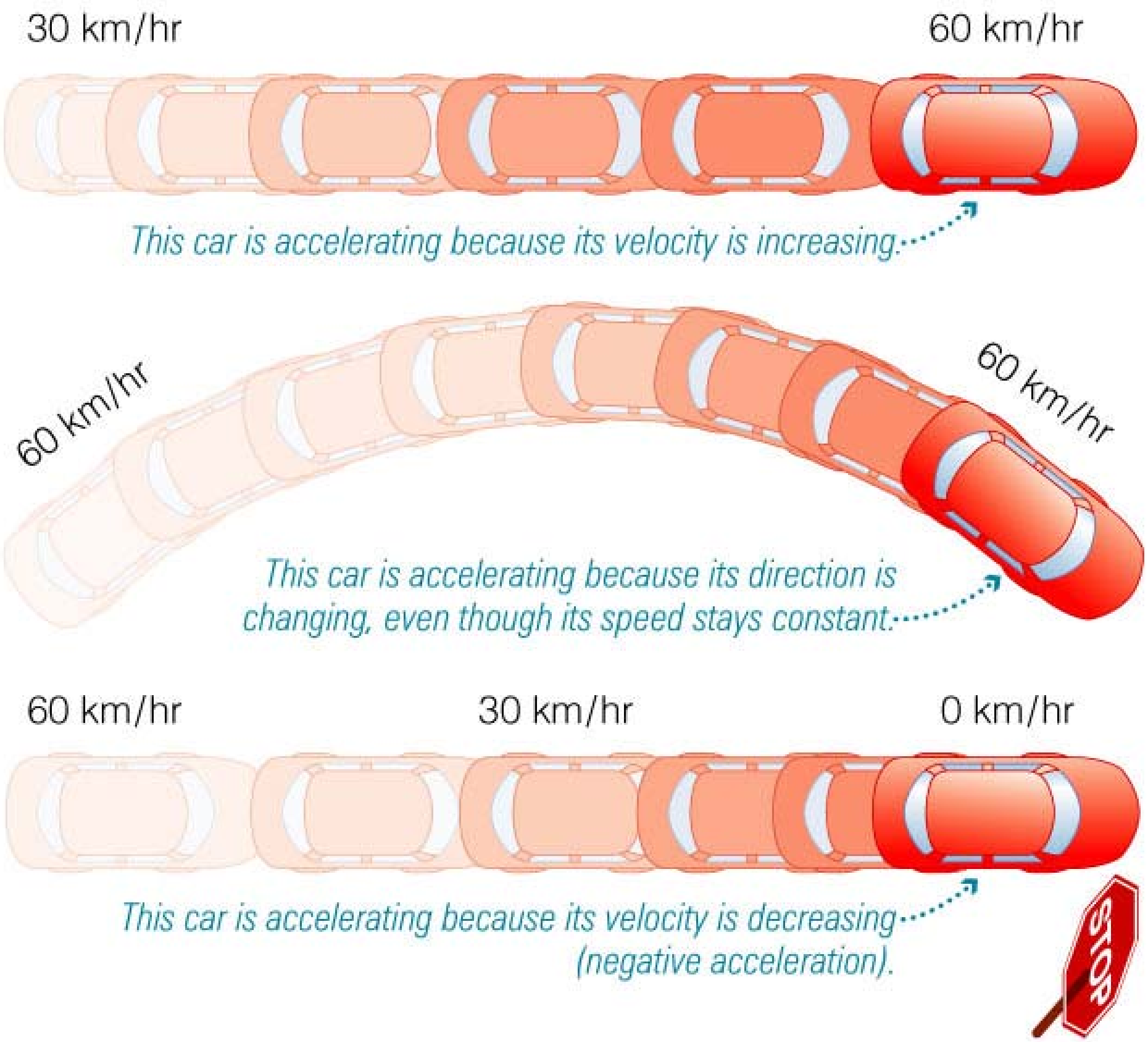
- Tides are caused by the difference in the Moon's gravitational attraction from one side of Earth to the other

Gravity on the Earth





- Why do things always fall down? Shouldn't they fall towards big mountains?
- We need a good description of **motion** to connect planetary orbits to falling objects


30 km/hr
60 km/hr
This car is accelerating because its velocity is increasing.
60 km/hr
60 km/hr
This car is accelerating because its direction is changing, even though its speed stays constant.
60 km/hr
30 km/hr
0 km/hr
This car is accelerating because its velocity is decreasing (negative acceleration).
STOP

Speed, velocity, and acceleration

- Speed describes how far you will travel in a certain time
- Velocity describes how far AND in what direction you will travel in a certain time
- Something is accelerating if its velocity is changing

- Can something accelerate even if its speed is not changing?

Working with acceleration

- Change in speed = Acceleration x time
  m / s m / s^2 s

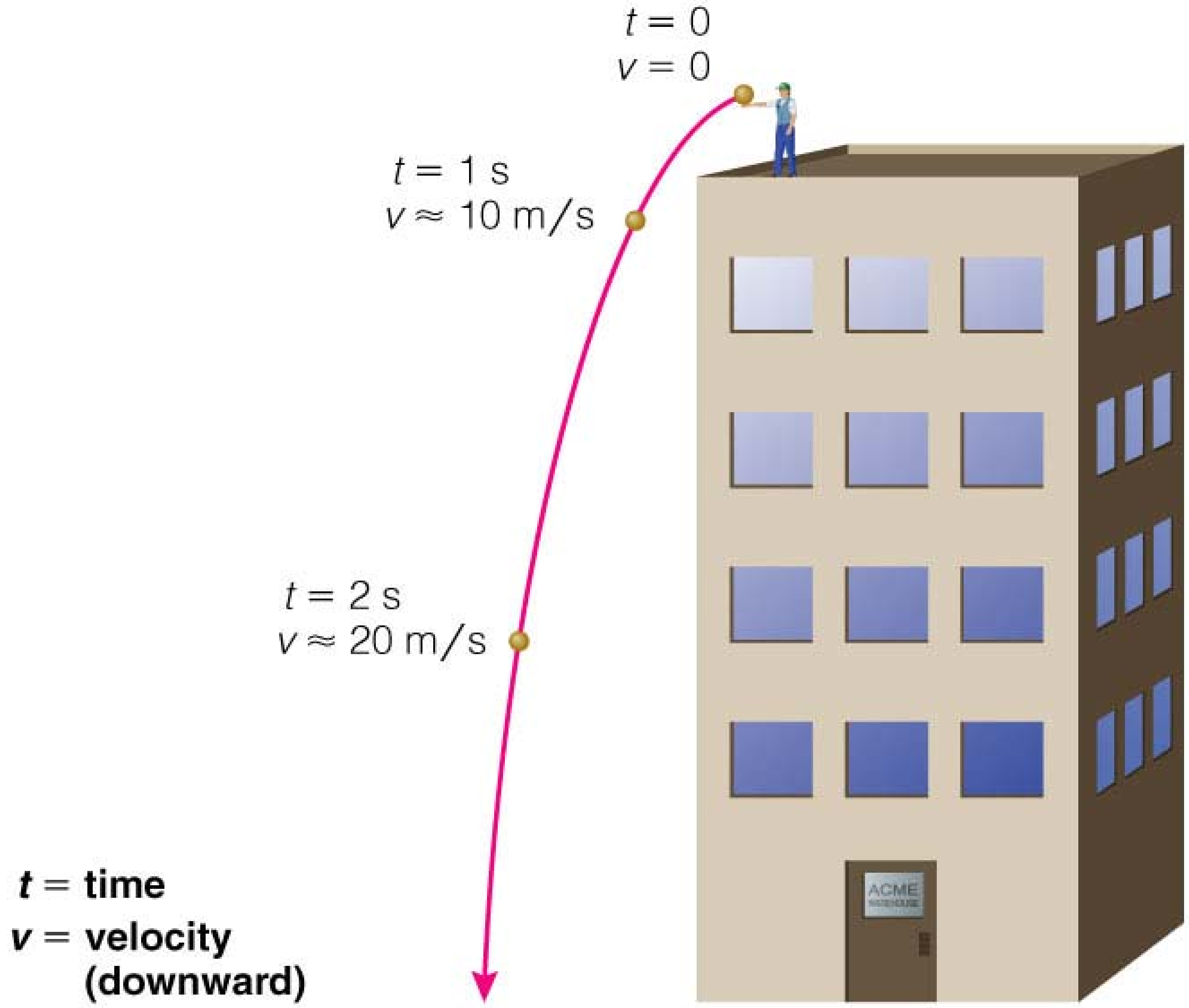
- If a car accelerates at 2 m/s^2 for 1 second, then its speed changes by 2 m/s^2 x 1 s or 2 m/s
- If a car accelerates at 2 m/s^2 for 2 second, then its speed changes by 2 m/s^2 x 2 s or 4 m/s

Some Exercises

- A car's speed is 60 km/hr. How far does it travel in ½ hour, in 2 hours, and in 5 hours?
- A car is travelling with a constant speed of 10 m/s. It then accelerates at 5 m/s^2. How fast is it travelling after 1 s, 2 s, and 10 s?

A Familiar Acceleration

- If you drop something, it falls down
- All dropped objects experience the same acceleration of 10 m/s^2
  - $g = 10\ m/s^2$
- Heavy objects do not drop faster than light objects
- This acceleration is caused by the gravitational attraction of the Earth



t = 0
v = 0
t = 1 s
v ≈ 10 m/s
t = 2 s
v ≈ 20 m/s
ACME
t = time
v = velocity
(downward)

Motion

- Can your body feel when it is moving?
  - Sitting in an airplane
  - Moving around the Sun once per year
- Can your body feel when it is accelerating?
  - When a car slams on its brakes
  - When an airplane takes off

- Forces cause acceleration

Never-ending Motion?

- On Earth, anything that is moving eventually slows down and stops
- In the heavens, the planets go round and round forever
- Are the physical laws that control motion different from things on Earth and things in the heavens?

Newton’s First Law

- An object moves at a constant velocity if there is no net (overall or total) force acting upon it

- A car that slows down when you lift your foot off the gas pedal is experiencing a force. In this case, friction between the tires and the road

Consequences of Newton's First Law

- Anything that changes its velocity is experiencing a force, even if the cause of the force isn't obvious
- You can walk around inside an airplane that is travelling at 500 mph
- You don't feel any effects from sitting on Earth as it travels at high speeds around the Sun and through the galaxy

Newton’s Second Law

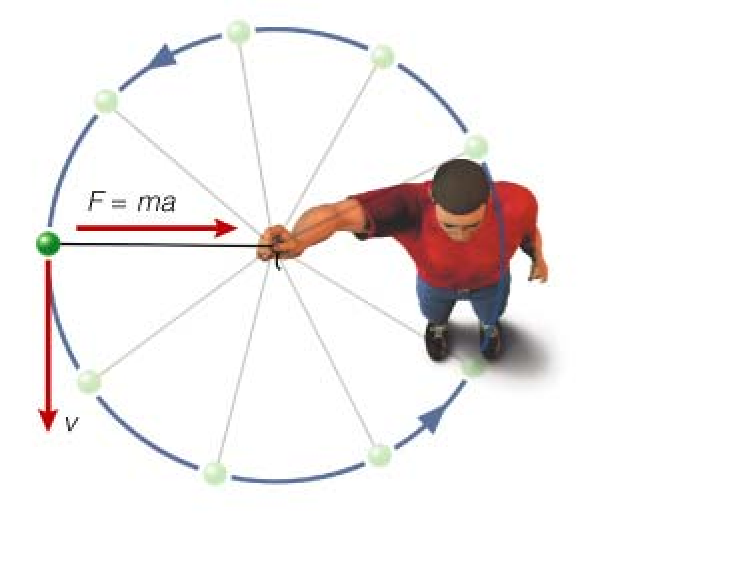
- Force = mass x acceleration
- F = m x a

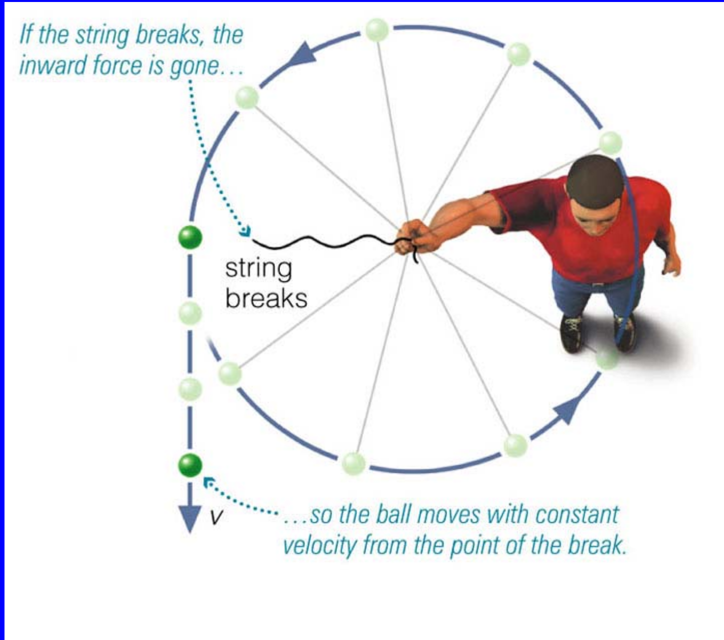
Consequences of Newton's Second Law

- You can throw a baseball further than a bowling ball
- Recall that the gravitational force of Earth on the Sun is the same as the gravitational force of the Sun on Earth
- F=ma explains why the Earth goes around the Sun rather than the Sun going around the Earth
- Is the Sun accelerated at all?

Consequences of Newton's Second Law

- An object going around a curve is being pulled inwards by some force
- For planets in curved orbits, this force is gravity





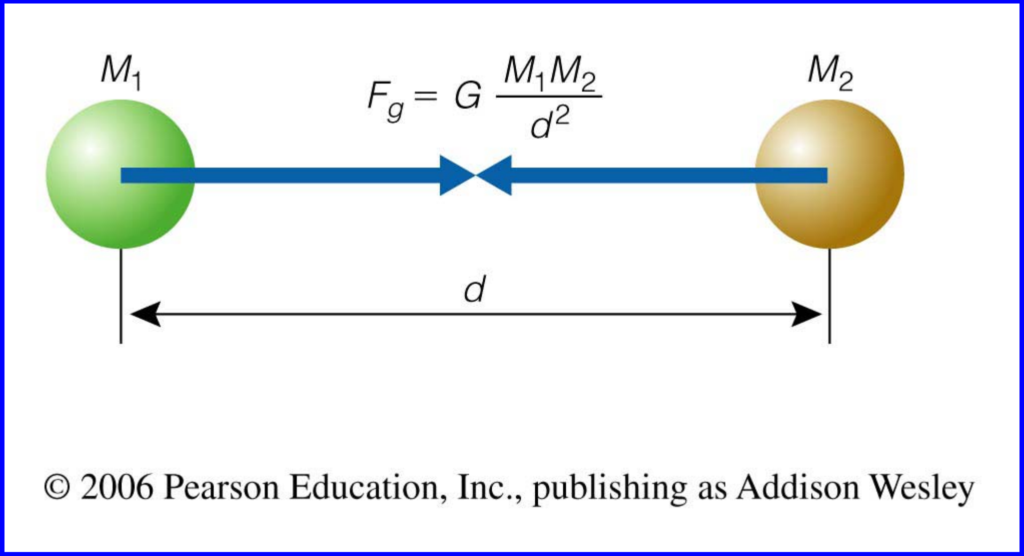
Newton’s Third Law

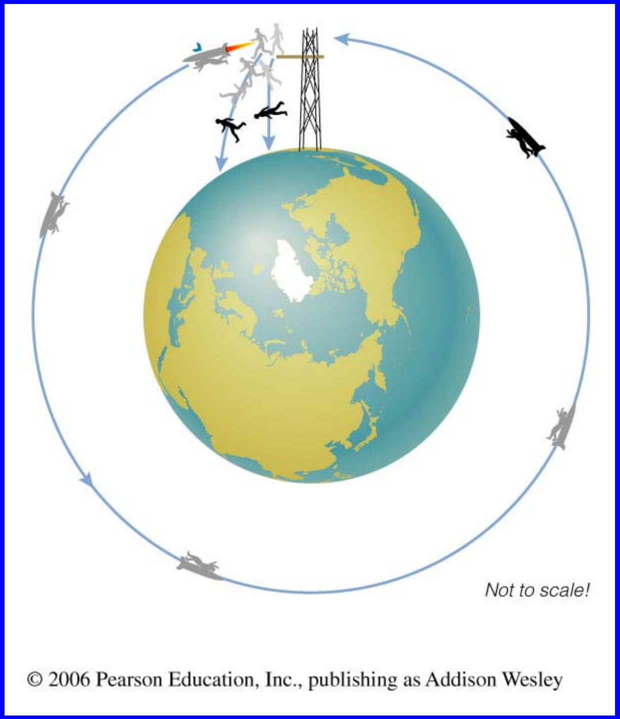
- For any force, there is always an equal and opposite reaction force

Consequences of Newton's Third Law

- If you drive a car into a fly, the fly experiences the same force during the collision as the car does, but in the opposite direction
- If you jump upwards, then the force accelerating you upwards is the same as a force accelerating Earth downwards. Can you detect the Earth moving downwards?

Gravity on the Earth





- Falling objects are attracted to Earth by its gravity as if all the mass of the Earth were concentrated in a small region at the centre of the Earth

Acceleration due to Gravity

- $M_{rock}\ a_{rock} = G\ M_{rock}\ M_{Earth}\ /\ d^2$

- $a_{rock} = G\ M_{Earth}\ /\ d^2$
  - does not depend on M_{rock} or any property of falling object
  - often give the symbol g
  - value is 10 m/s^2

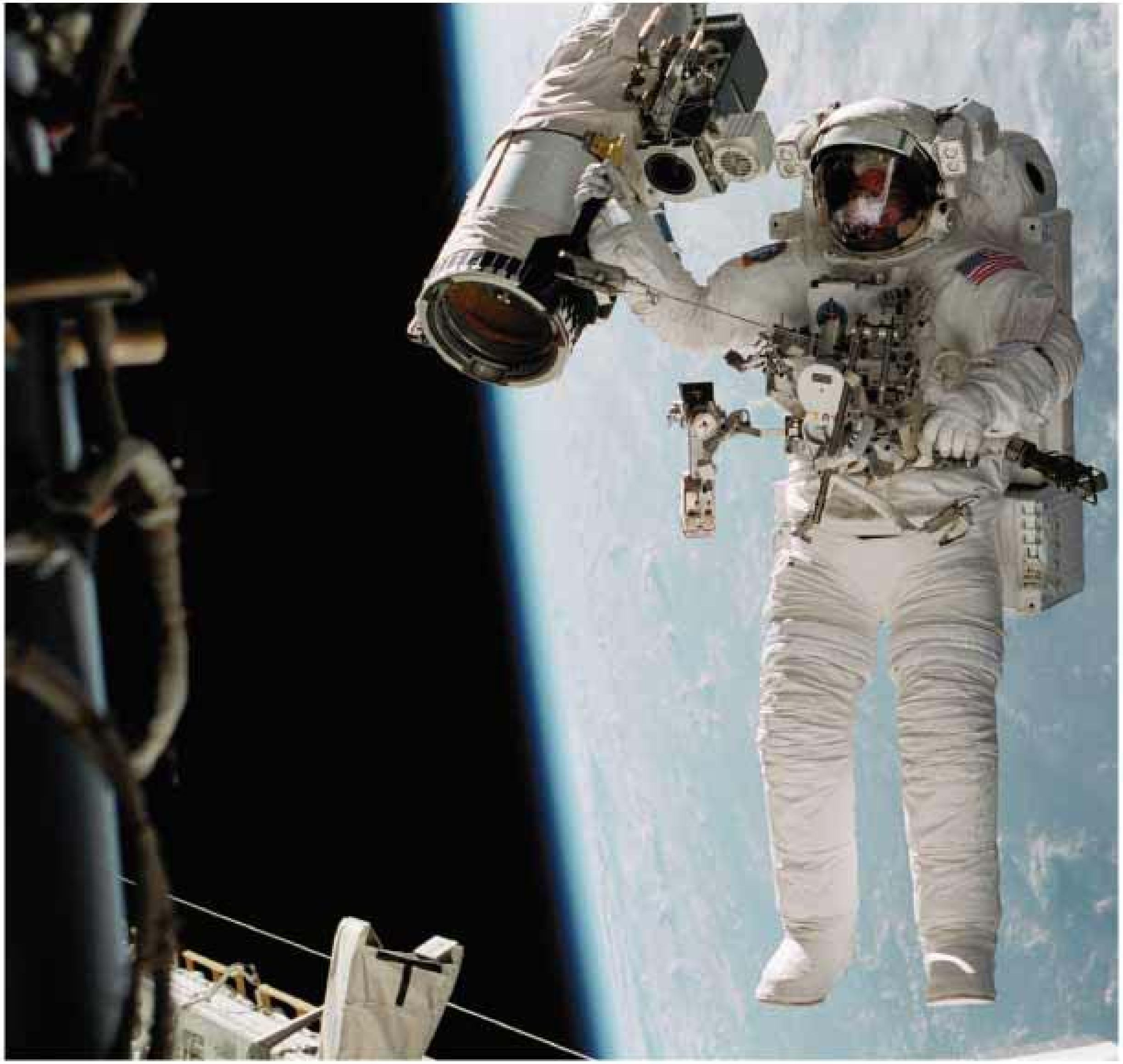
Gravity in Space

- What is g for a spacecraft orbiting Earth?

- $g_{surface} = G\, M_{Earth} / R_{Earth}^2$
- $g_{spacecraft} = G\, M_{Earth} / (R_{Earth} + 300\text{ km})^2$

- R_{Earth} = 6400 km, so g only decreases by a small fraction (p139 in textbook)

Why don't things fall in space?



Weightlessness
(A misleading word)

- Astronauts and other objects inside spacecraft don’t fall to the floor of the spacecraft
- The spacecraft is falling towards Earth just as quickly as the astronauts are
- The astronauts are accelerating towards Earth, but they are not accelerating towards the floor of the spacecraft

Goals for Learning

- What is Newton's Law of Gravity?
- What causes tides?
- What are speed, velocity, and acceleration?
- What are Newton's Laws of Motion?

Goals for Learning

- What is Newton's Law of Gravity?
  - Every mass attracts every other mass through the force called gravity
  - $F = G\, M_1 M_2 / d^2$
  - Explains Kepler's Laws, orbits of comets, and much more

Goals for Learning

- What causes tides?
  - Tides on Earth are caused by differences in the gravitational pull of the Moon from one side of Earth to the other
  - The Sun has a weaker effect on Earth’s tides

Goals for Learning

- What are speed, velocity, and acceleration?
  - Speed is how fast something is moving
  - Velocity is the combination of a speed and a direction
  - Something is accelerating if its velocity is changing
  - An accelerated object can be changing its speed, its direction, or both

Goals for Learning

- What are Newton's Laws of Motion?
  - An object moves with a constant velocity unless a force is acting on it
  - F = ma
  - For any force, there is always an equal and opposite reaction force

- http://upload.wikimedia.org/wikipedia/en/thumb/e/e4/ZeroG.jpg/375px-ZeroG.jpg