Physics 211

Sections 1 & 70

Dr. Geoffrey Lovelace

Fall 2012

Lecture 20 (11/6/12)

Lecture 20 outline

- Announcements
- Angular motion wrap-up
  - Period & frequency
  - Angular acceleration, angular kinematics
- Gravitation
  - Newton's law of gravitation
  - Gravitational potential energy
  - Kepler's laws of planetary motion
  - Escape velocity

Announcements

- Homework
  - Homework #9: due **Tuesday** at 11:59PM
- Exam #3: 1 week from today
- Reading: For Tuesday: temperature, heat, entropy. 10.1-10.2, 11.1, 12.1,12.4
- Office hours: 10AM-11AM, 4PM-5PM today
  - McCarthy Hall room 601B

Today

Oct 23	**Exam 2**
Oct 25	Linear momentum, conservation of linear momentum
Oct 30	Conservation of linear momentum, collisions
Nov 1	Center of mass, rockets, *HW #8 due*
Nov 6	Circular motion, gravitation
Nov 8	Gravitation, Kepler's laws
Nov 13	Special feature: temperature, heat, entropy *HW #9 due*
Nov 15	**Exam 3**
Nov 20	*Fall Recess — No class*
Nov 22	*Fall Recess — No class*
Nov 27	Rigid body rotation, torque, rotational dynamics
Nov 29	Rotational dynamics, rotational energy, *HW #10 due*
Dec 4	Angular momentum, conservation of angular momentur
Dec 6	Harmonic motion, *HW #11 due*
Dec 11	Harmonic motion & waves
Dec 13	Gravitational waves, harmonic motion, black holes, *HW*
Dec 20	**Final exam 9:30AM–11:20AM**

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7.2 Angular Speed and Velocity

The **period** is the time it takes for one rotation; the **frequency** is the number of rotations per second.

$$f = \frac{1}{T}$$

The relation of the **frequency *f*** to the **angular speed ω**:

$$\omega = \frac{2\pi}{T} = 2\pi f$$

Angular motion

- Angular displacement

$$\Delta\theta = \theta - \theta_0 \qquad\qquad 1 = \frac{2\pi \text{ rad}}{360^\circ}$$

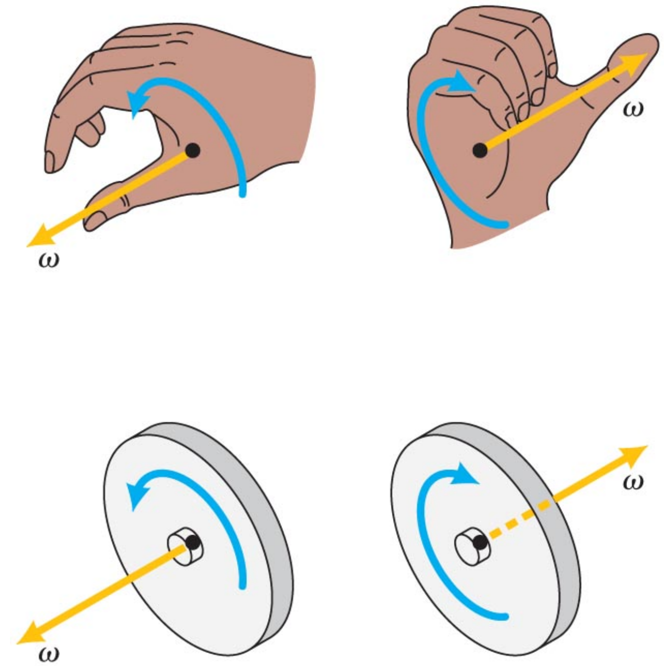
Note: angle measured in radians!

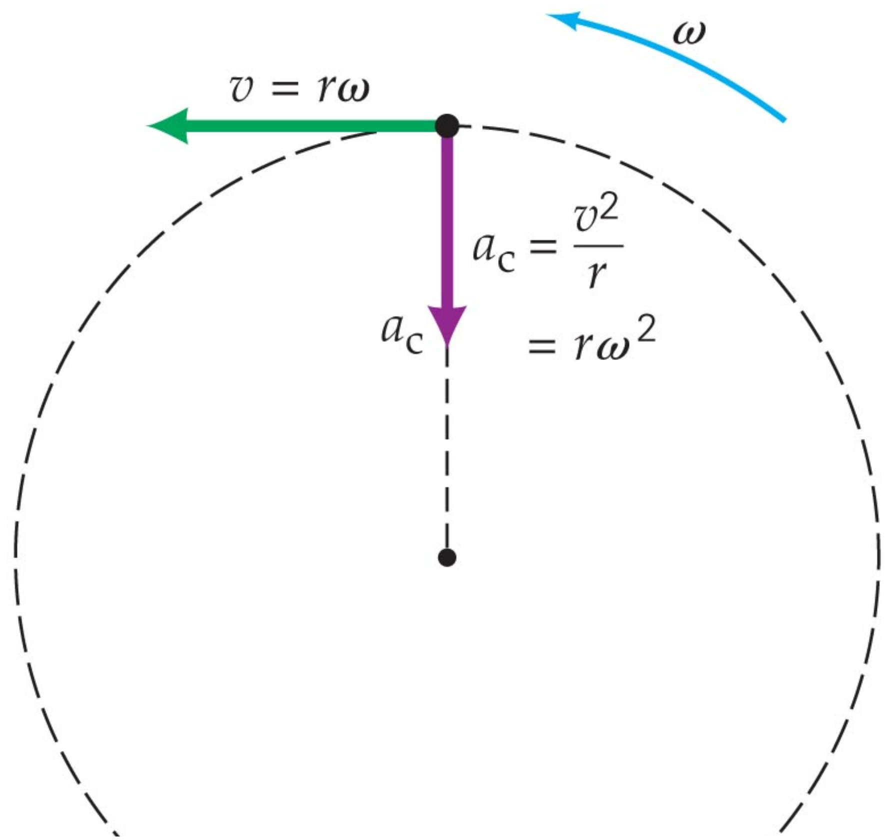
- Average angular velocity

Magnitude: $\bar{\omega} = \dfrac{\Delta\theta}{\Delta t}$

Direction: right hand rule

- Tangential velocity
  & centripetal acceleration



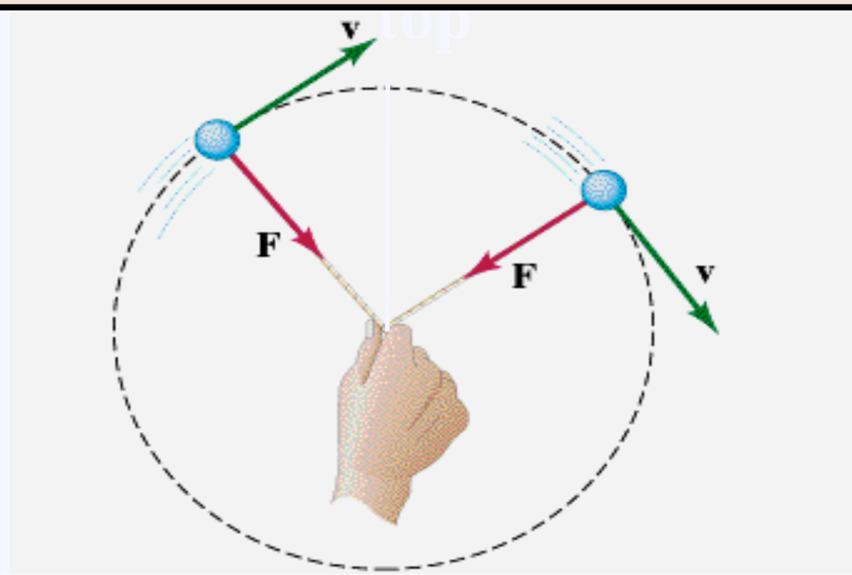


Clicker question #91

Question 7.6c Going in Circles III

You swing a ball at the end of string in a vertical circle. Because the ball is in circular motion there has to be a *centripetal force.* At the top of the ball's path, what is F_c equal to?

- A $F_c = T - mg$
- B $F_c = T + N - mg$
- C $F_c = T + mg$
- D $F_c = T$
- $F_c = mg$



Clicker question #88

Question 7.1 Tetherball

In the game of tetherball, the struck ball whirls around a pole. In what direction does the **net force** on the ball point?

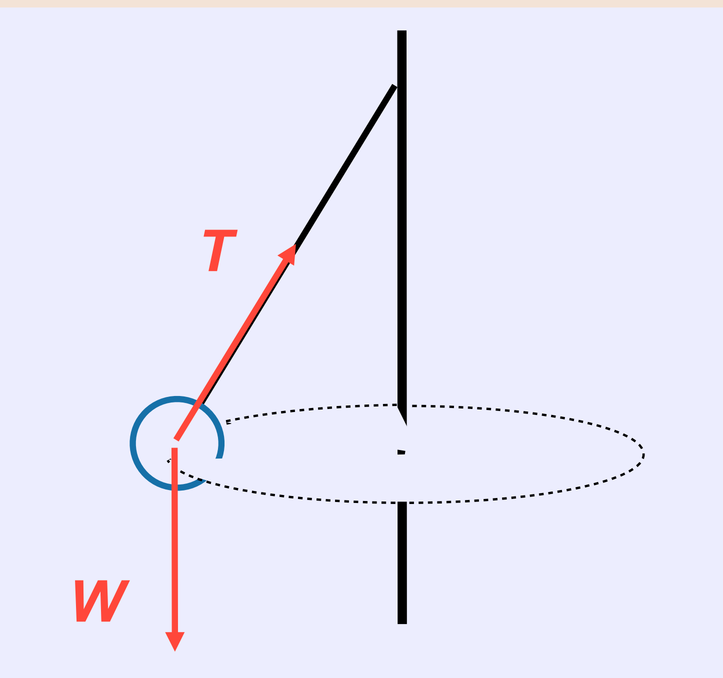
A toward the top of the pole

B toward the ground

C along the horizontal component of the tension force

D along the vertical component of the tension force

tangential to the circle

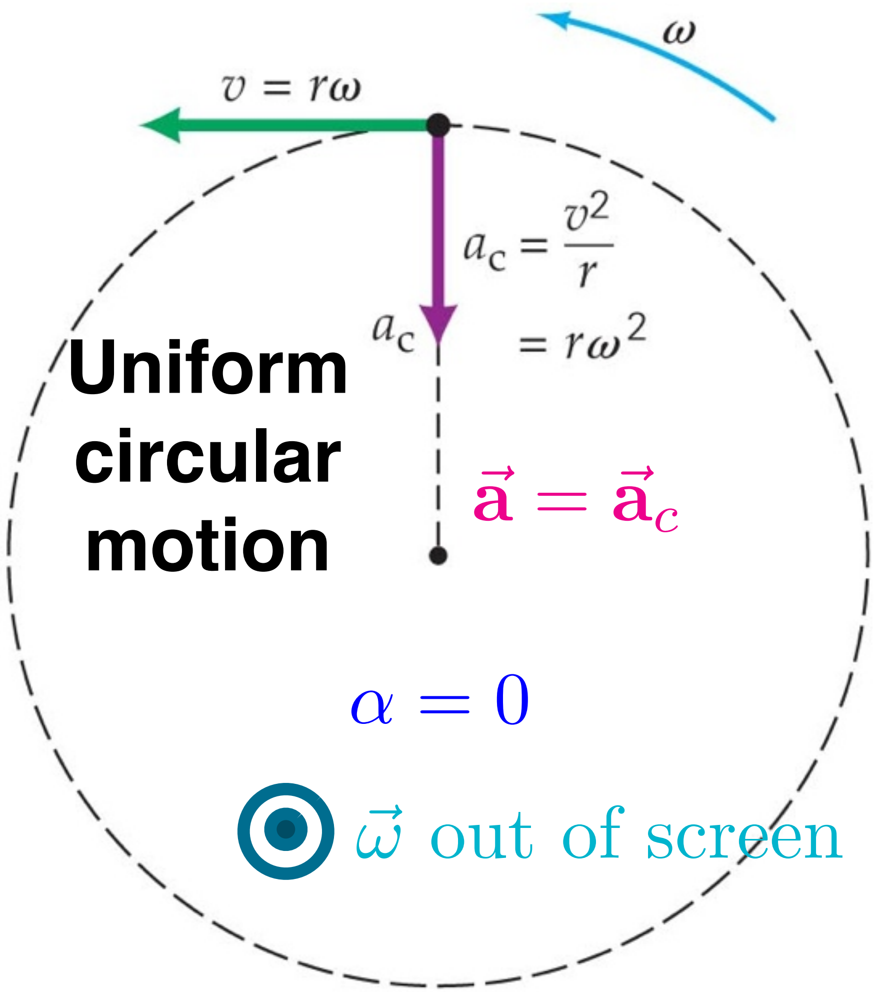


Angular acceleration

- Average angular acceleration

Magnitude: $\bar{\alpha} = \frac{\Delta\omega}{\Delta t}$

Direction: same as or opposite to angular velocity



Angular acceleration

- Average angular acceleration

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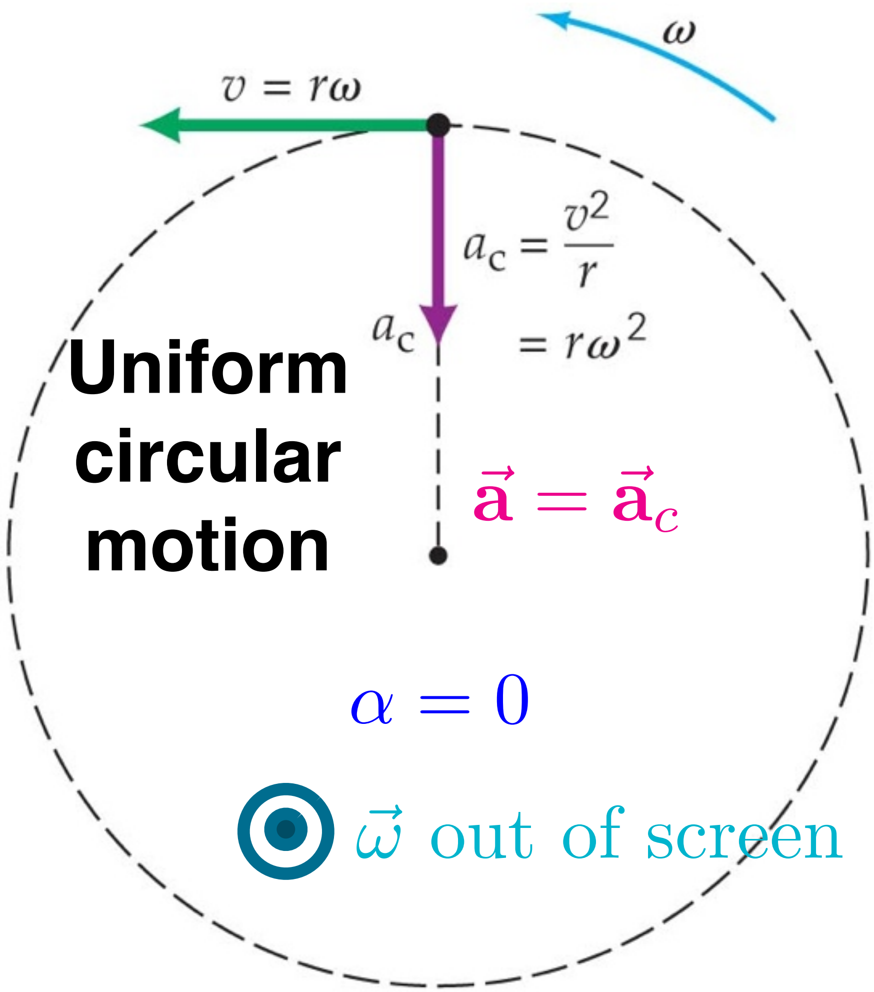
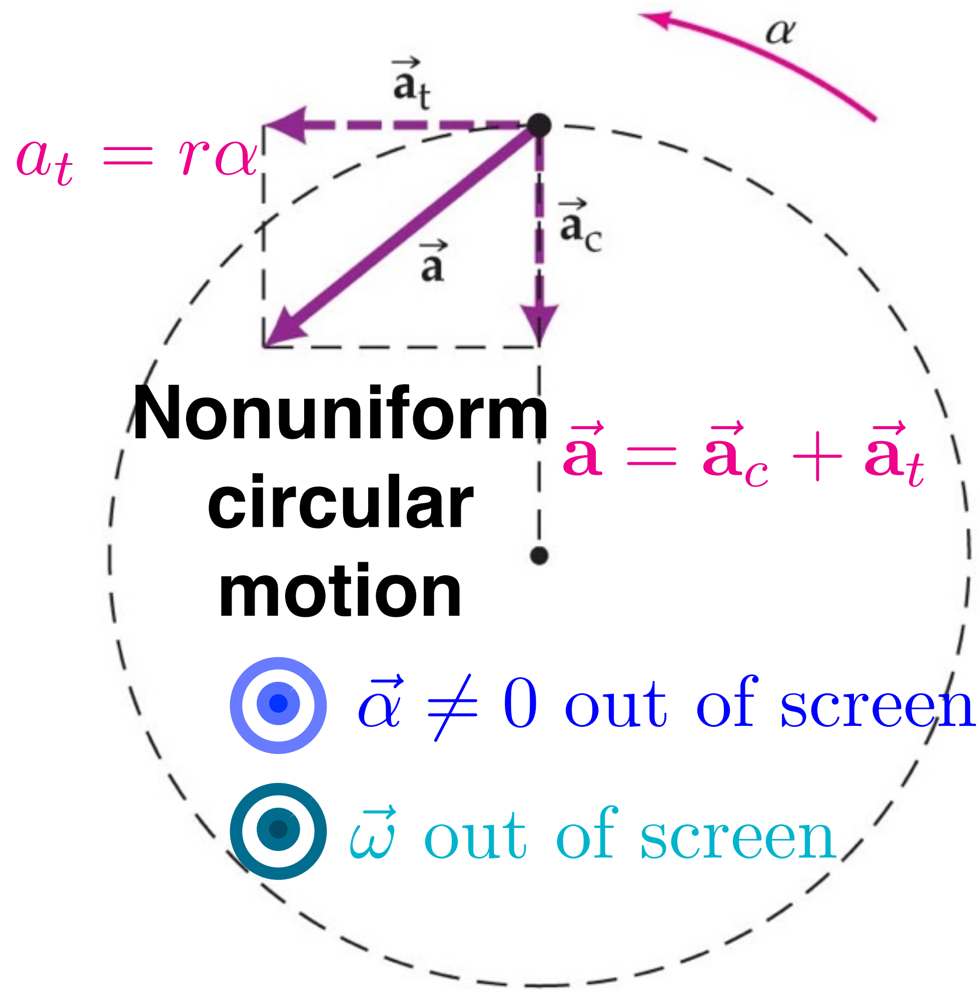




Angular kinematics

TABLE 7.2 Equations for Linear and Angular Motion with Constant Acceleration*

Linear	Angular	
$x = \bar{v}t$	$\theta = \bar{\omega}t$	(1)
$\bar{v} = \dfrac{v + v_o}{2}$	$\bar{\omega} = \dfrac{\omega + \omega_o}{2}$	(2)
$v = v_o + at$	$\omega = \omega_o + \alpha t$	(3)
$x = x_o + v_o t + \dfrac{1}{2}at^2$	$\theta = \theta_o + \omega_o t + \dfrac{1}{2}\alpha t^2$	(4)
$v^2 = v_o^2 + 2a(x - x_o)$	$\omega^2 = \omega_o^2 + 2\alpha(\theta - \theta_o)$	(5)

*The first equation in each column is general, that is, not limited to situations where the acceleration is constant.

Ex. 7.11: microwave

- A plate rotates in a microwave. The plate accelerates from rest at 0.87 rad/s/s for 0.50 s. How many revolutions does it make? What is the final angular speed?

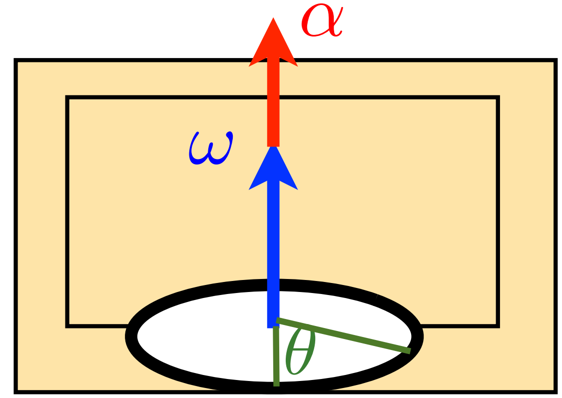
$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$
$$\omega = \omega_0 + \alpha t$$

Given:

$$\theta_0 = 0$$
$$\omega_0 = 0$$
$$\alpha = 0.87 \text{ rad/s/s}$$
$$t = 0.5 \text{ s}$$

Goal:

θ and ω



http://www.youtube.com/watch?v=ExSKW1bwBq8

Ex. 7.11: microwave

Given:

$$\theta_0 = 0$$
$$\omega_0 = 0$$
$$\alpha = 0.87 \text{ rad/s/s}$$
$$t = 0.5 \text{ s}$$

Goal:

θ and ω

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\theta = \frac{1}{2}\left(0.87\frac{\text{rad}}{\text{s}^2}\right)(0.50 \text{ s})^2 = 0.11 \text{ rad}\left(\frac{1 \text{ rev}}{2\pi \text{ rad}}\right) = 0.017 \text{ rev}$$

$$\omega = \omega_0 + \alpha t$$

$$\omega = \left(0.87\frac{\text{rad}}{\text{s}^2}\right)(0.50 \text{ s}) = 0.44\frac{\text{rad}}{\text{s}}\left(\frac{1 \text{ rev}}{2\pi \text{ rad}}\right)\left(\frac{60 \text{ s}}{\text{min}}\right) = 4.2\frac{\text{rev}}{\text{min}}$$

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Newton's law of gravity

- Gravity = attractive force of magnitude

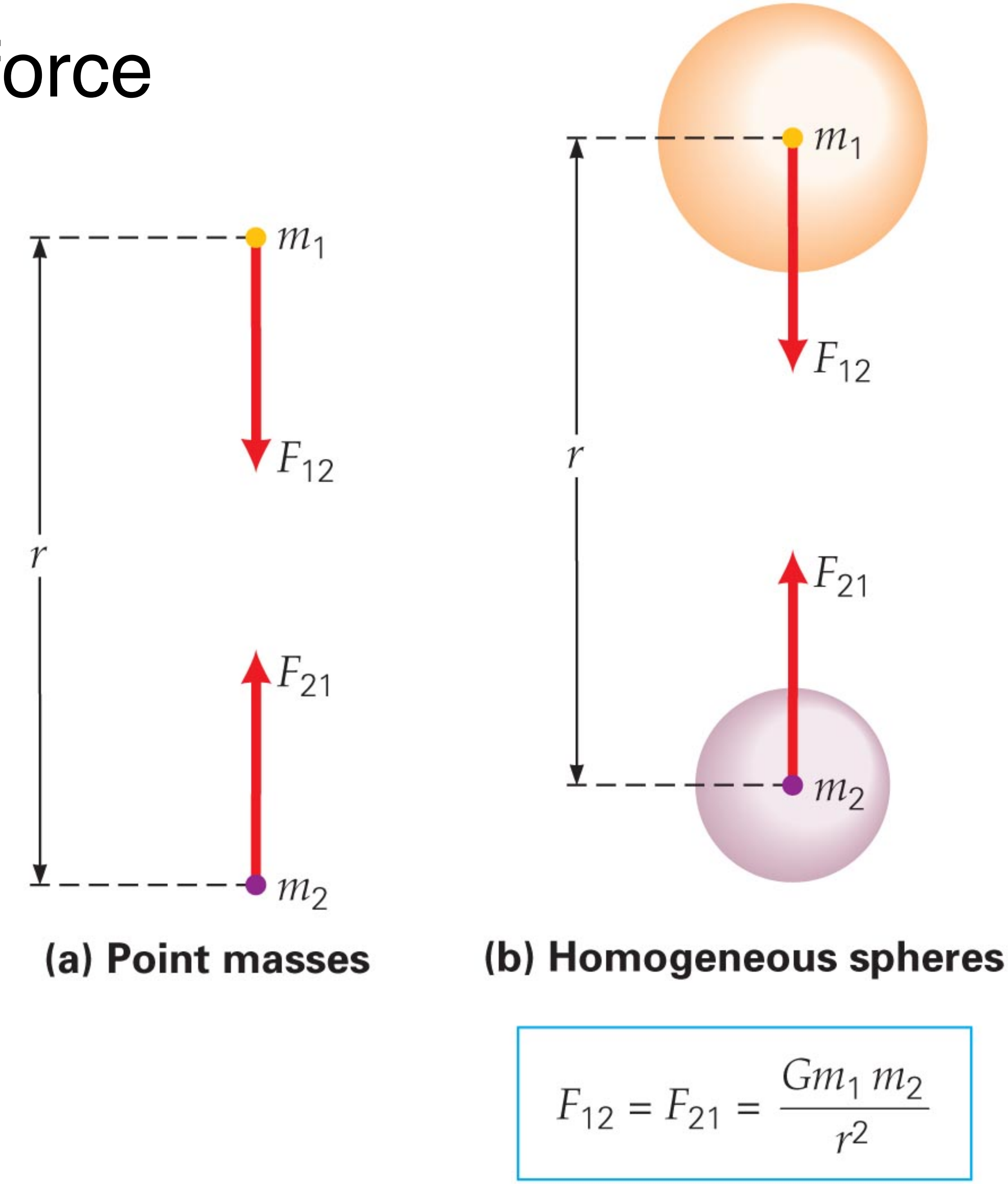
$$F = \frac{Gm_1m_2}{r^2}$$

$$G = 6.67 \times 10^{-11}\mathrm{N}\frac{\mathrm{m}^2}{\mathrm{kg}^2}$$

- Acceleration of gravity

$$F = mg = \frac{GmM_E}{R_E^2}$$

$$g = \frac{GM_E}{R_E^2}$$



Clicker question #92

Question 7.7a Earth and Moon I

Which is stronger, Earth's pull on the Moon, or the Moon's pull on Earth?

A) the Earth pulls harder on the Moon

B) the Moon pulls harder on the Earth

C) they pull on each other equally

D) there is no force between the Earth and the Moon

it depends upon where the Moon is in its orbit at that time

Clicker question #93

Question 7.7b Earth and Moon II

If the distance to the Moon were doubled, then the force of attraction between Earth and the Moon would be:

A) one quarter
B) one half
C) the same
D) two times
E) four times

Clicker question #94

Question 7.8 Fly Me Away

You weigh yourself on a scale inside an airplane that is flying with constant speed at an altitude of 20,000 feet. How does your measured weight in the airplane compare with your weight as measured on the surface of the Earth?

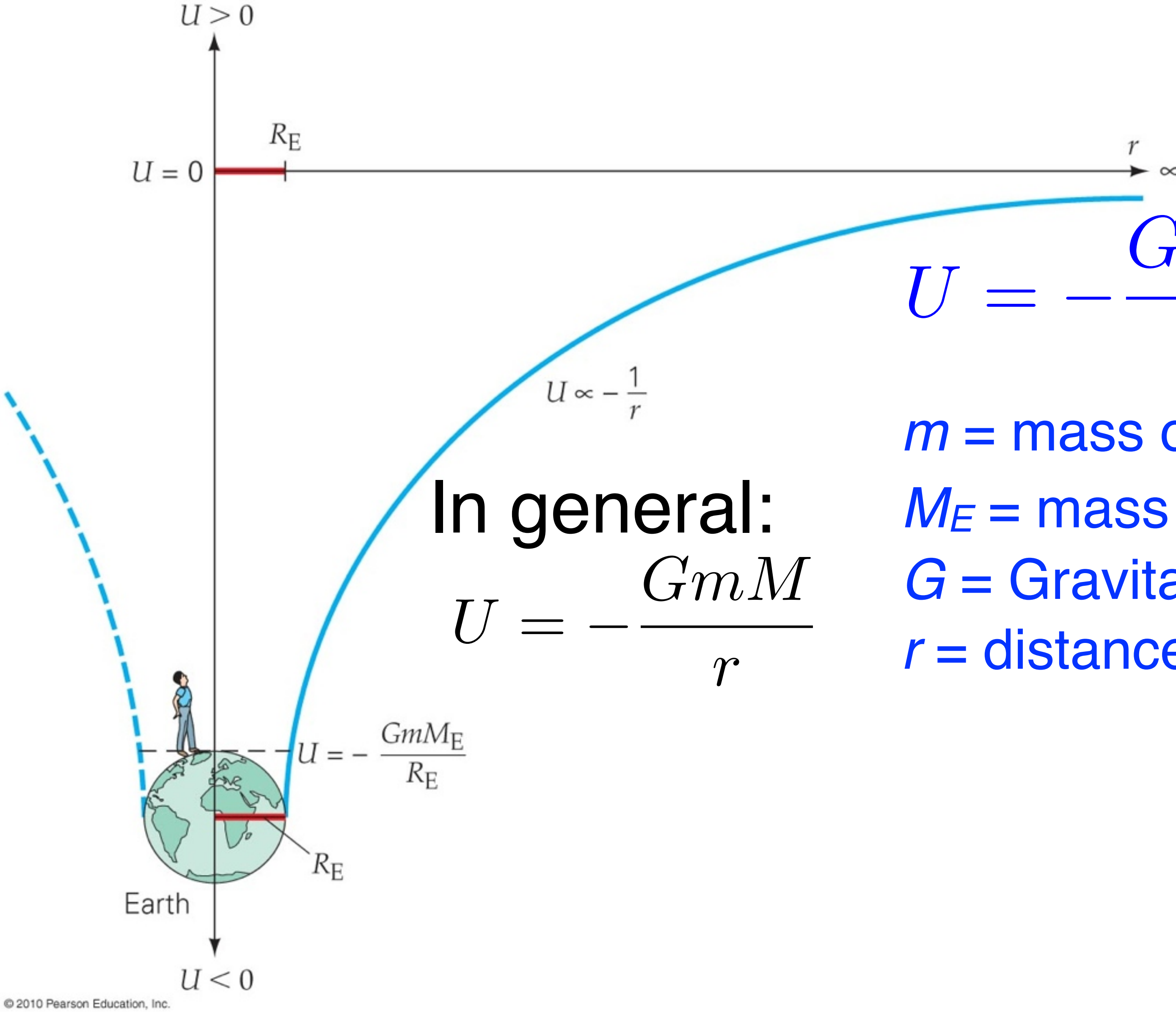
A greater than

B less than

C same

Gravitational potential energy

- Far from earth's surface, can't use *U=mgh*



$$U = -\frac{GmM_E}{r}$$

m = mass of object

M_E = mass of Earth

G = Gravitational constant

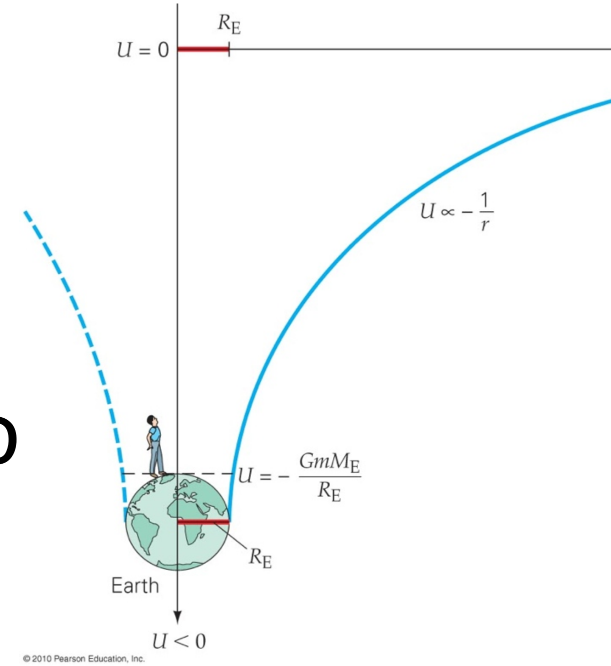
r = distance from earth center

In general:

$$U = -\frac{GmM}{r}$$

Escape velocity

- Escaping a gravity well
  - Need enough energy to turn into gravitational potential energy
  - Escape velocity



v = speed of escaping object
m = mass of escaping object
M = mass of planet
R = radius of surface of planet
G = Gravitational constant

$$\frac{1}{2}mv^2 - \frac{GmM}{R} = 0$$

$$\frac{1}{2}v^2 = \frac{GM}{R} \qquad v = \sqrt{\frac{2GM}{R}}$$

$$v_E = \sqrt{\frac{2GM_E}{R_E}} = 11\ \mathrm{km/s} = 25000\ \mathrm{mi/hr}$$

Schwarzschild radius

- What if escape velocity were the speed of light?
  - How small must "planet" be?

$$c = \sqrt{\frac{2GM}{R}} \qquad c^2 = \frac{2GM}{R}$$

$$R = \frac{2GM}{c^2}$$

c = speed of light
m = mass of escaping object
M = mass of planet
R = radius of surface of planet
G = Gravitational constant

Schwarzschild radius = radius of a black hole

How big are black holes?

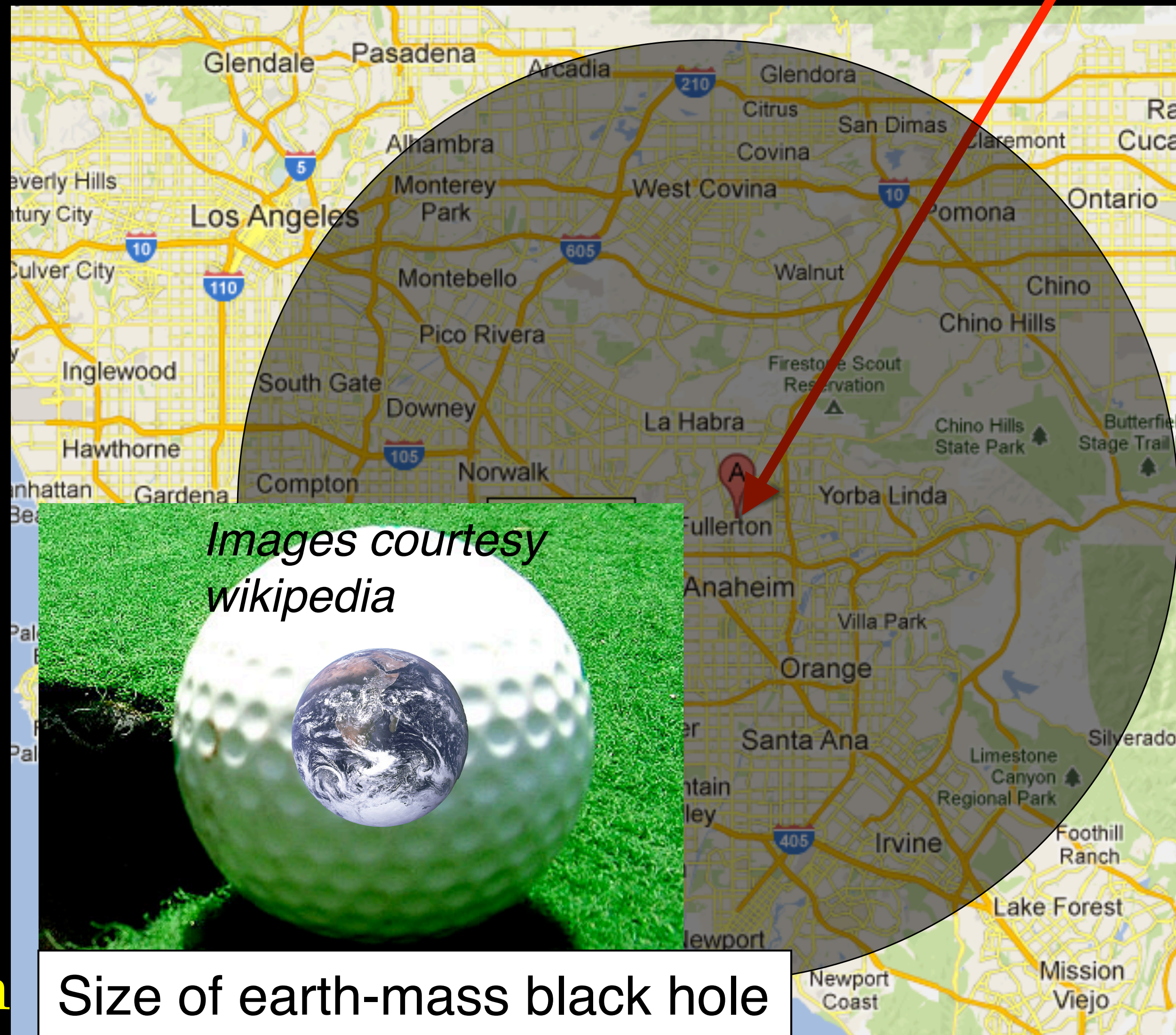
- Massive
  - Stellar: ≈ 3 - 30 solar masses
  - Supermassive: Millions - billions solar masses
- Compact

$$R_H = \frac{2GM}{c^2}$$

$$= \left(\frac{\text{Mass}}{\text{Solar mass}}\right) \times 3\ \text{km}$$

$$= \left(\frac{\text{Mass}}{\text{Earth mass}}\right) \times 9\ \text{mm}$$

Fullerton, CA



Size of earth-mass black hole

Size of 10-solar-mass black hole

Image courtesy Google maps

Class participation

- 0. Name
- 1. What is its angular velocity?
- 2. The earth is 1.5×10^{11} m from the sun. What is the earth's tangential velocity?

  (Formula sheet:)

$$\omega = \frac{2\pi}{T} = 2\pi f$$

$$v = r\omega$$