PHY131H1F - Class 13
Harlow's Last Class this semester ☹
on Monday Prof. Meyertholen takes over! ☺

Today, starting Chapter 8:

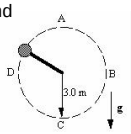
- Dynamics in Two Dimensions
- Dynamics of Uniform Circular Motion
- Banked Curves
- Orbits

Clicker Question 1

Last day at the end of class I asked:

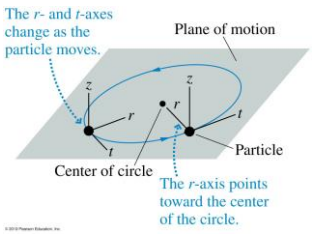
- A ball is whirled on a string in a vertical circle. As it is going around, the tension in the string is

A. greatest at the top of the motion
B. constant.
C. greatest at the bottom of the motion
D. greatest somewhere in between the top and bottom.



Class 13 Preclass Quiz on MasteringPhysics

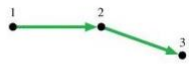
- This was due this morning at 8:00am
- 731 students submitted the quiz on time
- 53% of students answered correctly: Circular motion is best analized in a coordinate system with r-, t- and z- axes. If you use x- and y- axes, the x- and y- components are constantly changing!

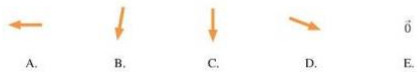


Clicker Question 2 – retry this morning's pre-class reading question.

Class 13 Preclass Quiz on MasteringPhysics

- 35% of students answered correctly: The diagram shows three points of a motion diagram. The particle changes direction with no change of speed. What is the acceleration at point 2?



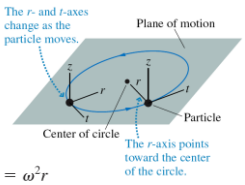


Class 13 Preclass Quiz on MasteringPhysics

- 25% of students answered correctly: A string is attached to the rear-view mirror of a car. A ball is hanging on the other end of the string. The car is driving around in a circle, at a constant speed. Which of the following lists gives all of the forces directly acting on the ball?
- Correct answer: Tension and Gravity ONLY.
- Centripetal Force is the Net force on an object moving in uniform circular motion.
- This net force is the vector sum of all the actual forces on the free body diagram.
- You do NOT draw centripetal force as an extra force acting on the object.

Uniform Circular Motion

FIGURE 8.3 The *rtz*-coordinate system.



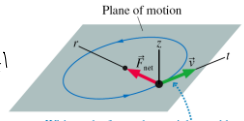
$$a_r = \frac{v^2}{r} = \omega^2 r$$
$$a_t = 0$$
$$a_z = 0$$

$v = v_t$ = instantaneous tangential speed.

Dynamics of Uniform Circular Motion

FIGURE 8.6 The net force points in the radial direction, toward the center of the circle.

$(F_{net})_r$ = "centripetal force"



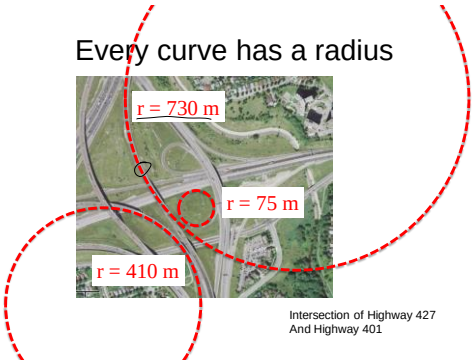
Without the force, the particle would continue moving in the direction of $\vec{v}$.

$$(F_{net})_r = \sum F_r = ma_r = \frac{mv^2}{r} = m\omega^2 r$$

$$(F_{net})_t = \sum F_t = ma_t = 0$$

$$(F_{net})_z = \sum F_z = ma_z = 0$$

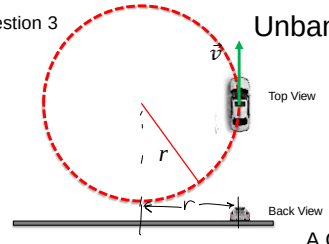
Every curve has a radius



Intersection of Highway 427
And Highway 401

Clicker Question 3

Unbanked Curve

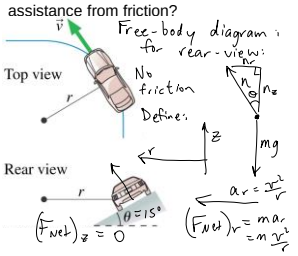


What horizontal force acts on the car to keep it on the curved path?

A. Gravity
B. Normal
C. Kinetic Friction
D. Static Friction
E. Rolling Friction

Banked Curve Example 8.5, pg. 197

A highway curve of radius 70.0 m is banked at a 15° angle. At what speed v_0 can a car take this curve without assistance from friction?



	r	z
$\vec{n}$	$n \sin\theta$	$n \cos\theta$
$\vec{F}_g$	0	$-mg$
$\vec{F}_{net}$	$n\sin\theta = m\frac{v^2}{r}$	$n\cos\theta - mg = 0$

From z-component: $n\cos\theta = mg$

$$n = \frac{mg}{\cos\theta}$$

Plug into r-component:

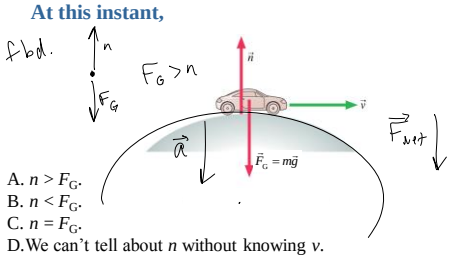
$$\left(\frac{mg}{\cos\theta}\right)\sin\theta = m\frac{v^2}{r}, \text{ solve for } v:$$

$$v = \sqrt{gr\frac{\sin\theta}{\cos\theta}} = \sqrt{9.8(70.0)\frac{\sin 15}{\cos 15}}$$

$$v = 14 \text{ m/s}$$

Clicker Question 4

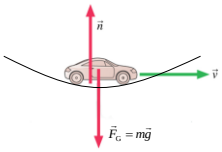
A car is rolling over the top of a hill at speed *v*. At this instant,



A. $n > F_G$.
B. $n < F_G$.
C. $n = F_G$.
D. We can't tell about *n* without knowing *v*.

Clicker Question 5

A car is driving at the bottom of a valley at speed *v*. At this instant,



A. $n > F_G$.
B. $n < F_G$.
C. $n = F_G$.
D. We can't tell about *n* without knowing *v*.

Class 13 Preclass Quiz on MasteringPhysics

- Some common or interesting student comments/feedback:
- *"Is the next test going to be of the same difficulty level as the one we just wrote?"*
- *"Is the next test supposed to be super difficult to on bring down thr average?"*
- *"I got 100 in test!!hahahah!!!"*
- Recall the average on Test 1 was 72%, which is the highest test 1 average I've had since I started teaching this course in 2004.
- Message from Paul Kushner, the Undergraduate Chair of Physics (my boss): "This test was easier than what you might normally expect for the course. The tests need to generally be more challenging, and the next one will be. Expected average on PHY131 tests are 65%, and this class did unexpectedly well on Test 1."

Class 13 Preclass Quiz on MasteringPhysics

- Some common or interesting student comments/feedback:
- *"I think in the first practical you said you were competing with a colleague at Ryerson to see who's class would to better in the pre-course assessment. Who ended up winning?"*
- Harlow note: At Ryerson 155 students wrote it in their PCS120 calculus-based physics course, their average was 35%. In this class 978 students wrote it and your average was 50%.
- *"My roommate says not to underestimate her abilities to reach high terminal velocities when only thrown out of a fourth floor window."*
- *"What does a Greek cow say? μ"*
- *"A student riding in a train looks up and sees Einstein sitting next to him. Excited he asks, 'Excuse me, professor. Does Boston stop at this train?'"*
- *+ Lots of nice messages of farewell – thank you!! I will miss you too!!*

Projectile Motion

In the absence of air resistance, a projectile has only one force acting on it: the gravitational force, $F_G = mg$, in the downward direction. If we choose a coordinate system with a vertical y-axis, then

no air resistance

We won't deal with air resistance projectile motion in PHY131.

$$\vec{F}_G = -mg\hat{j}$$

$$a_x = \frac{(F_G)_x}{m} = 0$$

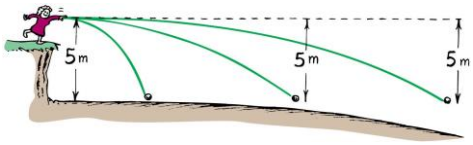
$$a_y = \frac{(F_G)_y}{m} = -g$$

The vertical motion is free fall, while the horizontal motion is one of constant velocity.

Clicker Question 6

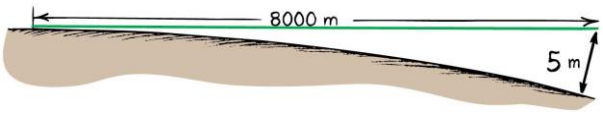
A girl throws a ball in a horizontal direction (dashed line). After the ball leaves the girl's hand, 1.0 seconds later it will have fallen

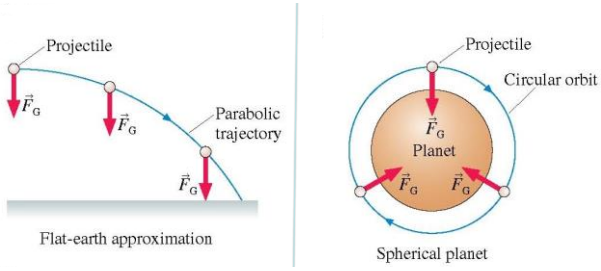
A. 9.8 meters.
B. 4.9 meters below the dashed line.
C. less than 4.9 meters below the straight-line path.
D. more than 4.9 meters below the straight-line path.



The Curvature of the Earth

- Earth surface drops a vertical distance of 5 meters for every 8000 meters tangent to the surface.

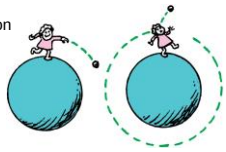




Circular Satellite Orbits

Satellite in circular orbit

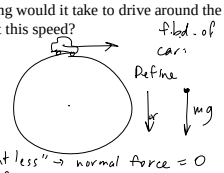
- Speed
  - must be great enough to ensure that its falling distance matches Earth's curvature.
  - is constant—only direction changes.
  - is unchanged by gravity.



Example $R_{Earth} = 6400 \times 10^3\ m$

(a) How fast would you have to drive in order to be "weightless" – ie, no normal force needed to support your car?

(b) How long would it take to drive around the world at this speed?



"weightless" → normal force = 0

$(F_{Net})_r = \cancel{m}g = \frac{\cancel{m}v^2}{r}$

Solve for v: $v = \sqrt{gr} = \sqrt{(9.8)(6400 \times 10^3 m)}$

$v = 7900\ m/s = 7.9\ km/s.$

(b) Circumference of the Earth: $C = 2\pi r$

$C = 2(3.14)(6400 \times 10^3 m)$

$= 40{,}000 \times 10^3 m = 40{,}000\ km$

$v = \frac{d}{t}$

$t = \frac{d}{v} = \frac{40{,}000\ km}{7.8\ km/s}$

$t = 5090$ seconds

$\boxed{t = 84 \text{ minutes}}$

Circular Orbits

An object moving in a circular orbit of radius r at speed v_{orbit} will have centripetal acceleration of

$$a_r = \frac{(v_{orbit})^2}{r} = g$$

That is, if an object moves parallel to the surface with the speed

$$v_{orbit} = \sqrt{rg}$$

then the free-fall acceleration provides exactly the centripetal acceleration needed for a circular orbit of radius r.
An object with any other speed will not follow a circular orbit.

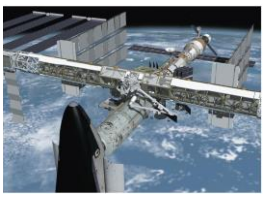
Clicker Question 7

Why are communications satellites typically launched with rockets to heights of more than 100 km?

A. To get above the Earth's atmosphere in order to avoid air resistance
B. To get closer to the Sun in order to collect more solar power
C. To get away from radio interference on Earth
D. To get outside Earth's gravitational pull so the satellite doesn't fall down

Image from http://www.zazzmotfunny.com/2009-52/ninja-sim-headed-for-bank-raging/

Circular Satellite Orbits



- Positioning: beyond Earth's atmosphere, where air resistance is almost totally absent
- Example: Low-earth orbit communications satellites are launched to altitudes of 150 kilometers or more, in order to be above air drag
- But even the ISS, as shown, experiences *some* air drag, which is compensated for with periodic upward boosts.

Before Class 14 on Monday

- Please read the rest of Knight **Chapter 8**, and/or watch the Pre-Class Video, now on portal
- MasteringPhysics Problem Set 6 is due on Monday evening.
- It's been a lot of fun – you are an excellent class!
- I'll be back! You will see me again in January for PHY132!
- I hope you keep coming to my office hours T2-3 and RF10-11 – I'd love to help!
- The next test is Nov. 19 on Chs. 6-10, which includes momentum and energy

- And I will definitely see you at the Final Exam Dec. 17 9:00am!

Image from http://selfie-gif.com/tag/id/114577-it-be-back-gifs