## Announcements

- This week's homework .... 2 parts
- Quiz on Friday, Chs 2 and 3
- Today's class:
$>$ Relative motion
$>$ Circular motion, what causes it ... centripetal acceleration
$>$ Circular kinematics, how to describe it ... same as linear motion
- Movie of the week, circular motion. Film it, measure the centripetal acceleration, identify its source (tension, gravity, etc,)



## ConcepTest 4.8.a Spinning

A particle moves cw around a circle at
constant speed for 2.0 s . It then
reverses direction and moves cew at
half the original speed until it has
traveled through the same angle.
Which is the particle's angle-versus-
time graph?

1. $\mathbf{a}$
2. b
3. $\mathbf{C}$
4. d

(a)

(b)

(c)

(d)

## ConcepTest 4.8.a Spinning

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Which is the particle's angle-versustime graph?


## ConcepTest 4.9.a Centrifuge

You load a centrifuge tube with mercury and water and you shake it. Then set it spinning at high speed. What happens to the water and mercury?

1. They mix together
2. They separate, water on top, mercury on bottom
3. They separate, mercury on top, water on bottom
4. Nothing happens

## ConcepTest 4.9.b Centrifuge

You load a centrifuge tube with mercury and water and you shake it. Then set it spinning at high speed. What happens to the water and mercury?

1. They mix together
2. They separate, water on top, mercury on bottom
3. They separate, mercury on top, water on bottom
4. Nothing happens

This is an example of artificial gravity required to create the
centripetal acceleration. How does it work, when the force is pointed inward? ... The effective gravity points to the bottom of the tube as if the tube were held vertically.

## Important Concepts

## Nonuniform Circular Motion

Angular acceleration $\alpha=d \omega / d t$.
The radial acceleration

$$
a_{r}=\frac{v^{2}}{r}=\omega^{2} r
$$


changes the particle's direction. The tangential component

$$
a_{t}=\alpha r
$$

changes the particle's speed.

## Spinning up

- What more can we ask about a rotating object?
$>$ How much did it rotate?
$>$ How fast did it spin?
$>$ How does it accelerate?

Why are these useful?

Angular displacement $\boldsymbol{\theta}$
Angular velocity $\omega$
Angular acceleration $\alpha$
Every point on a rotating object
has the same angular velocity
and angular acceleration

|  | angular |  |
| :--- | :--- | :--- |
| rotation | $\theta=\theta_{0}+\omega_{0} \mathrm{t}+1 / 2 \mathrm{at}^{2}$ | rad |
| velocity | $\Delta \omega=\omega_{0+} \alpha \mathrm{t}$ | $\mathrm{rad} / \mathrm{sec}$ |
| Acceleration | $\alpha=$ constant | $\mathrm{rad} / \mathrm{s}^{2}$ |
|  |  |  |

Just like in the linear case ... but with different symbols
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## Angular velocity and acceleration

A wheel rolls to the left along a horizontal surface, up a ramp, then continues along the upper horizontal surface. Draw graphs for the wheel's angular velocity $\omega$ and angular acceleration $\alpha$ as functions of time.


## Space Station

A projected space station consists of a circular tube that will rotate about its center (like a tubular bicycle tire) as shown in figure below. The circle formed by the tube has a diameter of about $\mathrm{D}=1.10 \mathrm{~km}$. What must be the rotation speed (in revolutions per day) if an effect equal to gravity at the surface of the Earth ( 1 g ) is to be felt? Do not enter units.


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## ConcepTest 5.1 Newton's First Law II

In which movie(s) is the net force zero

1) $A$
2) $B$
3) $C$
4) A and B
5) A and C
6) B and C
7) All of the movies


A


B


C


## ConcepTest 5.2 Newton's First Law II

A hockey puck slides on ice at constant velocity. What is the net force acting on the puck?

1) more than its weight
2) equal to its weight
3) less than its weight but more than zero
4) depends on the speed of the puck
5) zero

## ConcepTest 5.2 Newton's First Law II

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1) more than its weight
2) equal to its weight
3) less than its weight but more than zero
4) depends on the speed of the puck
5) zero

The puck is moving at a constant velocity, and
therefore it is not accelerating. Thus, there must
be no net force acting on the puck.

## Newton's First Law

## Law of Inertia: Objects resist change in motion

Objects do not resist motion, but change in motion

How much do they resist? It depends on their mass.
The more massive an object, the more resistant it will be.


MaSS: How much "stuff" (matter) an object has.

## Equilibrium

- Newton's first law implies Translational equilibrium:

$$
\Sigma F=0
$$



The following statements are equivalent:
$>$ The object is in equilibrium
$>$ The net force on the object is zero
$>$ The forces acting on the object are balanced
$>$ The object is at rest or moves with constant velocity
$>$ Every force has another force that balances it. The forces act in interaction pai

## A Tour de Force

- A force is a push or a pull that acts on an object
$>$ Contact forces:
objects in contact exert forces on each other
» you push on a box
» air pushes on a car (air resistance)

» tension in a rope

> Action at a distance:
" gravity
» electricity
» magnetism


All forces are vectors!

## ConcepTest 5.3 Newton's First Law III

A hollow tube forms threequarters of a circle. It is lying flat on a table. A ball is shot through the tube at high speed. As the ball emerges from the other end, does it follow path $A$, path $B$, or path C?


## ConcepTest 5.3 Newton's First Law III

A hollow tube forms threequarters of a circle. It is lying flat on a table. A ball is shot through the tube at high speed. As the ball emerges from the other end, does it follow path $A$, path $B$, or path C?


Once the ball exits the tube, the centripetal force is no longer exerted on it to keep accelerating it to the center of the circle. It then flies straight out.

## ConcepTest 5.4a Newton's First Law III

You put your book on the bus seat next to you. When the bus stops suddenly, the book slides forward off the seat. Why?

1) a net force acted on it
2) no net force acted on it
3) it remained at rest
4) it did not move, but only seemed to
5) gravity briefly stopped acting on it

## ConcepTest 5.4b Newton's First Law III

You put your book on the bus seat next to you. When the bus stops suddenly, the book slides forward off the seat. Why?

1) a net force acted on it
2) no net force acted on it
3) it remained at rest
4) it did not move, but only seemed to
5) gravity briefly stopped acting on it

The book was initially moving forward (since it was on a moving bus). When the bus stopped, the book continued moving forward, which was its initial state of motion, and therefore it slid forward off the seat.

[^0]


## A Free Body Diagram:

- Does not need to be pretty
- Technically a 'point' is enough, but a box, circle or schematic representation of the object at hand is enough
- 'Free Body' $\rightarrow$ no other objects, no background, ...
- Add the forces acting on the object
- Keep the magnitudes of the vectors roughly in proportion
- Add a coordinate system, choose wisely ..



## Whiteboards: Lift the blimp

Why is it possible for a single person to pick up the GoodYear blimp (60 m long, 6800 kg ), yet they cannot shake it back and forth? Draw a free body diagram


## Tangible: Forces on Textbooks

1. For each of the pictures below, draw the free-body diagram on the book. Be careful to include all forces on the book.
2. For 3,4 , and 5 assume that the book has a constant velocity
3. For 3 , push the book to get it moving. Is it more difficult to get the book started or to keep it moving?
4. Redo the free-body diagrams for $3,4,5$ under the assumption that the book's velocity is changing.
5. For \#6, draw the free body diagram for the upper and the lower book and for the books as a single unit.



## Forces can be divided into two classes:

- Some forces are more Active: There is a contact force in the form of a pull or push.

- Others are more Passive: Where they adjust their size as a "response" to an active force
$>$ normal force
$>$ tension
$>$ friction
$>$ Centripetal force


- How do we characterize this?
> Friction results in a force parallel to the surface, in a direction opposite to the direction of motion!
> Frictional force is perpendicular to Normal force
- Kinetic frictional force $f_{F}$ is proportional to the normal force $N$.
$>\boldsymbol{f}_{F}=\mu_{\mathrm{K}} \boldsymbol{N}$
$>$ The "heavier" something is, the greater the friction will be.... makes sense!


## Viscous Drag

- What does it do?
- It opposes motion!
- How do we characterize this?
> Drag results in a force in a direction opposite to the direction of motion! $\quad F_{D}$
> Drag force is proportional to v (small, slow objects) or $\mathbf{v}^{2}$ (large, fast objects)
For microscopic objects (paramecium, e.coli).
$>F_{D}=-6 K \pi \eta r v$
$\eta=$ viscosity, $r=$ radius, $v=$ velocity $K=$ geometric factor, K = 1 for a sphere
$>$ The "faster" something goes
... the greater the drag will be....


[^0]:    Follow-up: What is the force that usually keeps the book on the seat when stopping?

