

# Phy 211: General Physics I

## Chapter 6: Force & Motion II Lecture Notes

### Fluid (Air) Drag Forces

- When moving objects are in a fluid medium (i.e. air), the motion is impeded by interactions between the fluid and the object's surface. This is referred to as Fluid Drag (or Air Drag in the case of air).
- Drag forces always oppose the direction of motion
- In the simplest model, Drag forces are related to:
  - The object's relative motion within the fluid ( $v$ )
  - The density of the fluid ( $\rho$ )
  - The effective cross sectional area of the object ( $A$ )
  - Coefficient of drag ( $C$ ): a constant that characterizes the interaction between the fluid and the surface of the object

$$|\vec{F}_{\text{Drag}}| = \frac{1}{2} \rho C A v^2$$

- terminal velocity, ( $\vec{v}_T$ ) occurs when the drag force equals the forces that oppose it ( $\vec{F}_{\text{net}} = 0$ )

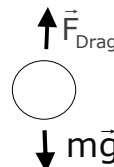
## Falling Objects with Air Drag

Consider a ball (1 kg), 0.20 m radius, dropped from a helicopter and subject to air drag. The coefficient of drag (C) is 0.5 and  $\rho_{\text{air}}$  is 1.21 kg/m<sup>3</sup>.

1. The effective cross-sectional area for the ball is:

$$A = \pi r^2 = 0.126 \text{ m}^2$$

2. As the ball descends, its free body diagram is:



$$\vec{F}_{\text{Net}} = \vec{F}_{\text{Drag}} - m\vec{g} = (F_{\text{Drag}} - mg)\hat{j}$$

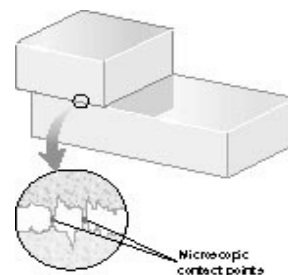
$$\vec{F}_{\text{Net}} = \left( \frac{\rho C A v^2}{2} - mg \right) \hat{j}$$

3. When  $F_{\text{drag}} = mg$ , the terminal velocity is:

$$|\vec{v}_T| = \sqrt{\frac{2mg}{\rho C A}} = 16.0 \frac{\text{m}}{\text{s}}$$

## Surface Frictional Forces

- When an object moves or tends to move along a surface, there is an interaction between the microscopic contact points on the 2 surfaces. This interaction results in a *frictional force*, that is
  - parallel to the surface
  - opposite to the direction of the motion
- There are 2 types of surface friction:
  - Static (sticking)
  - Kinetic (sliding)



## Static Friction

- *Static (or sticking) friction* ( $\vec{f}_s$ ) is the frictional force exerted when the object tends to move, but the external force is not yet strong enough to actually move the object.
- Increasing the applied force, the static frictional force increases as well (so the net force is zero). The force just before breakaway is the *maximum static frictional force*.
- The direction of the static friction force is always in opposition to the external forces(s) acting on the body
- The magnitude of the maximum static friction force is:

$$|\vec{f}_s^{\max}| = \mu_s^{\max} |\vec{F}_N|$$

Where:

- $\mu_s^{\max}$  is the coefficient (maximum) of static friction
- $F_N$  is the normal force

## Kinetic Friction

- Kinetic frictional force ( $\vec{f}_k$ ) is the frictional force exerted by the surface on an object that is moving along the surface
- Kinetic frictional force:
  - always opposes the direction of the motion
  - the direction is along the surface (parallel to the surface)
- The magnitude of the kinetic frictional force depends only on the normal force and the properties of the 2 surfaces in contact

$$|\vec{f}_k| = \mu_k |\vec{F}_N|$$

Where:

- $\mu_k$  is the coefficient of kinetic friction
- $F_N$  is the normal force

Notes:

- Kinetic friction is independent to the rate of travel of the sliding body
- Kinetic friction is independent to the surface area of contact

## Centripetal Force

- Center-seeking force that pulls an object into circular motion (object is not in equilibrium)

$$\vec{F}_{\text{net}} = \vec{F}_c = m\vec{a}_c$$

- The direction of the centripetal force is the same as the centripetal acceleration
- The magnitude of centripetal force is given by:

$$F_c = ma_c = mv^2/r$$

- For uniform circular motion, the centripetal force is the net force:

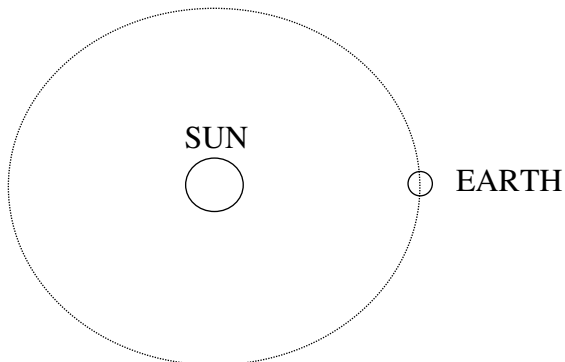
$$\vec{F}_{\text{net}} = \vec{F}_c = m\vec{a}_c$$

Notes:

- the faster the speed the greater the centripetal force
- the greater the radius of motion the smaller the force

## Centripetal Force & Gravitation

Let's assume the Earth travels about the Sun in uniform circular motion:



Questions:

1. What force is responsible for maintain the Earth's circular orbit?
2. Draw a Free-Body Diagram for the Earth in orbit.
3. Calculate gravitational force exerted on the Earth due to the Sun.
4. What is the centripetal acceleration of the Earth?
5. What is the Earth's tangential velocity in its orbit around the Sun?

## Centripetal Force vs. Centrifugal Force

- An object in uniform circular motion observes an outward force called centrifugal force (due to the object's inertia)
- Centrifugal force \_\_\_\_\_.
  - is a fictitious force (it is not really a force it is only perceived as one)
  - is due to the body's inertia acting against its circular motion (& its rotating environment)
  - has a magnitude equal to the centripetal force acting on the body

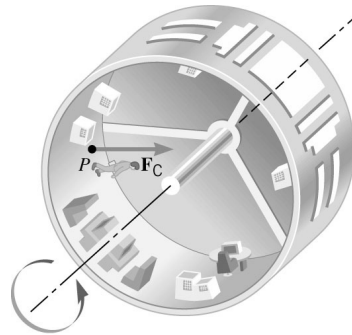
## Artificial Gravity

- Objects in a rotating environment “feel” an outward centripetal force (similar to gravity)
- What the object really experiences is the normal force of the support surface that provides centripetal force
- The magnitude of “effective” gravitational acceleration is given by:

$$a_c = g_{\text{artificial}} = \frac{v^2}{r}$$

- If a complete rotation occurs in a time,  $T$  ( $T$  is called the period) then the rotational (or angular) speed is given by

$$\omega = \frac{2\pi}{T} = \frac{d\theta}{dt}$$

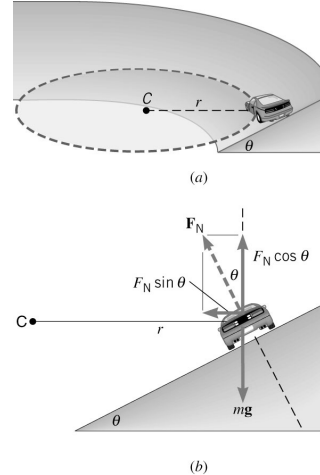


Note: there are  $2\pi$  radians ( $360^\circ$ ) in a complete rotation/revolution

- Since  $v = \omega r$  (rotational speed x radius),  $g_{\text{artificial}} = \omega^2 r = \frac{4\pi^2 r}{T^2}$
- Thus, the (artificial) gravitational strength is related to size of the structure ( $r$ ), rotational rate ( $\omega$ ) and square of the period of rotation ( $T^2$ )

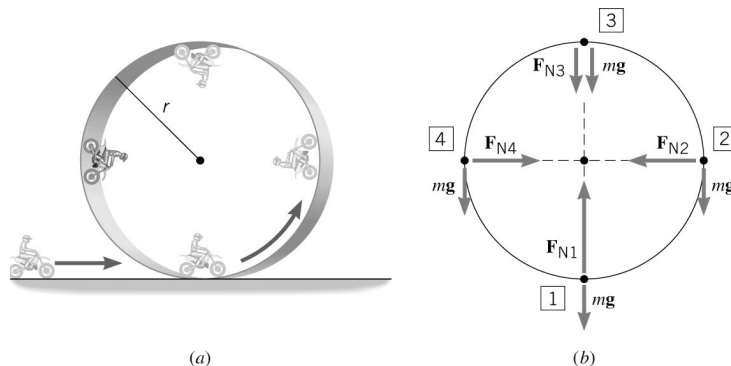
## Banked Curves

- Engineers design banked curves to increase the speed certain corners can be navigated
- Banking corners decreases the dependence of static friction (between tires & road) necessary for turning the vehicle into a corner.
- Banked corners can improve safety particularly in inclement weather (icy or wet roads) where static friction can be compromised
- **How does banking work?**
- The normal force ( $F_N$ ) of the bank on the car assists it around the corner!



## Vertical Circular Motion

- Consider the forces acting on a motorcycle performing a loop-to-loop:



- Can you think of other objects that undergo similar motions?