Fundamentals Physics

Eleventh Edition

Halliday

Chapter 6

Force and Motion–II

6-2 The Drag Force and Terminal Speed (1 of 8)

Learning Objectives

6.04 Apply the relationship between the drag force on an object moving through the air and the speed of the object.

6.05 Determine the terminal speed of an object falling through the air.

6-2 The Drag Force and Terminal Speed (2 of 8)

- A **fluid** is anything that can flow (gas or liquid)
- When there is relative velocity between fluid and an object there is a **drag force**:
  - That opposes the relative motion
  - And points along the direction of the flow, relative to the body
- Here we examine the drag force for
  - Air
  - With a body that is not streamlined
  - For motion fast enough that the air becomes turbulent (breaks into swirls)

6-2 The Drag Force and Terminal Speed (3 of 8)

- For this case, the drag force is:

$$D = \frac{1}{2} C\rho A v^2, \qquad \textbf{Equation (6-14)}$$

- Where:
  - v is the relative velocity
  - ρ is the air density (mass/volume)
  - C is the experimentally determined drag coefficient
  - A is the effective cross-sectional area of the body (the area taken perpendicular to the relative velocity)
- In reality, C is not constant for all values of v

6-2 The Drag Force and Terminal Speed (4 of 8)

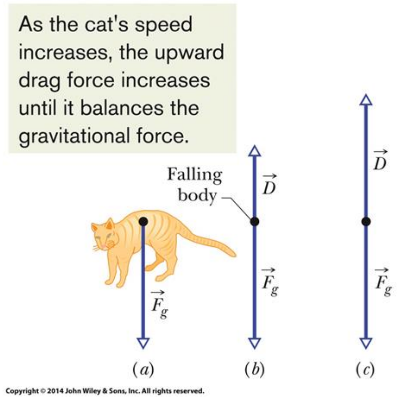

As the cat's speed increases, the upward drag force increases until it balances the gravitational force.

Figure 6-6

6-2 The Drag Force and Terminal Speed (5 of 8)

- The drag force from the air opposes a falling object

$$D - F_g = ma, \qquad \textbf{Equation (6-15)}$$

- Once the drag force equals the gravitational force, the object falls at a constant **terminal speed:**

$$v_t = \sqrt{\frac{2F_g}{C\rho A}}. \qquad \textbf{Equation (6-16)}$$

- Terminal speed can be increased by reducing A
- Terminal speed can be decreased by increasing A
- Skydivers use this to control descent

6-2 The Drag Force and Terminal Speed (6 of 8)

Example Speed of a rain drop:

- A raindrop with radius $R = 1.5$ mm falls from a cloud that is at height $h = 1200$ m above the ground. The drag coefficient C for the drop is 0.60. Assume that the drop is spherical throughout its fall. The density of water ρ_w is 1000 kg/m^3, and the density of air ρ_a is 1.2 kg/m^3.

- Spherical drop feels gravitational force $F = mg$:
  - Express in terms of density of water

$$F_g = V\rho_w g = \frac{4}{3}\pi R^3 \rho_w g.$$

6-2 The Drag Force and Terminal Speed (7 of 8)

Example Speed of a rain drop:

- So, plug in to the terminal velocity equation using the values provided in the text
  - Use $A = \pi R^2$ for the cross-sectional area

$$\begin{aligned} v_t &= \sqrt{\frac{2F_g}{C\rho_a A}} = \sqrt{\frac{8\pi R^3 \rho_w g}{3C\rho_a \pi R^2}} = \sqrt{\frac{8R\rho_w g}{3C\rho_a}} \\ &= \sqrt{\frac{(8)(1.5\times10^{-3}\,\mathrm{m})(1000\ \mathrm{kg/m^3})(9.8\,\mathrm{m/s^2})}{(3)(0.60)(1.2\,\mathrm{kg/m^3})}} \\ &= 7.4\ \mathrm{m/s} \approx 27\ \mathrm{km/h.} \quad \text{(Answer)} \end{aligned}$$

6-2 The Drag Force and Terminal Speed (8 of 8)

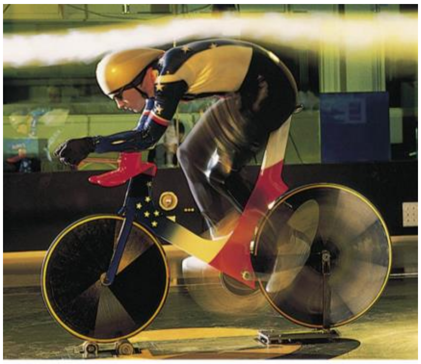
Example Speed of a rain drop:

- What would be the drop's speed just before impact if there were no drag force?
  - Because we know the acceleration is g, the initial velocity v_0 is 0, and the displacement $x - x_0$ is $-h$, thus,

$$v = \sqrt{2gh} = \sqrt{2\left(9.8\,\frac{\text{m}}{\text{s}^2}\right)(1200\text{ m})}$$
$$= 153\,\frac{\text{m}}{\text{s}} \approx 550\,\frac{\text{km}}{\text{h}}$$

Aerodynamic Design

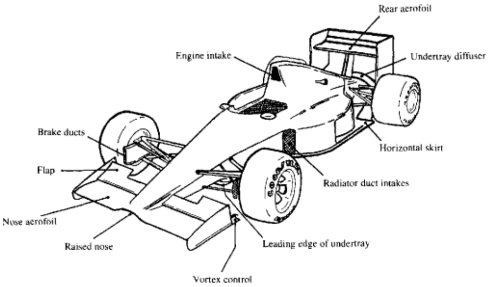
To Lower Drag Coefficient



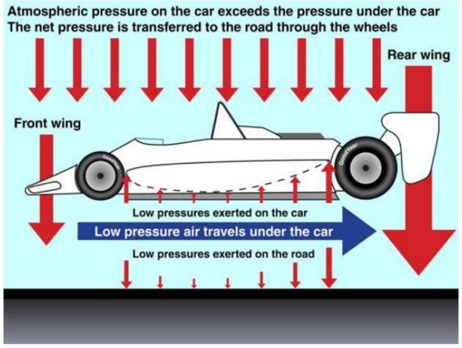
(b)

Aerodynamic Design

To Increase Down Force



https://www.semanticscholar.org/paper/Aerodynamics-of-Grand-Prix-Cars-Dominy/b304bdd220ebc83c056d27ee2f0a699986480bcf



https://www.catchmentsandcreeks.com.au/docs/Race-Car-Aerodynamics-print.pdf

6-3 Uniform Circular Motion (1 of 19)

Learning Objectives

6.06 Sketch the path taken in uniform circular motion and explain the velocity, acceleration, and force vectors (magnitudes and directions) during the motion.

6.07 Identify that unless there is a radially inward net force (a centripetal force), an object cannot move in circular motion.

6.08 For a particle in uniform circular motion, apply the relationship between the radius of the path, the particle's speed and mass, and the net force acting on the particle.

6-3 Uniform Circular Motion (2 of 19)

- Recall that circular motion requires a centripetal acceleration

$$a = \frac{v^2}{R} \qquad \textbf{Equation (6-17)}$$

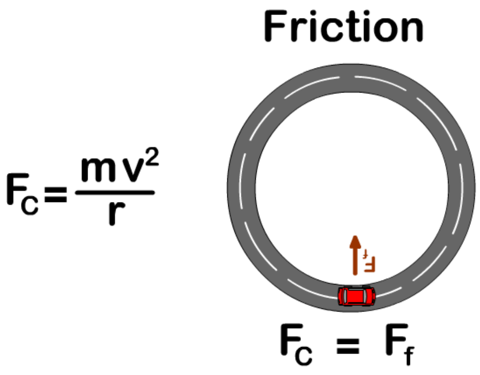
- Centripetal force is not a new kind of force, it is simply an application of force

$$F = m\frac{v^2}{R} \qquad \textbf{Equation (6-18)}$$

A centripetal force accelerates a body by changing the direction of the body's velocity without changing the body's speed.

6-3 Uniform Circular Motion (3 of 19)

Various force can act as the centripetal force.



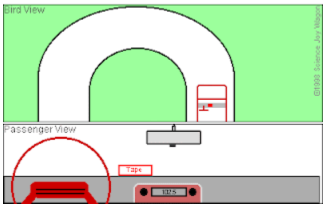
stickmanphysics.com

6-3 Uniform Circular Motion (4 of 19)

Examples You are a passenger:

- For a car, rounding a curve, the car accelerates toward the center of the curve due to a **centripetal force** provided by the inward friction on the tires. Your inertia makes you want to go straight ahead so you may feel friction from your seat and may also be pushed against the side of the car. These inward forces keep you in uniform circular motion in the car.

makeagif.com

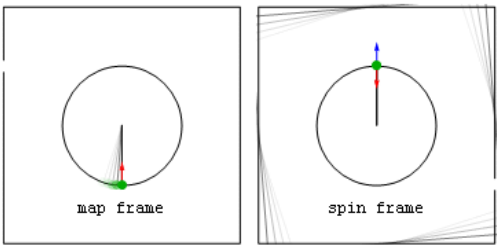


http://physicsanas.blogspot.com/

6-3 Uniform Circular Motion (5 of 19)

Examples You are a passenger:

- For a space shuttle, the shuttle is kept in orbit by the gravitational pull of Earth acting as a centripetal force. This force also acts on every atom in your body and keeps you in orbit around the Earth. You float with no sensation of force but are subject to a centripetal acceleration.



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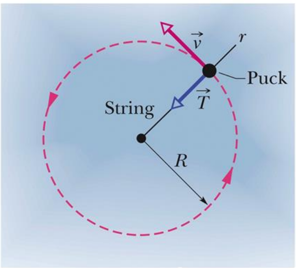
6-3 Uniform Circular Motion (6 of 19)

- For the puck on a string, the string tension supplies the centripetal force necessary to maintain circular motion



The puck moves in uniform circular motion only because of a toward-the-center force.

Figure 6-8

6-3 Uniform Circular Motion (7 of 19)

Checkpoint 2

As every amusement park fan knows, a Ferris wheel is a ride consisting of seats mounted on a tall ring that rotates around a horizontal axis. When you ride in a Ferris wheel at constant speed, what are the directions of your acceleration $\vec{a}$ and the normal force $\vec{F}_N$ you (from the always upright seat) as you pass through

(a) the highest point and

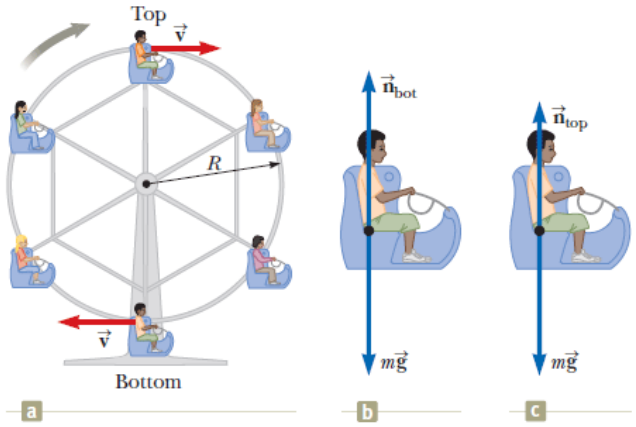
(b) the lowest point of the ride?

(c) How does the magnitude of the acceleration at the highest point compare with that at the lowest point?

(d) How do the magnitudes of the normal force compare at those two points?

6-3 Uniform Circular Motion (8 of 19)

Checkpoint 2



physics.stackexchange.com

6-3 Uniform Circular Motion (9 of 19)

Question:	**Answer:**
(a) the highest point and	(a) accel downward, F_N upward
(b) the lowest point of the ride?	(b) accel upward, F_N upward
(c) how does the magnitude of the acceleration at the highest point compare with that at the lowest point?	(c) the magnitudes must be equal for the motion to be uniform
(d) how do the magnitudes of the normal force compare at those two points?	(d) F_N is greater in (b) than in (a)

6-3 Uniform Circular Motion (10 of 19)

Example Bicycle going around a vertical loop:

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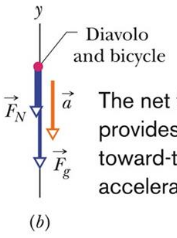


The normal force is from the overhead loop.

The net force provides the toward-the-center acceleration.

Figure 6-9

6-3 Uniform Circular Motion (11 of 19)

- At the top of the loop, we have:

$$-F_N - mg = m\left(-\frac{v^2}{R}\right).$$

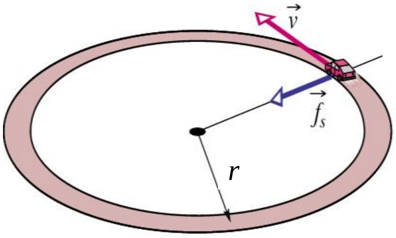
Equation (6-19)

- Solve for v and plug in our known values, including $F_N = 0$ for the minimum answer:

$$v = \sqrt{gR} = \sqrt{\left(9.8\,\frac{\text{m}}{\text{s}^2}\right)(2.7\text{ m})} = 5.1\,\frac{\text{m}}{\text{s}}$$

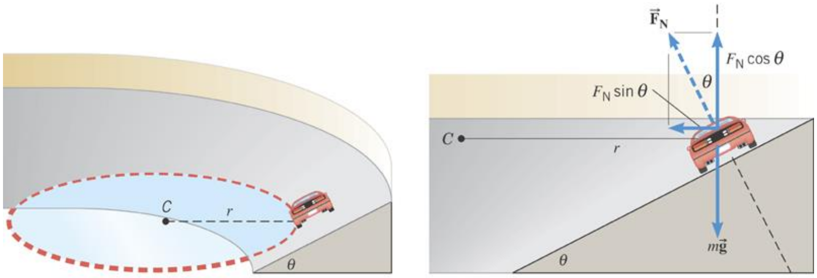
6-3 Uniform Circular Motion (12 of 19)

Example Car in a banked circular turn:



6-3 Uniform Circular Motion (13 of 19)

Example Car in a banked circular turn:



(a)

(b)

6-3 Uniform Circular Motion (14 of 19)

- ○ Sum components along the radial direction:

$$-F_N \sin \theta = m\left(-\frac{v^2}{R}\right).$$

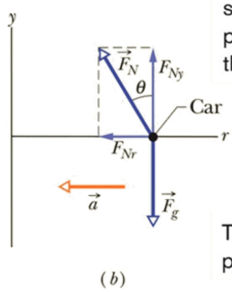
Equation (6-23)

- ○ Sum components along the vertical direction:

$$F_N \cos \theta = mg. \quad \textbf{Equation (6-24)}$$

- ○ Divide and replace $\frac{(\sin \theta)}{(\cos \theta)}$ with tangent.

$$\theta = \tan^{-1} \frac{v^2}{gR}$$



(b)

Tilted normal force supports car and provides the toward-the-center force.

The gravitational force pulls car downward.

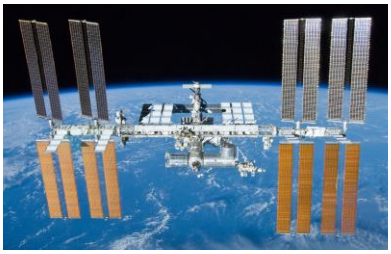
6-3 Uniform Circular Motion (15 of 19)

Astronauts in the International Space Station appears to be weightless, although the gravitational acceleration has the value of

$$g = \left[G\frac{M_E}{(R_E + 408)^2}\right] = 8.645\,\frac{m}{s^2}$$

They even do not free falling to the Earth.

How could this be?



en.wikipedia.org

destinationspace.uk

6-3 Uniform Circular Motion (16 of 19)

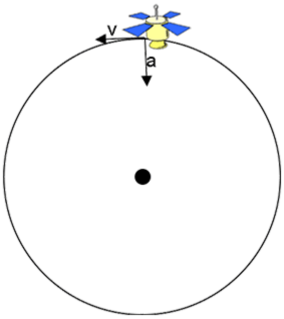
The International Space Station is orbiting the Earth in (assume) a circular orbit, hence the gravitational force on the ISS from the Earth acts as the Centripetal force

$$F_{grav} = F_{cp}$$

$$G\frac{M_E}{(R_E+h)^2}m_{ISS} = m_{ISS}\frac{v^2}{R_E+h}$$

Thus, the speed of ISS is

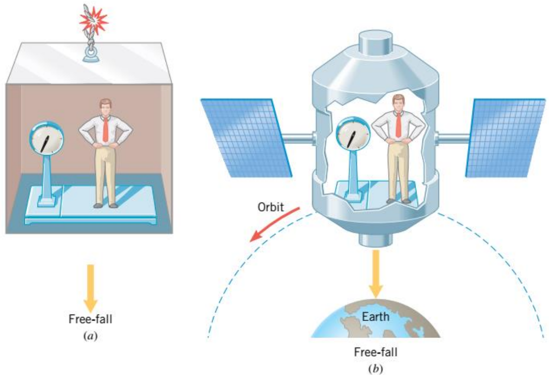
$$v = \sqrt{\frac{GM_E}{(R_E+h)}} = 7.66\frac{\text{km}}{\text{s}}$$



imagine.gsfc.nasa.gov

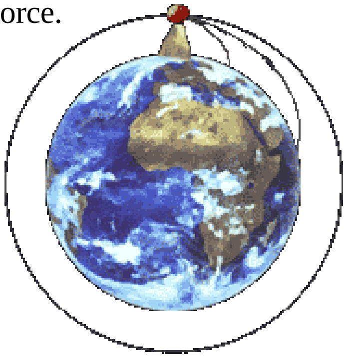
6-3 Uniform Circular Motion (17 of 19)

Because the astronauts in the International Space Station are orbiting the Earth inside the station, they appear to be weightless. This is the same situation as a person free-falling.



6-3 Uniform Circular Motion (18 of 19)

To make an object has a stationary orbit around the Earth and not fall down, the object needs to have a specific speed, too low it will fall back to the Earth, to high, it will escape the Earth gravitational force.



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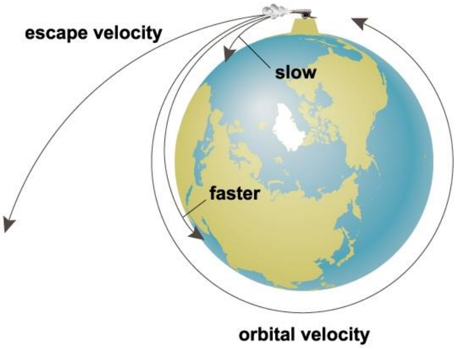
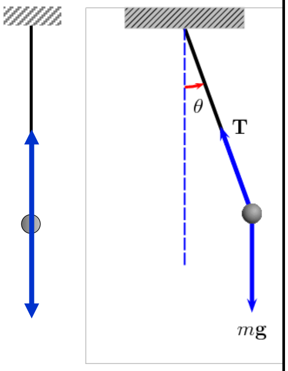


theifod.com

6-3 Uniform Circular Motion (19 of 19)

Conceptual Question : A Trapeze Act

In a circus, a man hangs upside down from a trapeze, legs bent over and arms downward, holding his partner. Is it harder for the man to hold his partner when the partner hangs straight down and is stationary or when the partner is swinging through the bottom position?



$$T - mg = \frac{mv^2}{r}$$

6 Summary (1 of 4)

Friction

- Opposes the direction of motion or attempted motion
- Static if the object does not slide
- Static friction can increase to a maximum

$$f_{s,\max} = \mu_s F_N, \qquad \textbf{Equation (6-1)}$$

- Kinetic if it does slide

$$f_k = \mu_k F_N, \qquad \textbf{Equation (6-2)}$$

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6 Summary (2 of 4)

Drag Force

- Resistance between a fluid and an object
- Opposes relative motion
- Drag coefficient *C* experimentally determined

$$D = \frac{1}{2} C\rho A v^2, \qquad \textbf{Equation (6-14)}$$

- Use the effective cross-sectional area (area perpendicular to the velocity)

6 Summary (3 of 4)

Terminal Speed

- The maximum velocity of a falling object due to drag

$$v_t = \sqrt{\frac{2F_g}{C\rho A}}.$$

Equation (6-16)

6 Summary (4 of 4)

Uniform Circular Motion

- Centripetal acceleration required to maintain the motion

$$a = \frac{v^2}{R}$$

Equation (6-17)

- Corresponds to a centripetal force

$$F = m\frac{v^2}{R}$$

Equation (6-18)

- Force points toward the center of curvature

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