Chapter 5

Applying Newton's Laws of Motion

Topic	Conceptual Problems (To be Discussed in Class)	In Class Problems	Assignment Problems
5.1: Using Newton's First law: Particles in Equilibrium,	TYU-5.1 TYU-5.3 TYU-5.4	**Example-** 5.1, 5.8, 5.13, 5.16, 5.21, 5.22, 5.23.	**Exercise** 5.10, 5.25, 5.28
5.2: Using Newton's Second law (Apparent weight & Weightlessness)			
5.3: Frictional Forces			
5.4: Dynamics of Circular Motion			

Particles in Equilibrium

A body is in equilibrium when it is at rest or moving with constant velocity in an inertial frame of reference. When a particle is in equilibrium, the net force acting on it—that is, the vector sum of all the forces acting on it—must be zero:

$$\sum \vec{F} = 0$$

In component form the above equation is written as:

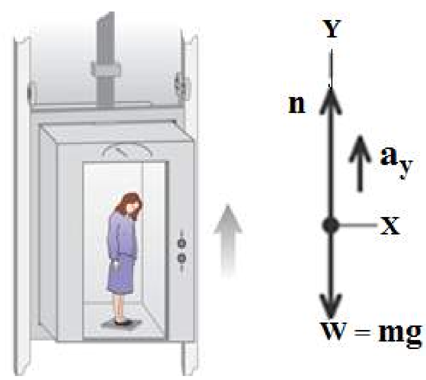
$$\sum F_x = 0 \quad \sum F_y = 0$$

Apparent weight and apparent weightlessness

Elevator Problem: Elevator is accelerating upward

When the elevator is accelerating upward, the forces acting on the passenger are:

- weight of the passenger (w = mg), in the downward direction,
- Normal reaction, ‘n’ in the upward direction,



The acceleration the passenger a_y is positive.

$$\sum F_y = m\,a_y \qquad \Rightarrow \qquad n + (-w) = m\,a_y$$

$$\Rightarrow \quad n - mg = m\,a_y \qquad \Rightarrow \qquad n = m\,(g + a_y)$$

Thus ‘n’ is greater than the passenger’s weight ‘w’, i.e the apparent weight increases.

Elevator is accelerating downward

When the elevator is accelerating downward, a_y is negative and n is less than the weight. Thus apparent weight of the passenger decreases.

$$n = m\,(g - a_y)$$

Weightlessness

- When a_y = g, the elevator is in free fall, then n = 0 and the passenger feels to be **weightless**.
- Similarly, an astronaut orbiting the earth in a spacecraft experiences **apparent weightlessness**.
- In each case, the person is not truly weightless because there is still gravitational force acting. But the person's sensation in this free-fall condition is exactly the same as though the person were in outer space with no gravitational force at all.

Frictional Forces

Force of friction is an example of contact force.

The friction force is such that it always opposes relative motion of the two surfaces in contact.

Static friction force (f_s): Friction forces may also act when there is no relative motion. This is known as static friction force. The magnitude of the static friction force is less than or equal to μ_s **n** as long as the body is at rest. When stronger force is applied the body just about to slide, then we have **$(f_s)_{max} = \mu_s$ n**

Kinetic friction force (f_k):The kind of friction that acts when a body slides over a surface is called a kinetic friction force f_k.

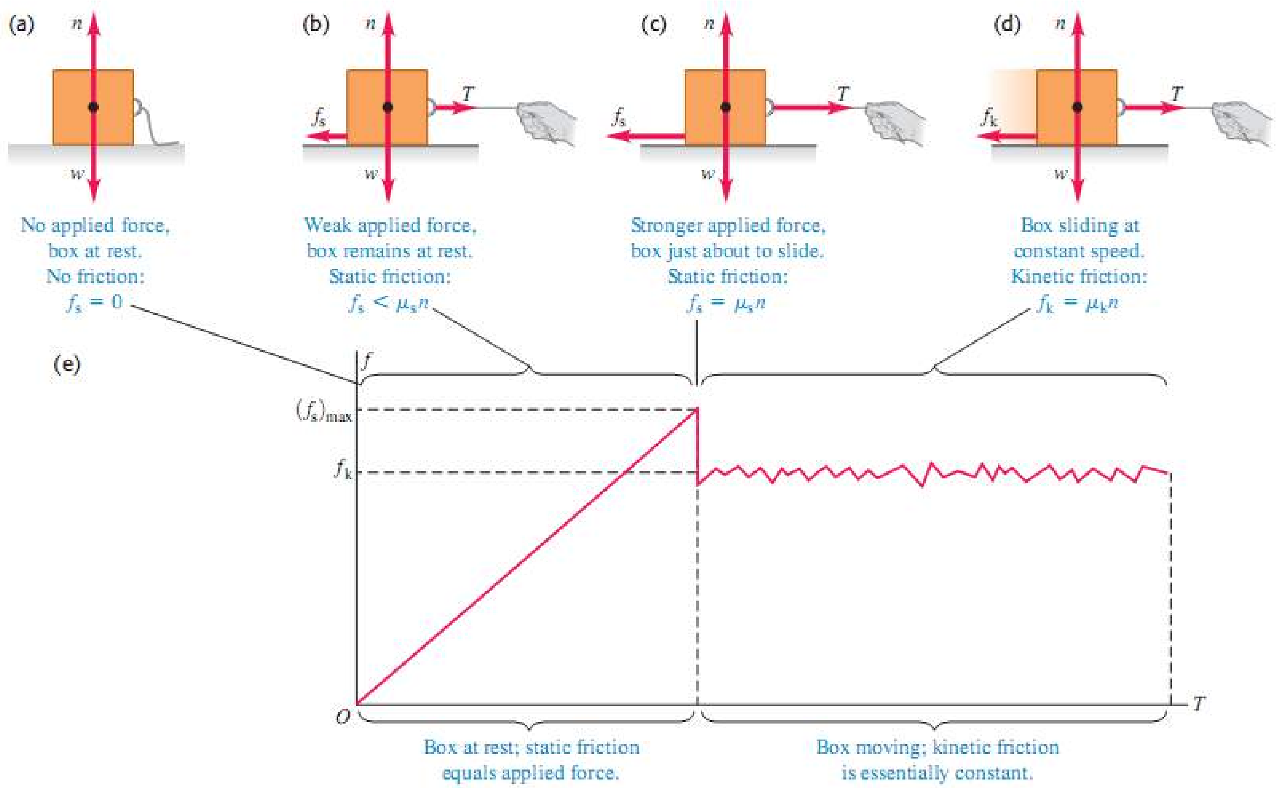
The magnitude of the kinetic friction force usually increases when the normal force (n) increases. It is represented by:

$f_k = \mu_k$ n ……… (1)

Where, μ_k is a constant called the coefficient of kinetic friction. If the surface is more slippery, then the coefficient becomes smaller.

Friction force ($\mathbf{f_k}$) and normal forces ($\mathbf{n}$) are always perpendicular. So Eq. (1) is not a vector equation rather, it is a scalar relationship between the magnitudes of the two forces.

A box is kept on the table and is pulled by a rope. Different stages are shown in the figure.



Rolling Friction

It's a lot easier to move a loaded filing cabinet across a horizontal floor using a cart with wheels than to slide it. We can define a **coefficient of rolling friction μ_r,**

$\mathbf{f_r = \mu_r\, n}$

Transportation engineers call μ_r the tractive resistance. Typical values of μ_r are 0.002 to 0.003 for steel wheels on steel rails and 0.01 to 0.02 for rubber tires on concrete. These values show one reason railroad trains are generally much more fuel efficient than highway trucks.

Fluid Resistance and Terminal Speed

The force that a fluid (a gas or liquid) exerts on a body moving through it is known as fluid resistance. The direction of the fluid resistance force acting on a body is always opposite the direction of the body's velocity relative to the fluid. The magnitude of the fluid resistance force (f) usually increases with the speed (v) of the body through the fluid.

For small objects moving at very ***low speeds***, the magnitude of the fluid resistance force (f) is approximately proportional to the body's speed (v).

$\mathbf{f = kv}$

where '**k**' is a proportionality constant that depends on the shape and size of the body and the properties of the fluid. The unit of k is N·s/m or kg/s

The express **f = kv** is for small objects moving at very ***low speeds***, for example, dust particles falling in air or a ball bearing falling in oil.

For larger objects moving through air at a faster speed, the resisting force (f) is approximately proportional to v^2. It is called **air drag** or simply **drag**. Airplanes, falling raindrops, and bicyclists all experience air drag.

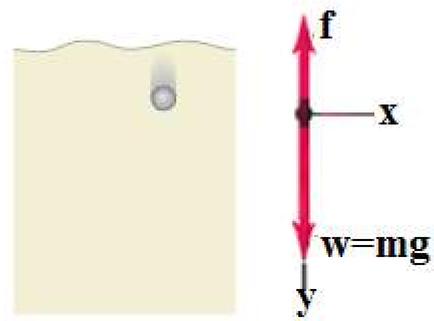
Thus the fluid resistance at high speed is given by

$$f = Dv^2$$

'D' depends on the shape and size of the body and on the density of the air. The units of the constant ***D*** are $N{\cdot}s^2/m^2$ or kg/m.

Because of the effects of fluid resistance, an object falling in a fluid does not have a constant acceleration.

Suppose a metal ball is dropped at the surface of a bucket of oil and let it fall to the bottom. It is shown in the figure along with the free body diagram.



When a body first starts to move, $v_y = 0$, the resisting force (f) = 0,

Initial acceleration is $a_y = g$.

- For slow wind speed, the fluid resistance is : $f = k\,v_y$

$$\sum F_y = m\,g + (-k\,v_y) = m\,a_y$$

- As the velocity increases, the air resistance force also increases, until finally it is equal in magnitude to the weight.
- At this time the net force applied on the body is zero. and there is no further increase in velocity. The final velocity $\mathbf{v_t}$, called the **<u>Terminal Velocity</u>.**

  So, we have,

$$\sum F_y = 0 \quad \Rightarrow \quad m\,g - k\,v_t = 0 \quad \Rightarrow \quad v_t = \frac{m\,g}{k}$$

Terminal velocity – fast moving object

When a body first starts to move, $v_y = 0$, the resisting force (f) = 0,

Initial acceleration is $a_y = g$.

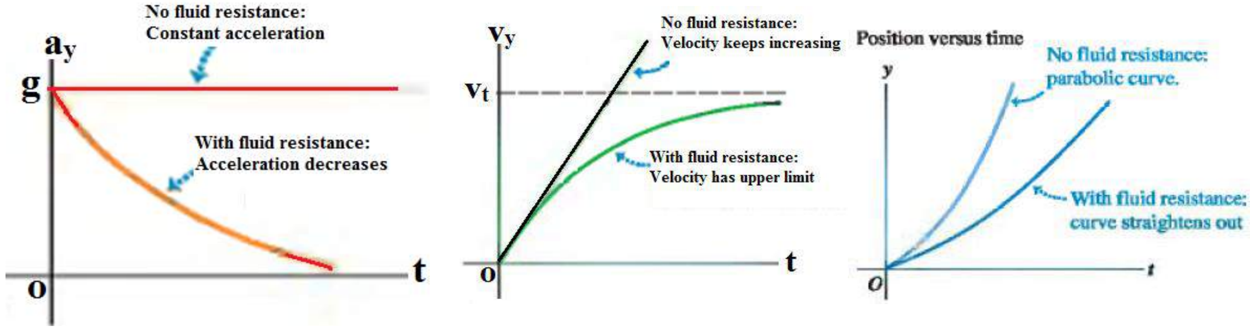
For fast wind speed, the fluid resistance is : $f = D\,v_y^2$

$$\sum F_y = m\,g + (-D\,v_y^2) = m\,a_y$$

As the velocity increases, the air resistance force also increases, until finally it is equal in magnitude to the weight. At this time the net force applied on the body is zero, and there is no further increase in velocity. The final velocity $\mathbf{v_t}$, called the **<u>Terminal Velocity</u>.**

So, we have,

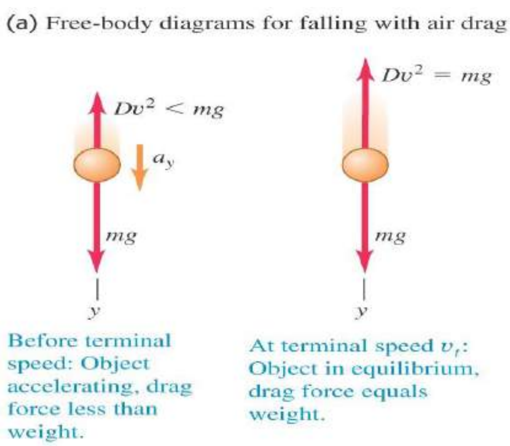
$$\sum F_y = 0 \quad \Rightarrow \quad m\,g - D\,v_t^2 = 0 \quad \Rightarrow \quad v_t = \sqrt{\frac{m\,g}{D}}$$

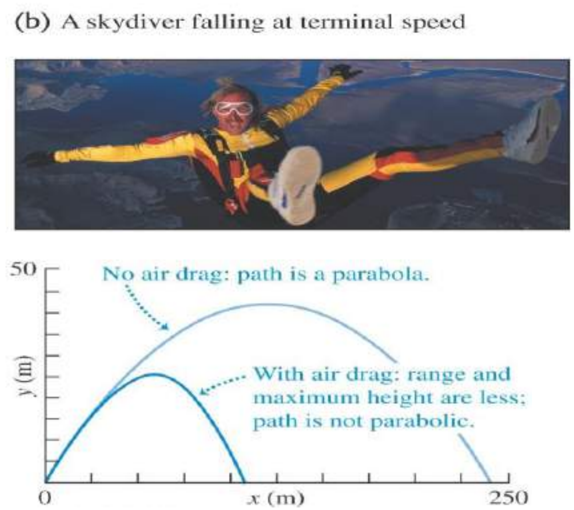


Determine the terminal speed of a sky diver

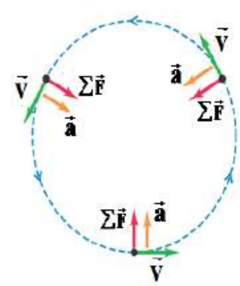
For a human body falling through air in a spread-eagle position, the numerical value of the constant *D* is about 0.25 kg/m. Find the terminal speed for a lightweight 50 kg skydiver.

v_t = 44 m/s





Dynamics of circular motion



When a particle moves in a circular path with constant speed, the particle's acceleration is always directed toward the center of the circle (perpendicular to the instantaneous velocity). This acceleration is called **centripetal acceleration**. The magnitude of the acceleration is constant and is given in terms of the speed (**v**) and the radius **R** of the circle by

Acceleration is given by $a_{rad} = \dfrac{v^2}{R}$

Expression for the centripetal acceleration in terms of the period T, the time for one revolution is give by

$$a_{rad} = \frac{v^2}{R} = \frac{4\pi^2 R}{T^2} \quad \left[\because v = \frac{2\pi R}{T}\right]$$

In uniform circular motion to make the particle accelerate toward the center of the circle, the net force F_{net} on the particle must always be directed toward the center and its magnitude is

$$F_{net} = m\,a_{rad} = m\frac{v^2}{R}$$

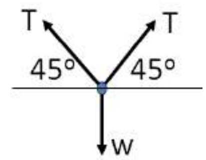
Test your Understanding: TYU-5.1, TYU-5.3, TYU-5.4

Test Your Understanding of Section 5.1

A traffic light of weight ‘w’ hangs from two light weight cables, one on each side of the light. Each cable hangs at a 45° angle from the horizontal. What is the tension in each cable?

(i) w/2 (ii) $w/\sqrt{2}$; (iii) w; (iv) $w\sqrt{2}$; (v) 2w

Answer: (ii)

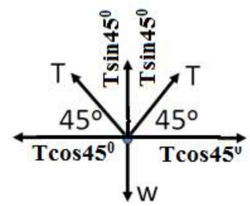


The two cables are arranged symmetrically, so the tension in either cable has the same magnitude *T*.

The vertical component of the tension from each cable is T $\sin 45^0$.

Vertical forces: $2T \sin 45^0 - w = 0$

$$T = \frac{w}{2\sin 45^0} = \frac{w}{\sqrt{2}} = 0.71w$$



Each cable supports half of the weight of the traffic light, but the tension is greater than w/2 because only the vertical component of the tension counteracts the weight.

Test Your Understanding of Section 5.3

Consider a box that is placed on different surfaces.

(a) In which situation(s) is there no friction force acting on the box?
(b) In which situation(s) is there a static friction force acting on the box?
(c) In which situation(s) is there a kinetic friction force on the box?

(i) The box is at rest on a rough horizontal surface.
(ii) The box is at rest on a rough tilted surface.
(iii) The box is on the rough-surfaced flat bed of a truck—the truck is moving at a constant velocity on a straight, level road, and the box remains in the same place in the middle of the truck bed.
(iv) The box is on the rough-surfaced flat bed of a truck—the truck is speeding up on a straight, level road, and the box remains in the same place in the middle of the truck bed.
(v) The box is on the rough-surfaced flat bed of a truck—the truck is climbing a hill, and the box is sliding toward the back of the truck.

Answers:

(a): (i), (iii) (b): (ii), (iv) (c): (v)

In situations (i) and (iii) the box is not accelerating (so the net force on it must be zero) and there is no other force acting parallel to the horizontal surface; hence no friction force is needed to prevent sliding. In situations (ii) and (iv) the box would start to slide over the surface if no friction were present, so a static friction force must act to prevent this. In situation (v) the box is sliding over a rough surface, so a kinetic friction force acts on it.

Test Your Understanding of Section 5.4

Satellites are held in orbit by the force of our planet’s gravitational attraction. A satellite in a small-radius orbit moves at a higher speed than a satellite in an orbit of large radius. Based on this information, what you can conclude about the earth’s gravitational attraction for the satellite?

(i) It increases with increasing distance from the earth.
(ii) It is the same at all distances from the earth.
(iii) It decreases with increasing distance from the earth.
(iv) This information by itself isn’t enough to answer the question.

Answer: (iii)

A satellite of mass ‘**m**’ orbiting the earth at speed (**v**) in an orbit of radius ‘**r**’ has an acceleration of magnitude v^2/R, so the net force acting on it from the earth’s gravity has magnitude mv^2/R. The farther the satellite is from earth, the greater the value of ‘**r**’, the smaller the value of ‘**v**’ and hence the smaller the values of v^2/R and of ‘**F**’. In other words, the earth’s gravitational force decreases with increasing distance.

Example Problems: 5.1, 5.8, 5.13, 5.16, 5.21, 5.22, 5.23.

Example:5.1

A gymnast with mass m_G = 50.0 kg suspends herself from the lower end of a hanging rope. The upper end of the rope is attached to the gymnasium ceiling.

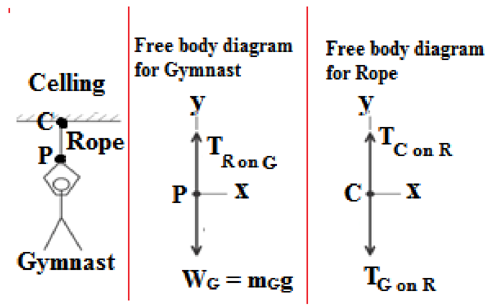
a) What is the gymnast's weight?
b) What force (magnitude and direction) does the rope exert on her?
c) What is the tension at the top of the rope? Assume that the mass of the rope itself is negligible.

Solution:

a) The magnitude of the gymnast's weight is
$w_G = m_G\, g$
$w_G = (50\text{ kg})(9.80\text{ m/s}^2)$
$w_G = 490\text{ N}$

b) Net force acting at P along the y-axis is
$\sum F_y = T_{R\text{ on }G} + (-W_g) = 0$
$T_{R\text{ on }G} = W_g = 490\text{ N}$

c) Net force acting at C along the y-axis is
$\sum F_y = T_{C\text{ on }R} + (-T_{G\text{ on }R}) = 0$
$T_{C\text{ on }R} = T_{G\text{ on }R} = 490\text{ N}$



Example-5.8

An elevator and its load have a combined mass of 800 kg (Fig.). The elevator is initially moving downward at 10 m/s, it slows to a stop with constant acceleration in a distance of 25.0 m. What is the tension T in the supporting cable while the elevator is being brought to rest?

Solution:

Given that

Mass of the elevator and its load = m = 800 kg

Speed of the elevator = v_{oy} = 10 m/s

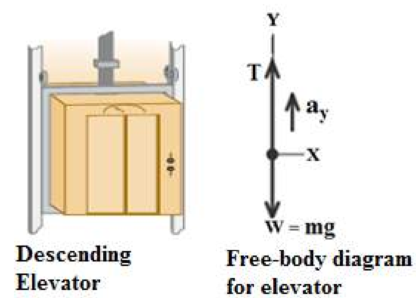
Distance the elevator came to rest = y = 25.0 m

The free-body diagram is shown in the figure. Forces acting on the elevator are:

Weight (w) of the elevator

Tension force (T) of the cable

The elevator is moving downward with **decreasing** speed, so its acceleration (a_y) is upward.



$$\sum F_y = m\,a_y \qquad \Rightarrow \quad T + (-w) = m\,a_y$$

$$\Rightarrow \quad T = w + m\,a_y \qquad \Rightarrow \quad T = m\,g + m\,a_y$$

$$\Rightarrow \quad T = m\left(g + a_y\right) \quad ....(1)$$

The elevator is moving in the negative y-direction, so it's initial y-velocity (v_{oy}) and the y-displacement are both negative.

We know that

$$v_y^2 = v_{oy}^2 + 2\,a_y y$$

$$\Rightarrow \quad a_y = \frac{v_y^2 - v_{oy}^2}{2\,y} = \frac{(0.0\text{ m/s})^2 - (-10\text{ m/s})^2}{2\,(-25\text{ m})} = +2\text{ m/s}^2$$

Now the tension (T) can be obtained from equation (1)

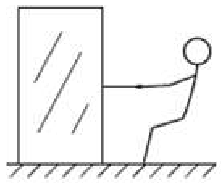
$$T = m\left(g + a_y\right) = (800\text{kg})\left(9.8\text{m/s}^2 + 2\text{m/s}^2\right) = 9440\text{ N}$$

Example-5.13

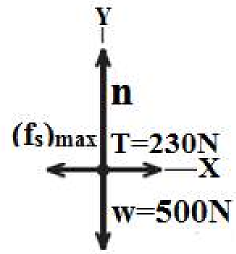
You want to move a 500-N crate across a level floor. To start the crate moving, you have to pull with a 230-N horizontal force. Once the crate "breaks loose" and starts to move, you can keep it moving at constant velocity with only 200 N. What are the coefficients of static and kinetic friction?

Solution

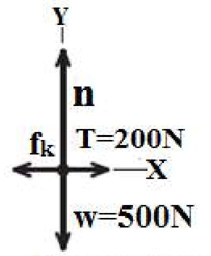
Free-body diagram for the instant just before the crate starts to move, when the static friction force has its maximum possible value is shown in the figure.



Pulling a crate



Free-body diagram for crate just before it starts to move



Free-body diagram for crate moving at constant speed

$\mathbf{(f_s)_{max} = \mu_s\, n}$

Once the crate is moving, the friction force changes to kinetic friction.

Forces acting on the crate:

Downward = weight (w)

Upward = normal force (*n*)

Right = Tension force (*T*

Left = friction force

Just before the crate starts to move, we have

$$\sum F_x = 0 \quad \Rightarrow \quad T + (-f_s)_{max} = 0 \quad \Rightarrow \quad T = (-f_s)_{max} = 230\text{N}$$

$$\sum F_y = 0 \quad \Rightarrow \quad n + (-w) = 0 \quad \Rightarrow \quad n = w = 500\text{N}$$

At this moment we have, $\mathbf{(f_s)_{max} = \mu_s\, n}$

$$\mu_s = \frac{(f_s)_{max}}{n} = \frac{230\text{N}}{500\text{N}} = 0.46$$

After the crate starts to move we have,

$$\sum F_x = 0 \quad \Rightarrow \quad T + (-f_k) = 0 \quad \Rightarrow \quad f_k = T = 200\text{N}$$

$$\sum F_y = 0 \quad \Rightarrow \quad n + (-w) = 0 \quad \Rightarrow \quad n = w = 500\text{N}$$

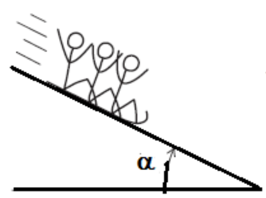
Thus,

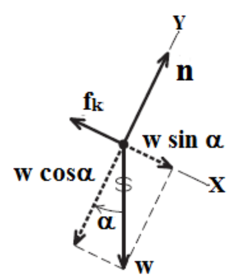
$$\mu_k = \frac{f_k}{n} = \frac{200\text{N}}{500\text{N}} = 0.40$$

The coefficient of kinetic friction is less than the coefficient of static friction.

Example-5.16:

A toboggan loaded with students (total weight w) slides down a slope. The hill slopes at a constant angle α. μ_k is coefficient of kinetic friction. The slope has just the right angle to make the toboggan slide with constant velocity. Find this angle in terms of w and μ_k





Free body diagram

Solution

Three forces act on the toboggan:

Weight (**w**), normal force (**n**), and kinetic friction force (**$\mathbf{f_k}$**)

Free-body diagram is shown in the figure.

The magnitude of the kinetic friction force is

$$f_k = n\, \mu_k$$

The toboggan is in equilibrium because its velocity is constant.

So, we use Newton's first law,

$$\sum F_x = 0 \quad \Rightarrow \quad w \sin\alpha + (-f_k) = 0 \quad \Rightarrow \quad w \sin\alpha - \mu_k n = 0 \quad \Rightarrow \quad \mu_k n = w \sin\alpha$$

$$\sum F_y = 0 \quad \Rightarrow \quad n + (-\,w\cos\alpha) = 0 \quad \Rightarrow \quad n = w\cos\alpha$$

From the above equations we get,

$$\mu_k = \frac{w\sin\alpha}{w\cos\alpha} \quad \Rightarrow \quad \mu_k = \tan\alpha \quad \Rightarrow \quad \alpha = \tan^{-1}\mu_k$$

The weight '**w**' doesn't appear in this expression. Any toboggan, regardless of its weight, slides down an incline with constant speed if $\mu_k = \tan\alpha$

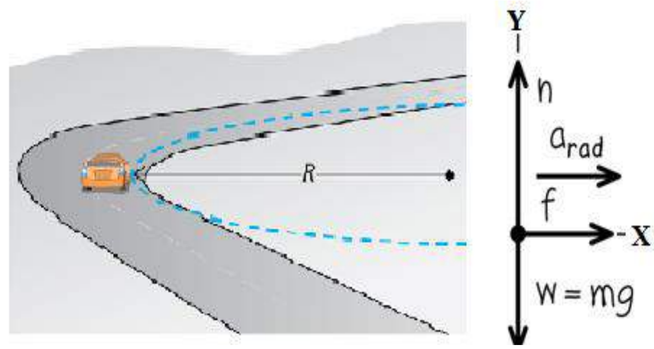
Example-5.21 (Rounding a flat curve)

The sports car is rounding a flat, unbanked curve with radius R. If the coefficient of static friction between tires and road is μ_s , what is the maximum speed v_{max} at which the driver can take the curve without sliding?

Solution:

The acceleration is $a_{rad} = \dfrac{v^2}{R}$

There is no vertical acceleration. Thus we have,



$$\sum F_x = f = m\,a_{rad} = m\frac{v^2}{R} \quad ---(1)$$

$$\sum F_y = n + (-\,m\,g) = 0$$

$$\Rightarrow \quad n = m\,g \qquad ------ \;(2)$$

But we know that,

$$f_{max} = \mu_s\, n = \mu_s m\, g$$

Thus, putting this in eqn (1), we get

$$\mu_s m\, g = m\frac{v_{max}^2}{R}$$

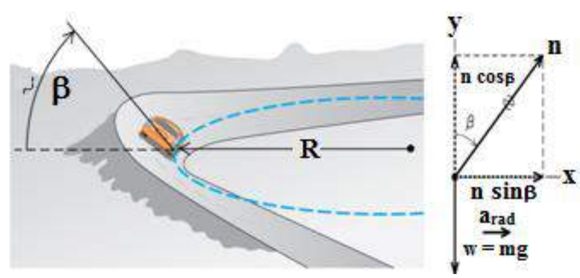
$$v_{max} = \sqrt{\mu_s\, g\, R}$$

Example-5.22: Rounding a banked curve

For a car travelling at a certain speed, it is possible to bank a curve at just the right angle so that no friction at all is needed to maintain the car's turning radius. Then a car can safely round the curve even on wet ice. Your engineering firm plans to rebuild the curve so that a car moving at a chosen speed can safely make the turn even with no friction. At what angle **β** should the curve be banked?

Solution:

Free body diagram is shown in the adjoining figure.



n = normal force (perpendicular to the roadway)

β = angle with the vertical

Thus n cosβ = vertical component of **n**

n cosβ = horizontal component **n**

Applying Newton's second law of motion

$$\sum F_x = n\sin\beta = m\,a_{rad}$$

$$\Rightarrow \quad n\sin\beta = m\,\frac{v^2}{R} \quad \Rightarrow \quad \sin\beta = \frac{m\,v^2}{n\,R}$$

$$\sum F_y = n\cos\beta + (-\,m\,g) = 0 \quad \Rightarrow \quad n\cos\beta = m\,g \quad \Rightarrow \quad \cos\beta = \frac{m\,g}{n}$$

From the above equations we get

$$\frac{\sin\beta}{\cos\beta} = \tan\beta = \frac{v^2}{Rg} \quad \Rightarrow \beta = \tan^{-1}\left(\frac{v^2}{Rg}\right)$$

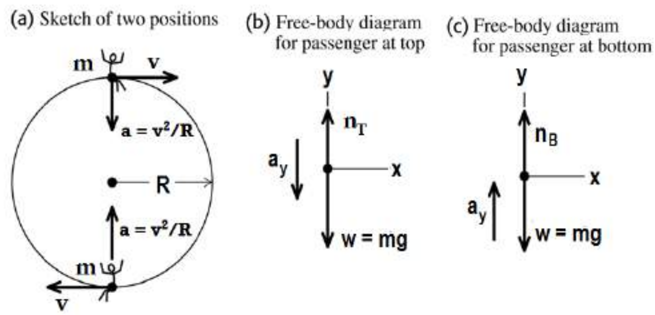
The bank angle depends on both the speed (v) and the radius (r). For a given radius, no one angle is correct for all speeds. In the design of highways and railroads, curves are often banked for the average speed of the traffic over them.

Example-5.23: Uniform circular motion in a vertical circle

A passenger on a carnival Ferris wheel moves in a vertical circle of radius R with constant speed v. The seat remains upright during the motion. Find expressions for the force the seat exerts on the passenger at the top of the circle and at the bottom.

Solution:

Passenger's velocity and acceleration at the two positions are shown in the figure.



n_T = upward normal force (seat applies to the passenger at the top of the circle)

n_B = upward normal force at the bottom.

The acceleration always points toward the center of the circle—downward at the top of the circle and upward at the bottom of the circle.

At each position the only forces acting are vertical: the upward normal force and the downward force of gravity.

We take the positive y-direction as upward in both cases.

Passenger at **top** position:

$$\sum F_y = n_T + (-mg) = -m\,a_{rad} = -m\frac{v^2}{R} \quad \Rightarrow \quad n_T = mg\left(1 - \frac{v^2}{gR}\right)$$

Passenger at **bottom** position:

$$\sum F_y = n_B + (-mg) = +m\,a_{rad} = m\frac{v^2}{R} \quad \Rightarrow \quad n_B = mg\left(1 + \frac{v^2}{gR}\right)$$

Case – I: From the above it is clear that $n_T < mg$

If $\frac{v^2}{R} = g$ then, $n_T = 0$. Then the seat applies **no force**, and the passenger is about to become airborne.

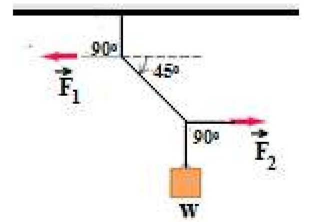
If 'v' becomes still larger, then If $\frac{v^2}{R} > g$ then, n_T = negative. This means that a downward force is needed to keep the passenger in the seat. For this we use a seat belt.

Case –I I: The normal force at the bottom (n_B) is always greater than the passenger's weight.

So the passenger feel the seat pushing up on him more firmly than when you are at rest. n_T and n_B are also known as the passenger's apparent weight at the top and bottom of the circle.

Solution to the Assignment Problems: 5.10, 5.25, 5.28

Exercise-5.10



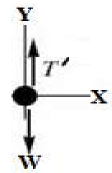
In the given Fig. the weight *w* is 60.0 N.

(a) What is the tension in the diagonal string?

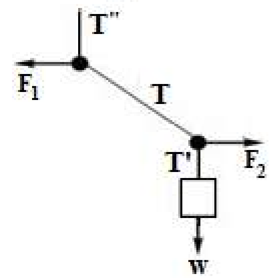
(b) Find the magnitudes of the horizontal forces $\vec{F_1}$ and $\vec{F_2}$ that must be applied to hold the system in the position shown.

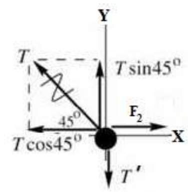
Solution:

(a)



$$\sum F_y = 0 \quad \Rightarrow \quad T' - w = 0 \quad \Rightarrow \quad T' = w = 60N$$

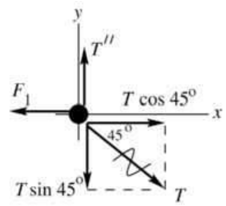




$$\sum F_y = 0 \quad \Rightarrow \quad T \sin 45^0 - T' = 0$$

$$\Rightarrow \quad T = \frac{T'}{\sin 45^0} = 60\sqrt{2}N = = 84.9N$$

(b)



$$\sum F_x = 0 \quad \Rightarrow \quad F_2 = T \cos 45^0 = 60N$$

$$\sum F_x = 0 \quad \Rightarrow \quad T \cos 45^0 - F_1 = 0$$

$$\Rightarrow \quad F_1 = (84.9N) \cos 45^0 \quad \Rightarrow \quad F_1 = 60N$$

Exercise-5.25

A person of mass 60 kg who is jumping from a height of 4 m comes to rest in 0.12 s. What will be the force acting on him that has took 6 s to comes to rest ($g = 9.8\ m/s^2$)?

Solution:

m = 60 kg, h = 4m , t = 0.12s

$$v_y^2 = v_{oy}^2 + 2\,g\,h \qquad \Rightarrow \quad v_y^2 = 0 + 2\left(9.8 m/s^2\right)(4m)$$

$$\Rightarrow \quad v_y = 8.85 m/s$$

(a) $$F_1 = \frac{\Delta P}{\Delta t} = \frac{m\,\Delta v}{\Delta t} = \frac{m\,(v - 0)}{0.12s} = \frac{60kg\,(8.85m/s)}{0.12s} = 4427N$$

(b) $$F_2 = \frac{\Delta P}{\Delta t} = \frac{m\,\Delta v}{\Delta t} = \frac{m\,(v - 0)}{6\,s} = \frac{60kg\,(8.85m/s)}{6\,s} = 88.5N$$

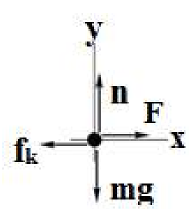
Exercise-5.28

A stockroom worker pushes a box with mass 11.2 kg on a horizontal surface with a constant speed of 3.5 m/s. The coefficient of kinetic friction between the box and the surface is 0.20.

(a) What horizontal force must the worker apply to maintain the motion?

(b) If the force calculated in part (a) is removed, how far does the box slide before coming to rest?

Solution:



Mass (m)of the box = 11.2 kg

Speed (v_{0x}) of the box = 3.5 m/s

$\mu_k = 0.2$

(a) $$\sum F_y = m\,a_y \quad \Rightarrow \quad n - mg = 0 \quad \Rightarrow \quad n = mg$$

So, $f_k = n\,\mu_k = mg\,\mu_k$

Again, $\sum F_x = 0 \Rightarrow F - f_k = 0 \Rightarrow F = f_k \Rightarrow F = \mu_k mg = (0.2)(11.2\text{ kg})(9.8\text{ m/s}^2) = 22\text{ N}$

(b) Frictional force (f_k) will produce a constant redardation.

So, $f_k = m(-a_x)$ => $22\text{ N} = -(11.2\text{ kg})\,a_x$ => $a_x = -1.96\text{ m/s}^2$

$v_x = 0$, $v_{0x} = 3.5$ m/s, $a_x = -1.96\text{ m/s}^2$

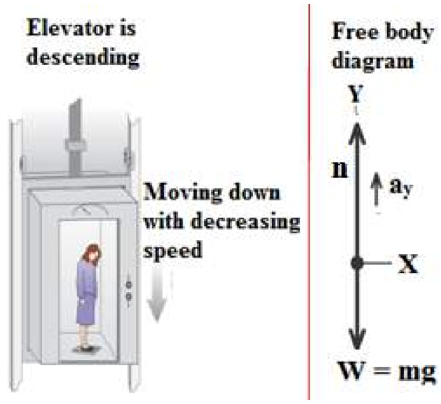
$$v_x^2 = v_{0x}^2 + 2a_x x$$

$$\Rightarrow \quad x = \frac{v_x^2 - v_{0x}^2}{2a_x} = \frac{0 - (3.5\text{ m/s})^2}{2\,(-3.5\text{ m/s}^2)} = 3.1\text{ m}$$

Example:5.9 (Extra)

An elevator and its load have a total mass of 800 kg. The elevator is originally moving downward at 10 m/s; it slows to a stop with constant acceleration in a distance of 25 m.

A woman inside the elevator, standing on a scale. How will the acceleration of the elevator affect the scale reading?



Solution

The acceleration is upward (positive).

The net force acting along y-axis is

$\sum F_y = n + (-w) = m\,a_y$

$n = w + m\,a_y$ => $n = mg + m\,a_y$ => $n = m(g + a_y)$

Acceleration of the elevator is:

$$v_y^2 = v_{oy}^2 + 2a_y(y - y_0)$$

$$\Rightarrow \quad a_y = \frac{v_y^2 - v_{oy}^2}{2\,(y - y_0)} \qquad \Rightarrow a_y = \frac{(0.0\text{ m/s})^2 - (10\text{ m/s})^2}{2\,(-25\text{ m})} = +2\text{ m/s}^2$$

The acceleration is upward (positive).

The net force acting along y-axis is

$\sum F_y = n + (-w) = m\,a_y$

$n = w + m\,a_y$ => $n = mg + m\,a_y$ => $n = m(g + a_y)$

$n = (50\text{ kg})[(9.80\text{ m/s}) + (2.00\text{ m/s}^2)] = 590\text{ N}$

When the elevator is stopping, the woman pushes down on the scale with a force of 590 N. So the scale reads 590 N, which is 100 N more than her actual weight. This weight is called the apparent weight.

If the elevator were accelerating downward with $a = -2\text{ m/s}^2$, then this would be the case if the elevator were moving upward with decreasing speed or moving downward with increasing speed.

To find the answer for this situation, we just insert a_y as negative, in the above equation. Thus,

$n = m(g + a_y) = (50\text{ kg})[(9.80\text{ m/s}) + (-2.00\text{ m/s}^2)] = 390\text{ N}.$