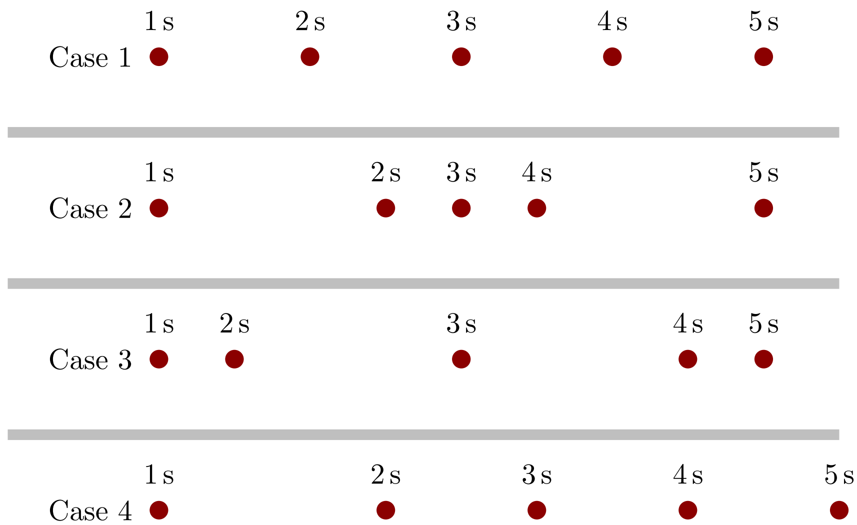
Phys 131: Exercises

One-Dimensional Kinematics

1 Motion diagrams: car slowing and accelerating

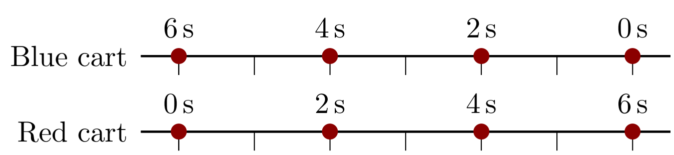
A car moves to the right. Earlier in its motion it slows down and later it speeds up. Which of the following (choose one) best represents its location as time passes? *(131F2022)*



Briefly explain your choice.

2 Motion diagrams: racing carts

Motion diagrams for two carts are as illustrated. *(131F2022)*

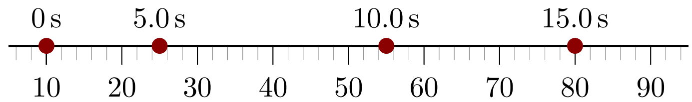


a) Is the speed of the red cart the same as or different to that of the blue cart? Explain your answer.

b) Is the velocity of the red cart the same as or different to that of the blue cart? Explain your answer.

3 Motion diagrams and average velocity

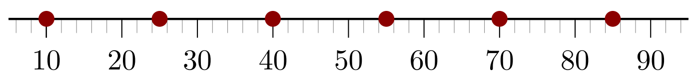
A car moves from left to right and its position, measured in meters, is recorded every 5.0 s. The resulting motion diagram is illustrated. *(131F2022)*



a) Determine the average velocity from 0 s to 5.0 s.
b) Determine the average velocity from 5.0 s to 10.0 s.
c) Determine the average velocity from 5.0 s to 15.0 s.
d) Determine the average velocity from 0 s to 15.0 s. Is this the average of the two velocities in the interval 0 s $\rightarrow$ 5.0 s and 5.0 s $\rightarrow$ 15.0 s?

4 Motion diagrams and position vs. time graphs, 1

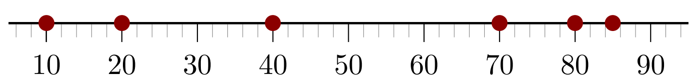
A car moves from left to right and its position, measured in meters, is recorded every 5.0 s. The resulting motion diagram is illustrated. *(131F2022)*



a) Produce a table of numerical data for position versus time for the car for the duration of the motion.
b) Produce a position versus time graph for the car for the duration of the motion. This graph must be drawn by hand using axes that are clearly labeled.

5 Motion diagrams and position vs. time graphs, 2

A car moves from left to right and its position, measured in meters, is recorded every 5.0 s. The resulting motion diagram is illustrated. *(131F2022)*



a) Produce a table of numerical data for position versus time for the car for the duration of the motion.
b) Produce a position versus time graph for the car for the duration of the motion. This graph must be drawn by hand using axes that are clearly labeled.

6 Average speed and average velocity

Determine the average speed and the average velocity for cars moving in a straight line as follows: *(131F2022)*

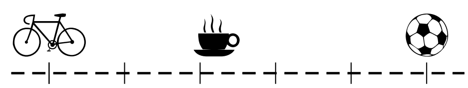
a) Red car moves right for 50 m in 10.0 s.

b) Blue car moves right for 16 m in 8.0 s and then continues right for 34 m in 2.0 s.

c) Red car moves right for 30 m in 5.0 s reverses and moves left for 20 m in 5.0 s.

7 Man versus dog

The following objects lie along a straight line: a bicycle, a coffee cup and a soccer ball. The distance from the coffee cup to the bicycle is 400 m and from the cup to the ball is 500 m. A man starts at the cup and travels in a straight line to the ball. This takes 200 s. A dog is initially at the cup and runs at constant speed to the bicycle, taking 50 s to do so. The dog immediately turns around and runs to ball; this takes the dog an additional 150 s. Consider the entire trip from the cup to the ball for each. Who has the larger average velocity for this entire trip? Explain your answer. *(131F2022)*



8 Displacement and average velocity

Various people move as described below over a total interval of 40 s. In each case determine the total displacement and the average velocity over the 40 s period. *(131F2022)*

a) Anna takes a trip in two stages. In the first stage, lasting 20 s, she moves 30 m to the right. In the second stage, lasting 20 s, she moves 10 m to the left.

b) Bill takes a trip in two stages. In the first stage, lasting 10 s, he moves 10 m to the left. In the second stage, lasting 30 s, he moves 30 m to the right.

c) Explain whether displacement and average velocity capture all the information about the motion of each. If not, how might one modify the description of the motion in terms of displacement and velocity to describe the motion more accurately?

9 Average velocity, speed for motion with changing directions

a) A person takes a trip, first walking 30 m to the right in 5.0 s and then returning to his starting point in another 10 s. Determine the average velocity of the person for the entire trip. *(131F2022)*

b) Anna takes a trip in two stages. First she moves 100 m right in 40 s. She briefly stops and then she moves 120 m to the left in another 60 s. Determine her average velocity for each stage of the trip and also for the entire trip.

c) Bill takes a trip in two stages. First he moves 200 m left in 100 s. He briefly stops and then he moves 150 m to the right in another 100 s. Determine his average velocity for each stage of the trip and also for the entire trip.

10 Average velocity and direction of motion

a) An object moves in such a way that during a certain period the average velocity of the object is negative. Is it possible that at the end of the period the object is to the right of the origin? Explain your answer. *(131F2022)*

b) An object moves in such a way that during a certain period the average velocity of the object is positive. Is it possible that at some point during the period the object moves to the left? Explain your answer.

11 Average velocity and displacement down a field

Three people, Alice, Bob and Charlie leave one end of a 100 m long field at the same instant and travel in the same direction toward the other end. *(131F2022)*

a) Alice travels at a constant speed of 8.0 m/s for half the distance and then at 4.0 m/s for the remaining half. Determine Alice's average velocity for the entire trip.

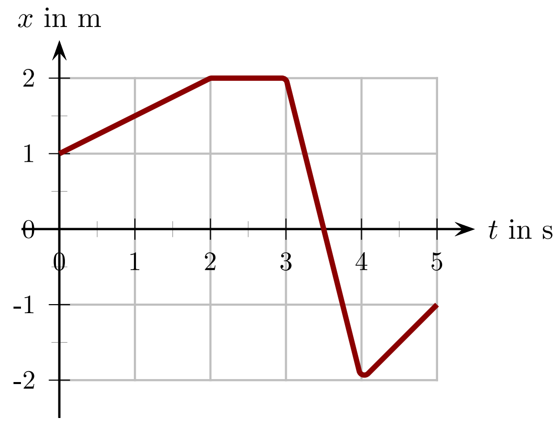
b) Bob travels at a constant speed of 10.0 m/s for half the distance and then at 2.0 m/s for the remaining half. Determine Bob's average velocity for the entire trip.

c) Charlie travels for half of the time at a constant speed of 8.0 m/s for the remaining half of the time at a constant speed of 4.0 m/s. Determine Charlie's average velocity for the entire trip.

d) Determine the order in which they arrive at the other end of the field.

12 Angry ant on a stick

An angry ant walks along a straight stick. The graph illustrates the ant's position vs. time. *(131F2022)*

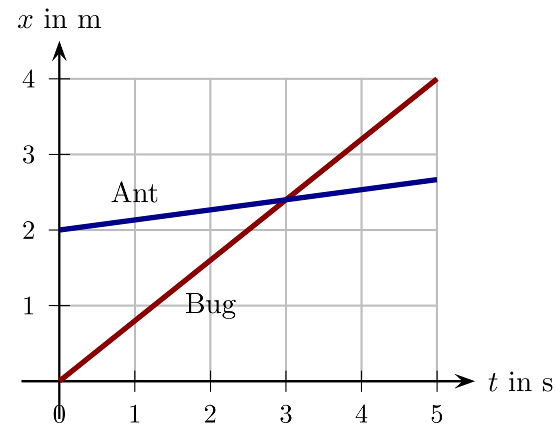


a) Describe in words qualitatively how the ant moves during the period from 0 s to 5 s. Include as much detail without using any numbers.

b) During which period is the ant's speed largest? During which period is it smallest? Explain your answers.

13 Ant and bug on a stick

An ant and a bug walk along a straight stick. The graph illustrates their position vs. time. Answer the following, explaining each answer. *(131F2022)*



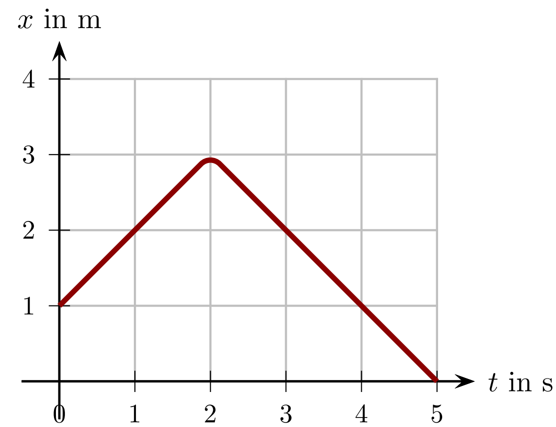
a) When and where, if ever, are the ant and the bug at the same location?

b) When, if ever, do the ant and the bug have the same speed?

c) When, if ever, does the ant move faster than the bug?

14 Ant on a stick

An ant walks along a straight stick. The graph illustrates the ant's position vs. time. Answer the following, giving explanations for each answer. *(131F2022)*



a) During which times is the ant moving right? During which times is it moving left?

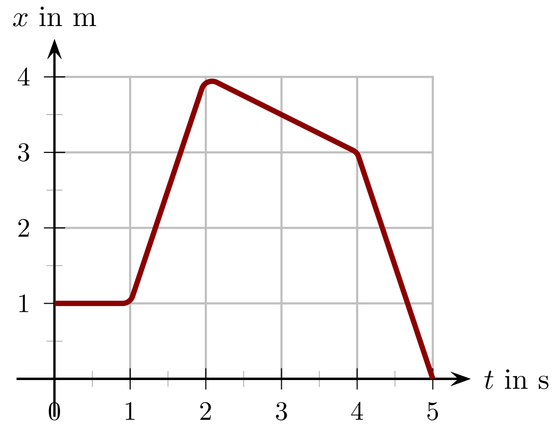
b) When, if ever, is the velocity of the ant 0 m/s?

c) How does the speed of the ant at 1.0 s compare to its speed at 4.0 s?

d) How does the velocity of the ant at 1.0 s compare to its velocity at 4.0 s?

15 Tick on a stick

A tick walks along a straight stick. The graph illustrates the tick's position vs. time. *(131F2022)*



a) Determine the velocity of the tick at 0.5 s.

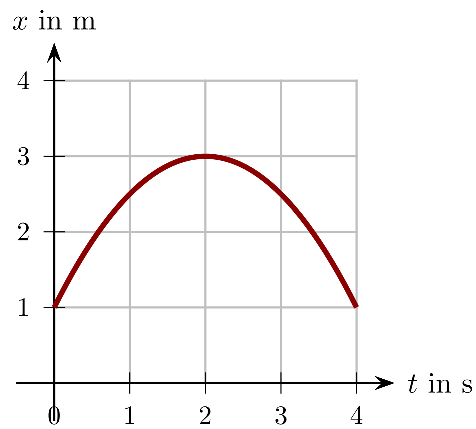
b) Determine the velocity of the tick at 1.5 s.

c) Determine the velocity of the tick at 3.0 s.

d) Determine the velocity of the tick at 4.5 s.

16 Bug on a stick

A bug walks along a straight stick. The graph illustrates the bug's position vs. time. In each of the following, explain your answers. *(131F2022)*



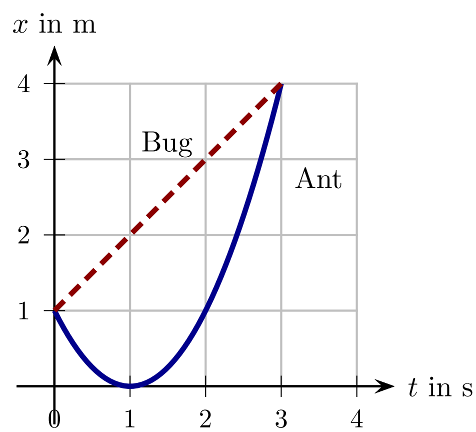
a) Does the bug ever return to the position that it occupied initially ($t = 0\,\mathrm{s}$)? If so, when?

b) Does the bug ever reverse direction? If so when?

c) Does the bug ever have zero velocity? If so, when?

17 Ant and bug on a stick: speeds

An ant and a bug walk along straight sticks. The solid graph illustrates the ant's position vs. time. The dashed graph indicates the bug's position vs. time. Answer the following, giving explanations for each answer. *(131F2022)*



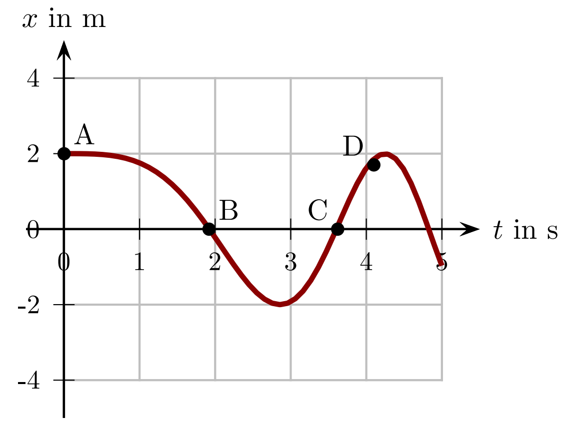
a) At what time(s) are the ant and bug at the same location?

b) Which is moving faster at 2 s?

c) Do the ant and bug ever have the same velocity? If so when?

18 Graceful ladybug on a stick

A ladybug insect walks gracefully back and forth along a straight stick. A graph of position vs. time for its motion is illustrated with several instants labeled A, B, C and D. Explain your answers for the following. *(131F2022)*



a) At which of these moments is the ladybug moving right?

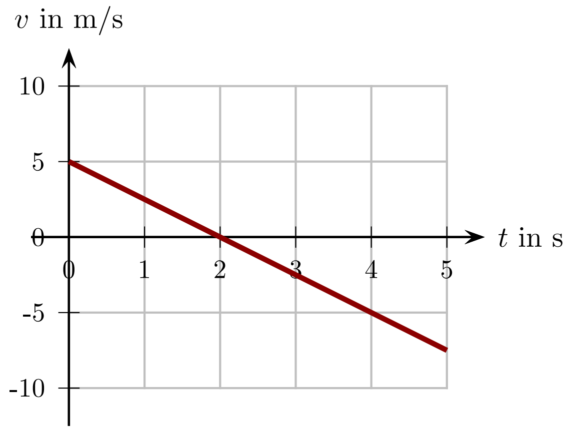
b) At which of these moments is the ladybug slowing down?

c) Rank the moments in order of increasing instantaneous speed.

d) Sketch a graph of velocity versus time for the ladybug.

19 Stick insect on a stick

A stick insect walks back and forth along a straight stick. A graph of velocity vs. time for its motion is illustrated. *(131F2022)*



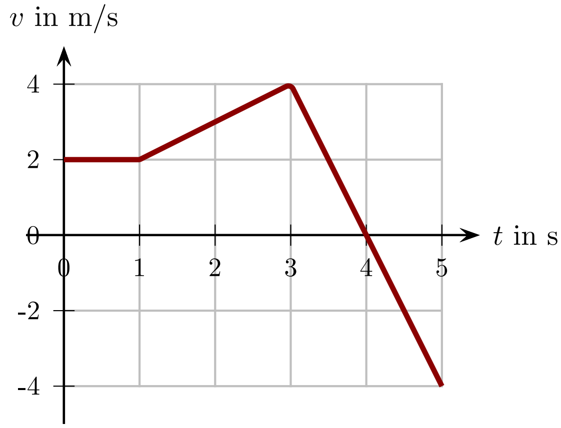
a) Determine the displacement of the stick insect from $t = 0\,\mathrm{s}$ to $t = 2\,\mathrm{s}$.

b) Determine the displacement of the stick insect from $t = 2\,\mathrm{s}$ to $t = 4\,\mathrm{s}$.

c) Determine the displacement of the stick insect from $t = 0\,\mathrm{s}$ to $t = 4\,\mathrm{s}$.

20 Ladybug on a stick

A ladybug insect walks back and forth along a straight stick. A graph of velocity vs. time for its motion is illustrated. The ladybug is initially at $x = -1.0\,\mathrm{m}$. *(131F2022)*



a) Determine the position of the ladybug at $t = 1\,\mathrm{s}$.

b) Determine the position of the ladybug at $t = 3\,\mathrm{s}$.

c) Determine the position of the ladybug at $t = 4\,\mathrm{s}$.

d) Determine the position of the ladybug at $t = 5\,\mathrm{s}$.

e) Describe in words how the position of the ladybug evolves with time during the illustrated interval.

21 Instantaneous velocity as a limit

An atom is trapped in such a way that it can move back and forth along one straight line. Its position is tracked as time passes and is represented by the function $x = t^2 - 2t - 1$ (the coefficients all have units such that x is in units of meters and t in seconds). *(131F2022)*

a) Produce a list of positions at every $0.5\,\mathrm{s}$ from $t = 0.0\,\mathrm{s}$ to $t = 4.0\,\mathrm{s}$. Use this data to plot an accurate graph of position versus time for $t = 0.0\,\mathrm{s} \leqslant t \leqslant 4.0\,\mathrm{s}$. *The graph must be drawn accurately enough to draw and calculate slopes of tangent lines.*

b) Determine the velocity of the atom at $3.0\,\mathrm{s}$ by using a tangent line construction for the graph of position versus time.

The aim of the next parts of this problem is to determine the instantaneous velocity at $3.0\,\mathrm{s}$.

c) Use the function of position versus time to determine the average velocity over the time interval from $t = 3.0\,\mathrm{s}$ to $t = 3.1\,\mathrm{s}$.

d) Use the function of position versus time to determine the average velocity over the time interval from $t = 3.00\,\mathrm{s}$ to $t = 3.01\,\mathrm{s}$.

e) Does the value of average velocity at $3.0\,\mathrm{s}$ appear to approach a limit as the time interval decreases? If so what does the limit appear to be?

f) Use the derivative of position to determine the exact instantaneous velocity at $3.0\,\mathrm{s}$. Does the result agree with your answer to the previous part?

g) At what time is the instantaneous velocity exactly zero? Explain your answer.

22 Velocity as a derivative, 1

Suppose that the position of an object is

$$x = \left(5\,\text{m/s}^2\right)\, t^2 + \left(3\,\text{m/s}\right)\, t$$

Determine the velocity of the object at $t = 3\,\text{s}$. *(131F2022)*

23 Velocity as a derivative, 2

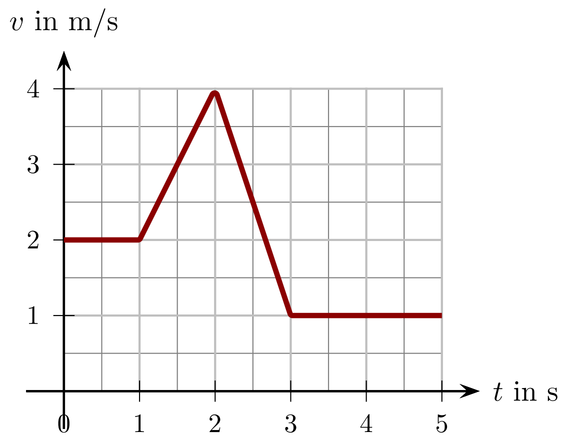
Suppose that the position of an object is

$$x = \left(2\,\text{m/s}^2\right)\, t^3 + \left(6\,\text{m/s}\right)\, t^2$$

Determine the velocity of the object at $t = 2\,\text{s}$. Is this the same as x/t? *(131F2022)*

24 Wandering ant

An ant walks along a straight stick. The graph illustrates the ant's velocity vs. time. Answer the following, giving explanations for each answer. *(131F2022)*



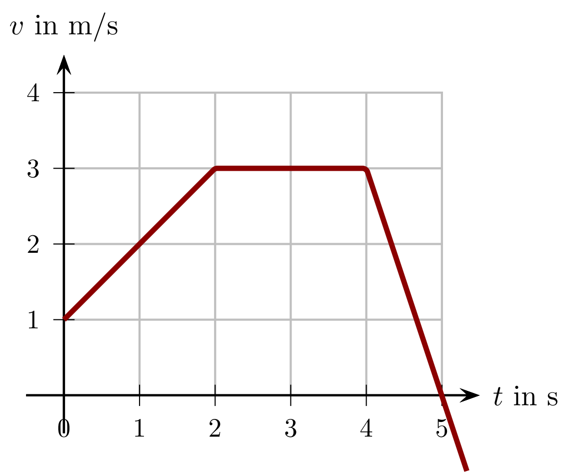
a) How does the magnitude of the ant's acceleration at 1.5 s compare (larger, smaller, same) to its acceleration at 2.5 s?

b) How does the magnitude of the ant's acceleration at 0.5 s compare (larger, smaller, same) to its acceleration at 2.5 s?

c) How does the magnitude of the ant's acceleration at 0.5 s compare (larger, smaller, same) to its acceleration at 4.0 s?

25 Accelerating bug on a stick

A bug walks along a straight stick. The graph illustrates the bug's velocity vs. time. At $t = 0\,\text{s}$ the bug is at the $x = 2.0\,\text{m}$ mark. *(131F2022)*



a) Determine the position, velocity and acceleration of the bug at 1.0 s.

b) Determine the position, velocity and acceleration of the bug at 3.0 s.

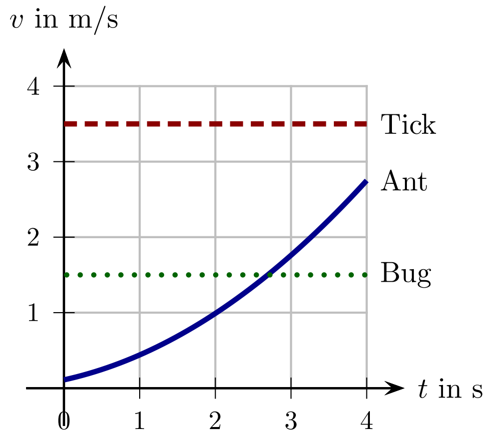
c) Determine the position, velocity and acceleration of the bug at 5.0 s.

26 Cyclist versus skateboarder

A skateboarder moves down a gentle slope. She passes a cyclist, who is at rest and at this moment the skater's speed is $4.0\,\mathrm{m/s}$. At an instant $10\,\mathrm{s}$ later the skater's speed is $10.0\,\mathrm{m/s}$ and the cyclist's is $8.0\,\mathrm{m/s}$. During this period, who has the greater acceleration? Explain your answer. *(131F2022)*

27 Insects on sticks

An ant, a tick and a bug walk along straight sticks. The solid graph illustrates the ant's velocity vs. time. The dashed graph indicates the tick's velocity vs. time. The dotted line indicates the bug's velocity versus time. *(131F2022)*



a) Which of the following is true during the period from $0s$ to $4s$? Explain your answer.

   i) The acceleration of the ant is the same as that of the tick.
   ii) The acceleration of the tick is always larger than that of the ant.
   iii) The acceleration of the tick is always smaller than that of the ant.
   iv) The acceleration of the tick is sometimes smaller than that of the ant, sometimes larger.

b) Which of the following is true during the period from $0s$ to $4s$? Explain your answer.

   i) The acceleration of the ant is the same as that of the bug.
   ii) The acceleration of the bug is always larger than that of the ant.
   iii) The acceleration of the bug is always smaller than that of the ant.
   iv) The acceleration of the bug is sometimes smaller than that of the ant, sometimes larger.

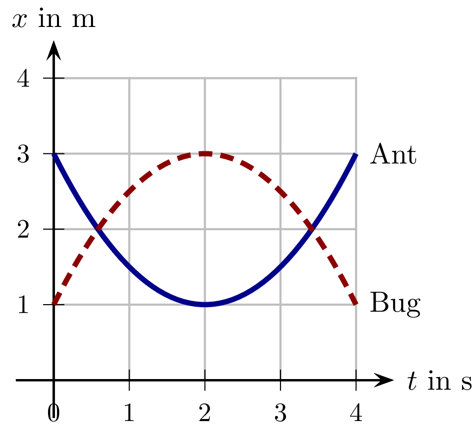
28 Acceleration sign

A bicycle can move east (positive) or west (negative). *(131F2022)*

a) If the bicycle moves east can the acceleration be negative? Explain your answer.
b) If the bicycle moves west can the acceleration be positive? Explain your answer.

29 Ant and bug on sticks

An ant and a bug walk along straight sticks. The solid graph illustrates the ant's position vs. time. The dashed graph indicates the bug's position vs. time. *(131F2022)*



a) For the bug and, separately, the ant, which of the following is true during the period from 0s to 4s? Explain your answers.

   i) Velocity is zero at all times.
   ii) Velocity is positive at all times.
   iii) Velocity is negative at all times.
   iv) Velocity is first positive and later negative.
   v) Velocity is first negative and later positive.

b) For the bug and, separately, the ant, which of the following is true during the period from 0s to 4s? Explain your answers.

   i) Acceleration is zero at all times.
   ii) Acceleration is positive at all times.
   iii) Acceleration is negative at all times.
   iv) Acceleration is first positive and later negative.
   v) Acceleration is first negative and later positive.

30 Person walking left and right

A person walks along a horizontal line. Positions are marked in meters along the line with positive numbers to the right of the origin and negative to the left. His velocity is recorded at equally spaced intervals in time. The data is:

Time in s	Velocity in m/s
10.00	-1.00
10.10	-0.80
10.20	-0.60
10.30	-0.40
10.40	-0.20
10.50	0.00
10.60	0.20
10.70	0.40
10.80	0.60
10.90	0.80

a) During which period is the person moving left? During which period is the person moving right?

b) Determine the person's acceleration while moving left.

c) Determine the person's acceleration while moving right.

d) Does the person's acceleration appear to change during the period from 10.10 s to 10.90 s?

e) At what moment does the person reverse direction? According to the data is the acceleration zero or not at this moment? *(131F2022)*

31 Bungee jumper

A bungee jumper falls downward stretching the cord, reaching a low point, after which the cord pulls him up again. His velocity is recorded at equally spaced intervals in time. The data is:

Time in s	Velocity in m/s
10.0	−20.0
10.5	−15.0
11.0	−10.0
11.5	−5.0
12.0	0.0
12.5	5.0
13.0	10.0
13.5	15.0
14.0	20.0

a) During which period is the man falling? When is he rising?

b) By how much does the man's velocity change per second? Is this change constant throughout the recorded motion?

c) Determine the man's acceleration while he is falling and also while he is rising. Are these accelerations the same or not?

d) What is the man's acceleration (according to the data) at his low point? *(131F2022)*

32 Moving man

Go to the moving man animation at:

http://phet.colorado.edu/en/simulation/moving-man

Run the moving man animation. Click on the charts tab. Set the position to 0.00 m, the velocity to $-5.00\,\mathrm{m/s}$ and the acceleration to $2.00\,\mathrm{m/s^2}$. Run the animation, stopping it just before the man hits the wall. The animation will have recorded the motion. Check the playback button at the bottom. You can slide the light blue bar left and right to get data for the motion. Gray zoom icons at the right will let you rescale the charts. *(131F2022)*

a) Consider the interval from 2.0 s to 3.0 s. Describe the motion verbally during this time.

b) How does the speed of the man at 2.0 s compare to that at 3.0 s? Explain your answer.

c) How does the velocity of the man at 2.0 s compare to that at 3.0 s? Explain your answer.

d) Will the average acceleration over the interval from 2.0 s to 3.0 s be positive, negative or zero? Explain your answer.

e) If the acceleration is not zero, does it vary during this interval? Explain your answer.

f) Determine the average acceleration over the interval from 2.0 s to 3.0 s.

33 Person moving with constant acceleration

A person is initially at rest and subsequently moves right with a constant acceleration. The person's reaches speed 6.0 m/s at a point 9.0 m to the right of the starting location. The aim of this exercise will be to determine the time taken to reach this point. A first step will be to determine the acceleration of the person. *(131F2022)*

a) Sketch the situation, illustrating the person at the two instants described above.

List all relevant variables for the two instants:

$t_{\mathrm{i}} =$	$t_{\mathrm{f}} =$
$x_{\mathrm{i}} =$	$x_{\mathrm{f}} =$
$v_{\mathrm{i}} =$	$v_{\mathrm{f}} =$

b) Determine the acceleration by selecting one of the kinematic equations, substituting and solving for a.

c) Using a different kinematic equation, find the time that it takes the person to reach speed 6.0 m/s.

d) Suppose that you had tried to find the time taken to reach speed 6.0 m/s by using

$$v = \frac{\Delta x}{\Delta t} \Rightarrow 6.0\,\mathrm{m/s} = \frac{9.0\,\mathrm{m}}{\Delta t}.$$

What time does this give? Does it agree with the answer that you obtained to the previous part? Is it correct?

34 Avoid the wall!

A skateboarder slides toward a wall. Initially the skateboarder is 18 m left of the wall and moving with speed 6.0 m/s to the right. The aim of this exercise will be to determine the minimum acceleration to barely avoid hitting the wall. *(131F2022)*

a) Sketch the situation, illustrating the skateboarder at the initial instant and the instant just before reaching the wall.

   List all relevant variables for the two instants:

$$t_0 = \qquad\qquad t =$$
$$x_0 = \qquad\qquad x =$$
$$v_0 = \qquad\qquad v =$$

b) Determine the acceleration by selecting one of the kinematic equations, substituting and solving for a.

c) Use one of the kinematic equations to determine the time that it takes for the skateboarder to reach the wall.

d) Would the equation

$$v = \frac{\Delta x}{\Delta t} \quad \Rightarrow \quad 6.0\,\mathrm{m/s} = \frac{18\,\mathrm{m}}{\Delta t}$$

   allow one to find the time taken to reach the wall correctly? Why or why not?

e) Set up the moving man animation at:

   http://phet.colorado.edu/en/simulation/moving-man

   and run this to check your prediction. In order to verify that you have done this, use the animation to provide the times at which the man is 10 m to the left of the wall.

35 Braking car, 1

A car travels to the right with speed 30.0 m/s (about 67 mph). The car brakes and slows to a stop with constant acceleration. It does this in a distance of 80.0 m (about 260 ft). The aim of this exercise is to find the time taken to do this. *(131F2022)*

a) Sketch the situation, illustrating the car at two key instants.

   List all relevant variables for the two instants:

b) Determine the acceleration using one of the kinematic equations. Write down the equation, substitute from your list of variables and solve for a. (is acceleration positive or negative?)

   Answer: $-5.63\,ms^2$

c) Using a different kinematic equation, find the time that it takes the car to stop. Write down the equation, substitute from your list of variables and solve for time.

   Answer: $5.33\,s$

36 Braking car, 2

A car travels to the right with speed 24.6 m/s (about 55 mph). The car brakes, coming to a stop in 50 m (about 165 ft). The acceleration during the braking process is constant. *(131F2022)*

a) Determine the acceleration of the car while it brakes.

b) Determine the time taken for the car to stop.

37 Accelerating aircraft

An aircraft accelerates from rest to a speed of 120.0 m/s. It does this with a constant acceleration of $4.00\,\mathrm{m/s^2}$. The aim of this exercise is to find the distance traveled by the aircraft during this process. *(131F2022)*

a) Sketch the situation, illustrating the aircraft at two key instants.

   List all relevant variables for the two instants and list the acceleration:

b) Determine the distance traveled by the aircraft using one of the kinematic equations. Write down the equation, substitute from your list of variables and solve for the relevant variable.

   Answer: 1800 *m*

c) Using a different kinematic equation, find the time that it takes for the aircraft to reach this speed. Write down the equation, substitute from your list of variables and solve for time.

   Answer: 30 *s*

d) Would it have worked to use $v = \frac{\Delta x}{\Delta t} \Rightarrow 120.0\,\mathrm{m/s} = \frac{1800\,\mathrm{m}}{\Delta t}$?

38 Accelerating cart

A cart travels in one direction. At an initial instant it passes the 4.0 m mark while traveling to the right with speed 15 m/s. *(131F2022)*

a) Determine the location of the cart at an instant 6.0 s later if its acceleration is $3.0\,\mathrm{m/s^2}$.

b) Determine the location of the cart at an instant 6.0 s later if its acceleration is $-3.0\,\mathrm{m/s^2}$.

39 Reversing cart

At an initial instant a cart travels to the left with speed 12 m/s. Subsequently the cart's acceleration is $4.0\,\mathrm{m/s^2}$. *(131F2022)*

a) How long does it take for the cart to reverse its direction of travel?

b) How far does the cart travel before it reverses its direction of travel?

40 Racing cyclists

Two cyclists can ride along a straight road. Juliette moves right with a constant speed of 20 m/s. She passes Elisa, who is at rest. At the moment that Juliette passes, Elisa begins to move, accelerating at a constant rate of $2.0\,\mathrm{m/s^2}$. Elisa maintains this for 12.0 s and after that she moves with constant velocity.

(131F2022)

a) Explain how you can be sure that Elisa eventually passes Juliette.

b) Determine the time (after Elisa starts to move) that it takes Elisa to catch up to Juliette.

c) Determine the distance traveled by each when Elisa catches up with Juliette.

41 Runway design

The takeoff speed for an aircraft under certain conditions is 260 km/h. During takeoff, one wants the acceleration to be as low as possible. *(131F2022)*

a) Suppose that the runway has length 1500 m. Determine the aircraft's minimum acceleration so that it can take off on this runway.

b) Suppose that the acceleration is only $0.20g = 1.96\,\mathrm{m/s^2}$. Determine the minimum length of the runway so that the aircraft could take off successfully.

Note: It is useful to describe acceleration in terms of g as this is correlated to what humans can feel. An acceleration of g is what you feel when jumping off a diving board. An acceleration of around $6g$ will cause a person to blackout.

42 Jumping cat

A cat jumps, launching itself vertically. During it's subsequent motion up and down, air resistance is negligible. In the following let the upward direction be positive. *(131F2022)*

a) Which of the following is true in the period after the cat's feet have left the ground and before the cat reaches its highest point above the ground?
   - i) Acceleration is zero at all times.
   - ii) Acceleration is positive at all times.
   - iii) Acceleration is negative at all times.

b) Which of the following is true in the period while the cat drops back to the ground?
   - i) Acceleration is zero at all times.
   - ii) Acceleration is positive at all times.
   - iii) Acceleration is negative at all times.

c) Which of the following is true when the cat is at is highest point above the ground?
   - i) Acceleration is zero at all times.
   - ii) Acceleration is positive at all times.
   - iii) Acceleration is negative at all times.

43 Ball launched vertically

A ball is launched vertically from Earth's surface with speed $10\,\text{m/s}$. The aim of the first part of this exercise is to determine the maximum height reached by the ball and time taken to reach the maximum height. *(131F2022)*

a) Sketch the situation, illustrating the ball at two key instants.

List all relevant variables, including the acceleration, for the two instants:

b) Determine the maximum height reached by the ball by using one of the kinematic equations. Write down the equation, substitute from your list of variables and solve for the maximum height variable.

Answer: $5.1\,m$

c) Determine the time taken to reach the maximum height by using one of the kinematic equations. Write down the equation, substitute from your list of variables and solve for the maximum height variable.

Answer: $1.0\,s$

The second part of this exercise aims to find the speed of the ball just before returning to the ground using the fall from its maximum height.

d) Sketch the situation for the falling ball, illustrating the ball at two key instants.

List all relevant variables, including the acceleration, for the two instants:

e) Determine the speed of the ball just before hitting the ground the ball by using one of the kinematic equations. Write down the equation, substitute from your list of variables and solve for the velocity variable.

Answer: *velocity:* $-10\,m/s$, *speed:* $10\,m/s$.

44 Parachuting package

A package is released from rest at a height of 100 m above Earth's surface. It falls freely until it is 40 m above Earth's surface. At that instant it deploys a parachute and after this is falls with a constant speed. The aim of this exercise is to determine the time taken to reach Earth.

To do this we will calculate the time taken for the free fall motion, Δt_A, and separately that time taken to fall with the parachute open, Δt_B.

The aim of the first part of this exercise is to determine Δt_A. *(131F2022)*

a) Sketch the situation, illustrating the ball at two key instants that will allow one to determine the time for the free fall portion of the motion.

   List all relevant variables for the two instants and the acceleration.

b) Determine Δt_A by using one of the kinematic equations. Write down the equation, substitute from your list of variables and solve for Δt_A.

   Answer: 3.5 *s.*

The second part of this exercise aims to find Δt_B.

c) Sketch the situation for the falling ball, illustrating the ball at two key instants that will allow one to determine the time for the parachuting portion of the motion.

   List all relevant variables for the two instants and the acceleration.

d) There is one quantity that one can obtain from the free fall part of the motion that will be needed to analyze the parachuting portion of the motion. Identify and compute this and insert it in to the list of variables from the previous part.

e) Now determine Δt_B by using one of the kinematic equations. Write down the equation, substitute from your list of variables and solve for Δt_B.

   Answer: 1.2 *s.*

f) Determine the total time taken to fall.

   Answer: 4.7 *s.*

45 Thrown rock

A rock is thrown vertically down from a bridge. It leaves the hand with speed 20 m/s and hits the water 15 m below. Determine its speed at the instant before it hits the water. *(131F2022)*

Answer: 26 m/s

46 Ball thrown from above the ground

A ball is thrown vertically upwards, leaving the hand at a height of 1.2 m above the ground. It hits the ground 2.5 s after leaving the hand. *(131F2022)*

a) Determine the speed with which the ball left the hand.

b) Determine the maximum height above the ground reached by the ball.

47 Diver

A diver stands on a diving board that is 10 m above the surface of the water. The diver launches herself vertically up, leaving the board with a speed of 5.0 m/s. *(131F2022)*

a) Determine the time taken for the diver to hit the water. ***Answer:*** 2.0 s

b) Determine the diver's speed when she hits the water. ***Answer:*** 15 s

48 Jumping flea

A flea is at rest on a bed and launches itself vertically. A child watching this thinks that it the flea is airborne for a total time of about 2 s. Determine the maximum height above the bed that the flea would reach if this were true. Ignore air resistance. Is it plausible that the flea could have been airborne for that long? What might be a more realistic range of times? *(131F2022)*

49 Penny and a well

A penny is held at rest at the top of a well. The penny is released, falls freely and takes 1.75 s to hit the water below. Determine the depth (distance from the top to the water) of the well. *(131F2022)*

Answer: 15 m

50 Rocket flight

A rocket is at rest on the ground. Its engine then fires, producing a constant acceleration of 40 $\mathrm{m/s^2}$ for a period of 15 s and propelling the rocket vertically. The engine then stops and the rocket continues to move upward. *(131F2022)*

a) Determine the maximum altitude (height) reached by the rocket.

b) Determine the time taken by the rocket to reach its maximum altitude.

c) Determine the time taken for the rocket to fall back to the ground after reaching its maximum height.

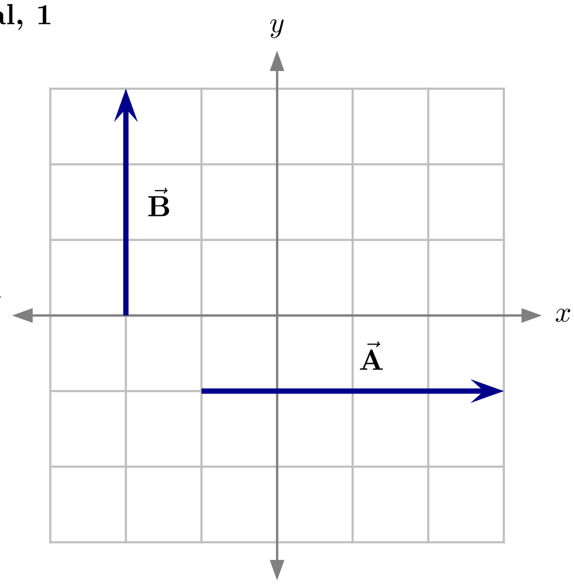
Vectors

51 Vector addition and subtraction: graphical, 1

Two displacement vectors, $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$, are illustrated. *(131F2022)*

a) Sketch $\vec{\mathbf{C}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$. Determine the magnitude and direction of $\vec{\mathbf{C}}$.

b) Let A be the magnitude of $\vec{\mathbf{A}}$, let B be the magnitude of $\vec{\mathbf{B}}$ and C be the magnitude of $\vec{\mathbf{C}}$. In this case, do these magnitudes satisfy $C = A + B$? Explain your asnwer



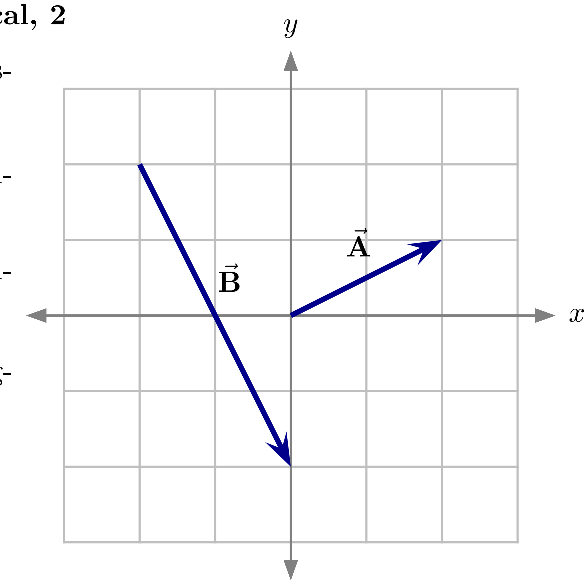
52 Vector addition and subtraction: graphical, 2

Two displacement vectors, $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$, are illustrated. *(131F2022)*

a) Sketch $\vec{\mathbf{C}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$. Determine the magnitude and direction of $\vec{\mathbf{C}}$.

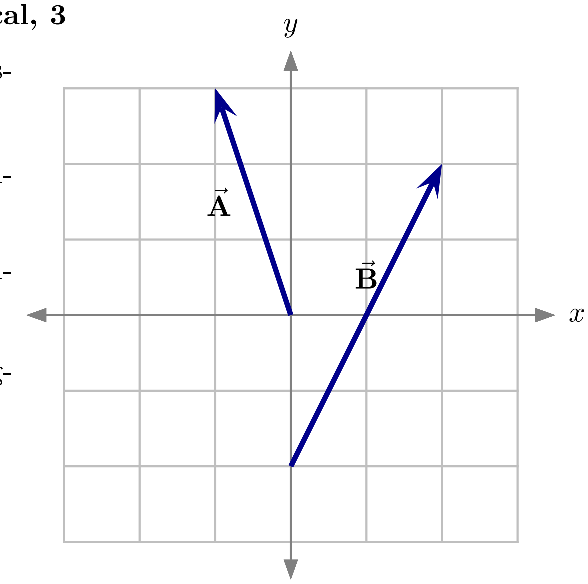
b) Sketch $\vec{\mathbf{C}} = \vec{\mathbf{A}} - \vec{\mathbf{B}}$. Determine the magnitude and direction of $\vec{\mathbf{C}}$.

c) Sketch $\vec{\mathbf{C}} = 2\vec{\mathbf{A}} - \frac{1}{2}\vec{\mathbf{B}}$. Determine the magnitude and direction of $\vec{\mathbf{C}}$.



53 Vector addition and subtraction: graphical, 3

Two displacement vectors, $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$, are illustrated. *(131F2022)*



a) Sketch $\vec{\mathbf{C}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$. Determine the magnitude and direction of $\vec{\mathbf{C}}$.

b) Sketch $\vec{\mathbf{C}} = \vec{\mathbf{A}} - \vec{\mathbf{B}}$. Determine the magnitude and direction of $\vec{\mathbf{C}}$.

c) Sketch $\vec{\mathbf{C}} = 2\vec{\mathbf{A}} - \frac{1}{2}\vec{\mathbf{B}}$. Determine the magnitude and direction of $\vec{\mathbf{C}}$.

54 Vector algebra: conceptual

Consider two vectors labeled $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$. *(131F2022)*

a) Suppose that $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ are perpendicular. Explain whether it is possible that $\vec{\mathbf{A}} - \vec{\mathbf{B}} = 0$.

b) Suppose that the magnitudes satisfy $B = 2A$. Let $\vec{\mathbf{C}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$. Explain whether it is possible that the magnitude of $\vec{\mathbf{C}}$ satisfies $C = A$. Explain whether it is possible that the magnitude of $\vec{\mathbf{C}}$ satisfies $C = 2A$.

55 Adding two vectors

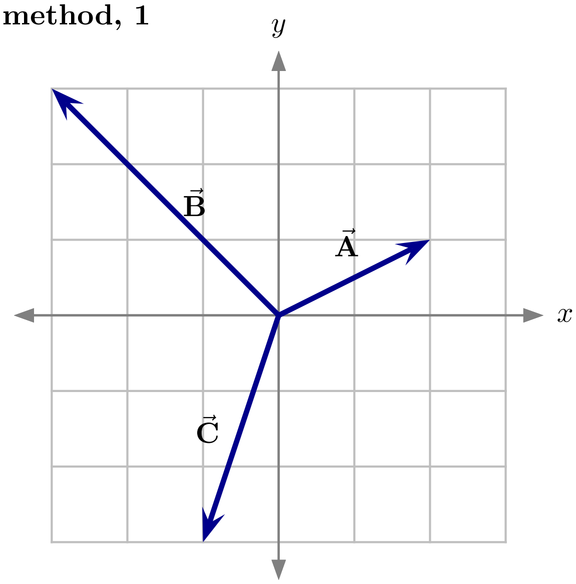
Consider displacement vectors $\vec{\mathbf{A}}$, whose magnitude is $4.0\,\mathrm{m}$, and $\vec{\mathbf{B}}$, whose magnitude is $3.0\,\mathrm{m}$. Their directions are not specified. Let $\vec{\mathbf{C}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$. *(131F2022)*

a) What is the maximum possible magnitude for $\vec{\mathbf{C}}$? How must the vectors be arranged to give this?

b) What is the minimum possible magnitude for $\vec{\mathbf{C}}$? How must the vectors be arranged to give this?

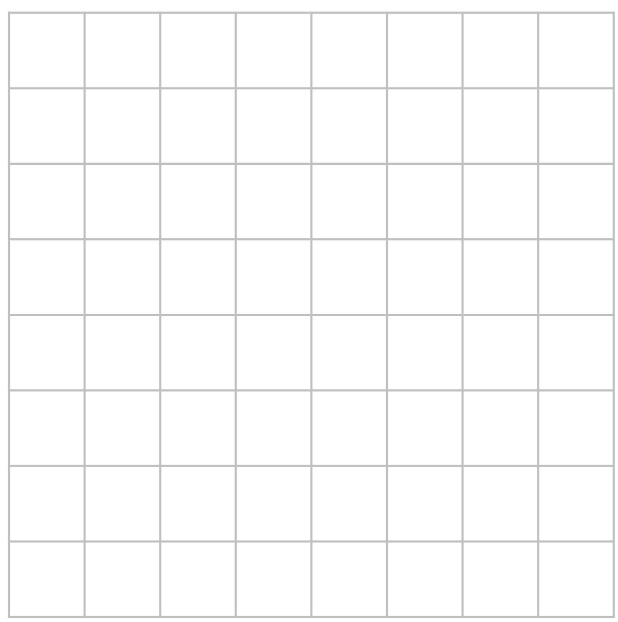
56 Vector addition: graphical and algebraic method, 1

Displacement vectors, $\vec{\mathbf{A}}, \vec{\mathbf{B}}$, and $\vec{\mathbf{C}}$ are illustrated. Let $\vec{\mathbf{D}} = \vec{\mathbf{A}} + \vec{\mathbf{B}} + \vec{\mathbf{C}}$. *(131F2022)*



a) Using the graph sheet below, determine $\vec{\mathbf{D}}$ graphically via the head–to–tail method. Use the result to determine the magnitude of $\vec{\mathbf{D}}$.

b) List the horizontal and vertical components of each of $\vec{\mathbf{A}}, \vec{\mathbf{B}}$, and $\vec{\mathbf{C}}$ and use these components to determine the components of $\vec{\mathbf{D}}$. Use the result to determine the magnitude of $\vec{\mathbf{D}}$.



57 Vector components: conceptual

Consider a vector $\vec{\mathbf{A}}$ in two dimensions.*(131F2022)*

a) Is it possible that either A_x or A_y is larger than the magnitude, A? Explain your answer.

b) Is it possible that both components of $\vec{\mathbf{A}}$ can be non-zero and the magnitude of $\vec{\mathbf{A}}$ is zero? Explain your answer.

58 Vector addition: algebraic method, 1

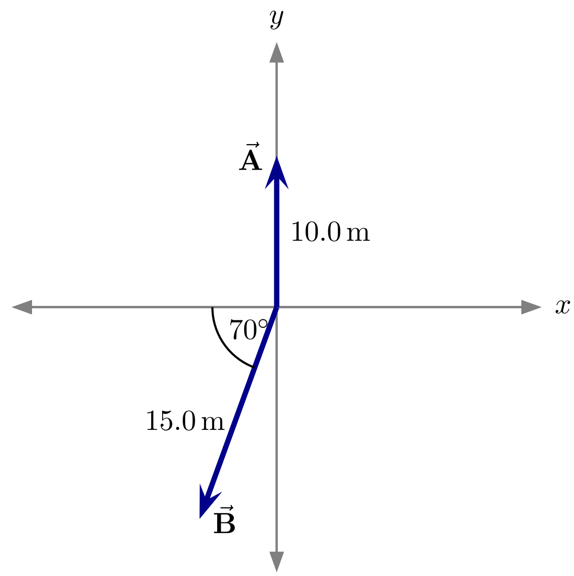
Two displacement vectors, $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ are illustrated. *(131F2022)*

a) Determine the components of $\vec{\mathbf{A}}$.

b) Determine the components of $\vec{\mathbf{B}}$.

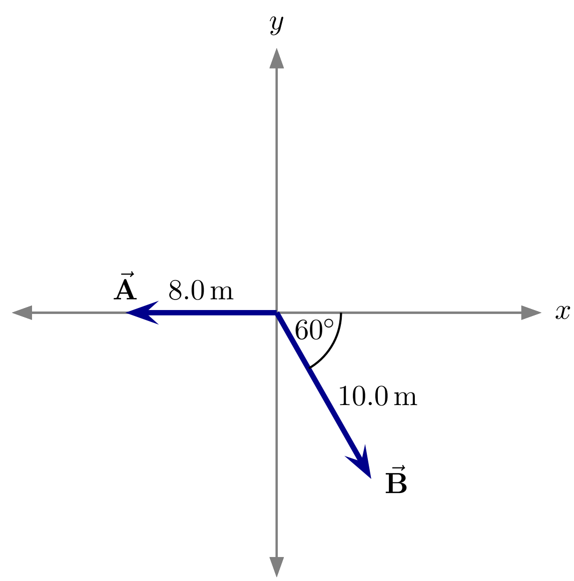
c) Determine the components of $\vec{\mathbf{C}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$.

d) Determine the magnitude of $\vec{\mathbf{C}}$.



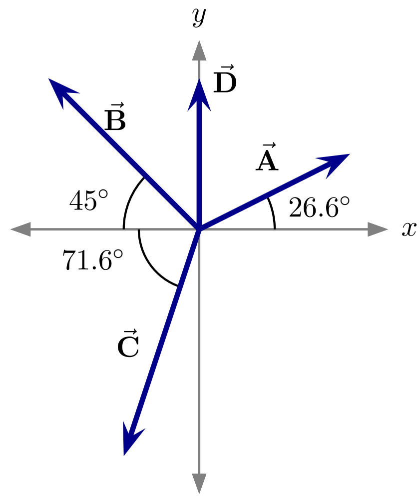
59 Vector addition: algebraic method, 2

Two displacement vectors, $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ are illustrated. Determine the magnitude of $\vec{\mathbf{C}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$. *(131F2022)*



60 Vector algebra using components

Displacement vectors, $\vec{\mathbf{A}}, \vec{\mathbf{B}}, \vec{\mathbf{C}}$, and $\vec{\mathbf{D}}$ are illustrated. Their magnitudes are $A = 2.0\,\mathrm{m}, B = 2.5\,\mathrm{m}, C = 3.0\,\mathrm{m}$ and $D = 1.5\,\mathrm{m}$. *(131F2022)*



a) Determine the x and y components for each vector.

b) Determine the x and y components for $\vec{\mathbf{E}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$. Determine the magnitude of $\vec{\mathbf{E}}$.

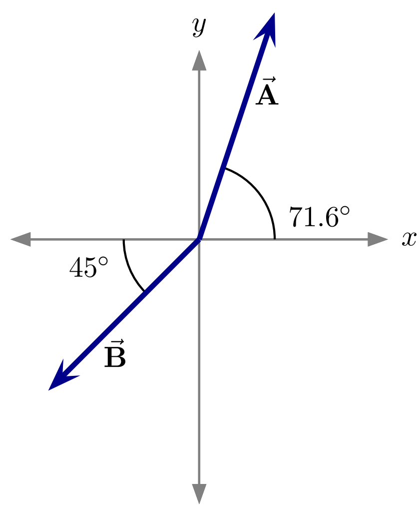
c) Determine the x and y components for $\vec{\mathbf{E}} = \vec{\mathbf{B}} + \vec{\mathbf{C}}$. Determine the magnitude of $\vec{\mathbf{E}}$.

d) Determine the x and y components for $\vec{\mathbf{E}} = \vec{\mathbf{B}} + \vec{\mathbf{D}}$. Determine the magnitude of $\vec{\mathbf{E}}$.

e) Determine the x and y components for $\vec{\mathbf{E}} = \vec{\mathbf{B}} + \vec{\mathbf{C}} + \vec{\mathbf{D}}$. Determine the magnitude of $\vec{\mathbf{E}}$.

61 Vector subtraction using components

Displacement vectors, $\vec{\mathbf{A}}, \vec{\mathbf{B}}$ are illustrated. Their magnitudes are $A = 3.16\,\mathrm{m}$ and $B = 2.83\,\mathrm{m}$. *(131F2022)*

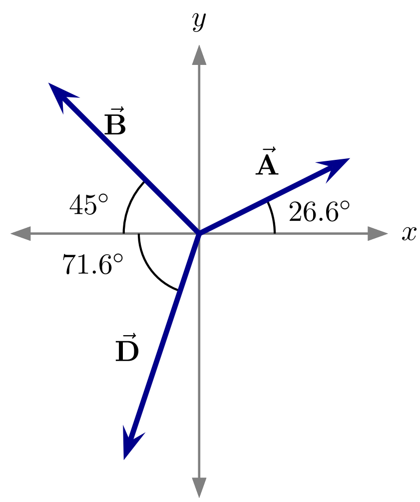


a) Determine the components of $\vec{\mathbf{C}} = \vec{\mathbf{A}} - \vec{\mathbf{B}}$. Determine the magnitude of $\vec{\mathbf{C}}$.

b) Determine the components of $\vec{\mathbf{C}} = 4\vec{\mathbf{A}} - 3\vec{\mathbf{B}}$. Determine the magnitude of $\vec{\mathbf{C}}$.

62 Vector algebra using unit vectors

Displacement vectors, $\vec{\mathbf{A}}, \vec{\mathbf{B}}$, and $\vec{\mathbf{D}}$ are illustrated. Let $\vec{\mathbf{D}} = 3\vec{\mathbf{A}} + 2\vec{\mathbf{B}} + \vec{\mathbf{C}}$. Their magnitudes are $A = 2.0\,\mathrm{m}, B = 3.5\,\mathrm{m}$ and $D = 6.0\,\mathrm{m}$ Express each of the vectors in terms of unit vectors and use these to determine $\vec{\mathbf{C}}$. *(131F2022)*



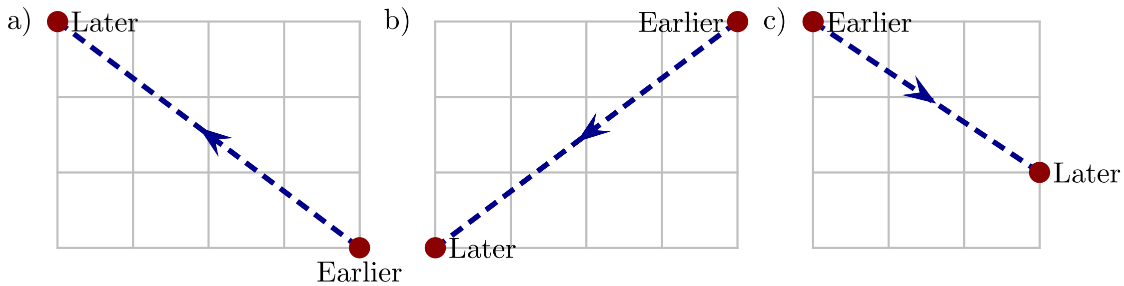
63 Marching soldier

A soldier marches around a playing field whose edges are along North-South (N-S) and East-West (E-W) lines. The soldier starts in the southwest corner, marches in a straight line in the direction 30° N of E for 40 m. He then marches straight south for 12 m. Finally he marches in a a straight line in the direction 50° N of W for 30 m. After this, how far is the soldier from his starting point? *(131F2022)*

Two dimensional kinematics

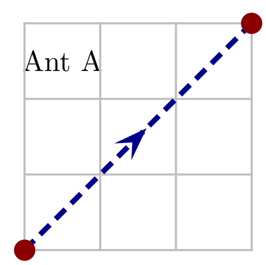
64 Velocity vectors from motion

Particles move along the illustrated trajectories. Their locations are illustrated at instants 4.0 s apart. The grid units are meters. For each case determine the average velocity vector for the particle over the entire interval and express it in terms of the conventional unit vectors. *(131F2022)*



65 Ants on a table

Two ants move on a flat surface between two grains of sugar. Their trajectories are illustrated. The ants take the same time to move between the grains but follow different trajectories. Which of the following is true about the average velocities of the ants for the entire trip? Explain your answer. *(131F2022)*

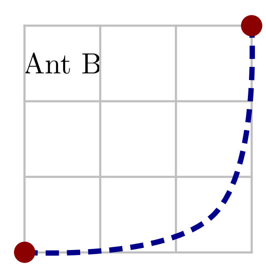


i) The average velocities are the same.

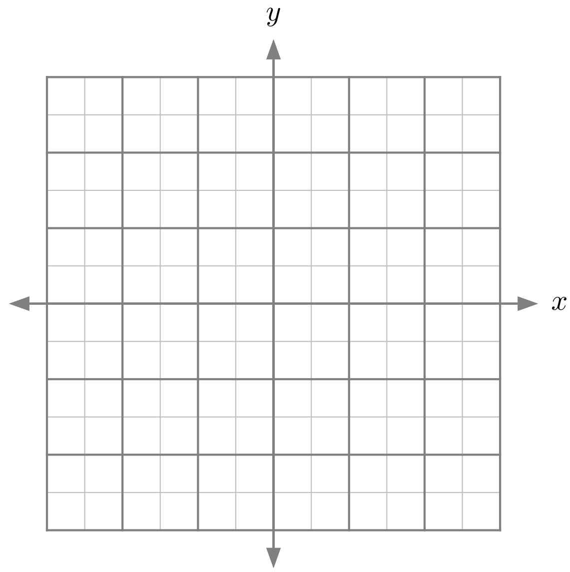
ii) The average velocity of ant A is smaller than that for ant B.

iii) The average velocity of ant A is larger than that for ant B.

iv) The average velocities are different but one cannot say which is larger.



66 Model moon motion



A moon of a planet in a demonstration model of a planetary system travels a trajectory described by the position vector

$$\vec{\mathbf{r}}(t) = 2.0\,\mathrm{m}\cos(\omega t)\hat{\mathbf{i}} + 2.0\,\mathrm{m}\sin(\omega t)\hat{\mathbf{j}}.$$

where $\omega = 0.50\pi\,\mathrm{rad\ s^{-1}}$ (note that this expresses the arguments of the trigonometric functions in terms of radians). *(131F2022)*

a) Determine expressions for the horizontal and vertical coordinates $x(t)$ and $y(t)$ for the moon from $t = 0\mathrm{s}$ to $t = 2.0\mathrm{s}$.

b) Sketch the trajectory of the moon as accurately as possible on the illustrated grid.

c) Determine the displacement vector from $t = 1.0\,\mathrm{s}$ to $t = 1.5\,\mathrm{s}$ and use this to get the average velocity vector from $t = 1.0\,\mathrm{s}$ to $t = 1.5\,\mathrm{s}$.

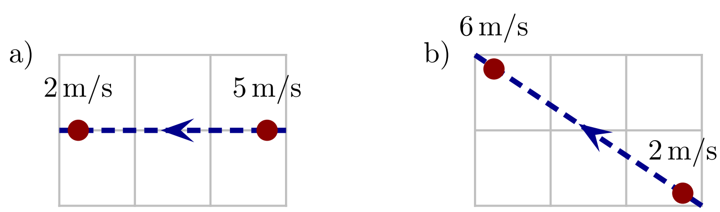
d) Determine the displacement vector from $t = 1.0\,\mathrm{s}$ to $t = 1.1\,\mathrm{s}$ and use this to get the average velocity vector from $t = 1.0\,\mathrm{s}$ to $t = 1.1\,\mathrm{s}$.

e) Determine the displacement vector from $t = 1.0\,\mathrm{s}$ to $t = 1.01\,\mathrm{s}$ and use this to get the average velocity vector from $t = 1.0\,\mathrm{s}$ to $t = 1.01\,\mathrm{s}$.

f) What do you results suggest about the direction of the instantaneous velocity vector at $t = 1.0\,\mathrm{s}$? Explain your answer.

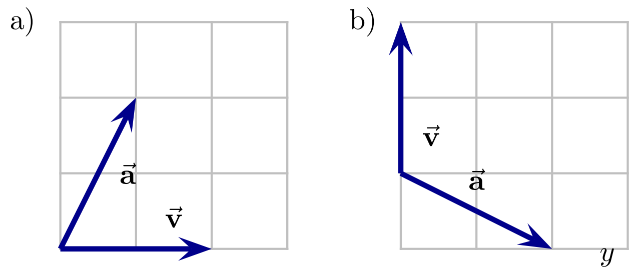
67 Acceleration vectors from motion

Two particles move along the illustrated trajectories. Their locations and speeds are illustrated at instants 0.25 s apart. For each case determine the acceleration vector for the particle. *(131F2022)*

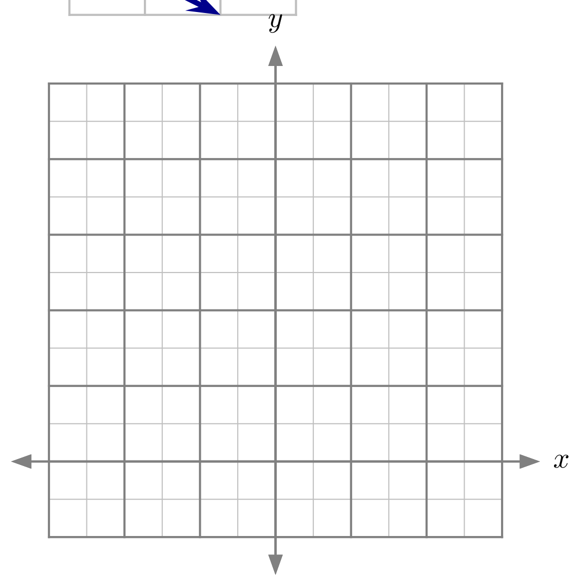


68 Velocity and acceleration vectors and motion

Position and acceleration vectors for two particles at one moment are illustrated. For each case, describe whether the particle is speeding up, slowing down or moving with constant velocity. Also describe how the direction of the particle's motion changes. *(131F2022)*



69 Ball moving in two dimensions



A ball travels along a trajectory described by the position vector

$$\vec{\mathbf{r}}(t) = (t-2)\,\hat{\mathbf{i}} + \left(-\frac{(t-2)^2}{2} + 4\right)\hat{\mathbf{j}}.$$

from $t = 0$ to $t = 4$. *(131F2022)*

a) Determine expressions for the horizontal and vertical coordinates $x(t)$ and $y(t)$ for the ball.

b) Sketch the trajectory of the ball as accurately as possible on the illustrated grid.

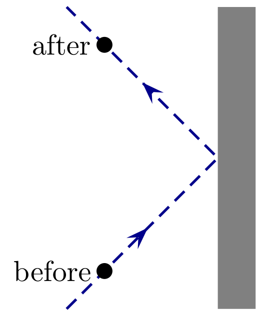
c) Determine the displacement vector from $t = 1.5$ to $t = 2$ and use this to get the average velocity vector from $t = 1.5$ to $t = 2$.

d) Determine the displacement vector from $t = 2$ to $t = 2.5$ and use this to get the average velocity vector from $t = 2$ to $t = 2.5$.

e) Determine an expression for the instantaneous velocity vector and use this to obtain the average acceleration from $t = 1.8$ to $t = 2.2$. What does this imply for the direction of the acceleration at $t = 2$?

70 Bouncing hockey puck

A hockey puck slides along a horizontal surface toward a board, hitting it at an angle and bouncing off with unchanged speed. The view from above is as illustrated. *(131F2022)*

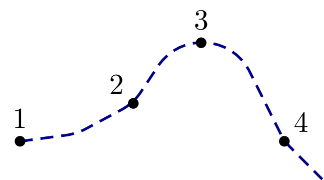


a) Draw the velocity vectors of the puck just before and just after hitting the board, use these to draw the vector $\Delta\vec{\mathbf{v}}$, and use the result to draw the direction of the acceleration vector.

b) If the puck traveled backwards along the same path (i.e. reversed direction), what would the direction of the acceleration vector be?

71 Ants moving along a curved path

Various ants follow the same path on a horizontal surface, starting at point 1. The path is as illustrated. Ant A moves with a constant speed, ant B gradually speeds up and ant C gradually slows. *(131F2022)*

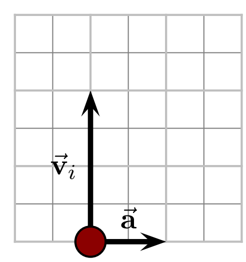


a) Draw the velocity vector at points 1, 2, 3 and 4.

b) Does any of the ants have zero acceleration at all times? Explain your answer.

72 Motion with constant acceleration

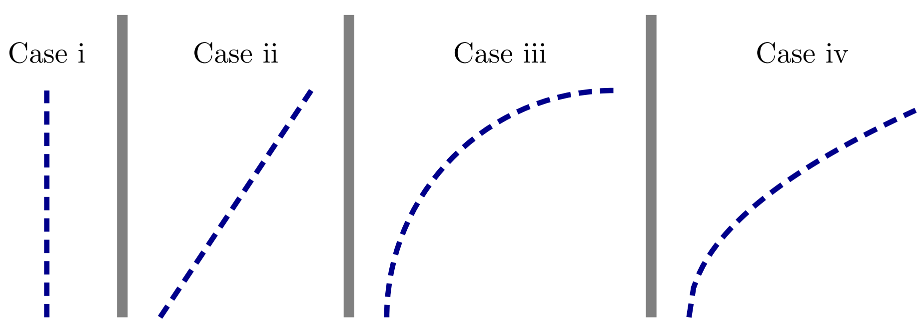
A ball can slide along a horizontal surface. At an initial instant its velocity, $\vec{\mathbf{v}}_i$, is as illustrated. At all later times it accelerates with a constant acceleration, $\vec{\mathbf{a}}$, as illustrated. *(131F2022)*



a) Draw, as accurately as possible, the velocity vector at an instant 0.5 s after the initial instant.

b) Draw, as accurately as possible, the velocity vector at an instant 1.0 s after the initial instant.

c) Which of the following best represents the trajectory of the particle? Explain your answer.



73 Dropping a coin on a ship

A person is on the deck of a ship. While the ship is at rest in a harbor, the person drops a coin from rest and the coin lands on the deck of the ship. The person marks the spot where the coin lands. Later the ship sails with constant speed in a straight line and the person returns to the same spot and drops the coin again. Does the coin land at the original mark, in front of it or behind it? Explain your answer. *(131F2022)*

74 Jumping monkey

A monkey jumps leaving the Earth at an angle of 45° from the surface. Which of the following is true when the monkey reaches the highest point along the trajectory? Explain your answer. *(131F2022)*

i) The acceleration of the monkey is zero.
ii) The acceleration of the monkey is horizontal in the forwards direction.
iii) The acceleration of the monkey is horizontal in the backwards direction.
iv) The acceleration of the monkey is vertical downward.
v) The acceleration of the monkey is vertical upward.

75 Red vs. blue ball

Two balls, one red and the other blue, are on a horizontal table. The are made to roll off the table. At the instants that they leave the speed of the blue ball is four times that of the red ball. Which of the following is true regarding the times taken to hit the floor on which the table stands? Explain your answer. *(131F2022)*

i) The time taken for blue ball is a quarter of that for the red ball.
ii) The time taken for blue ball is half that for the red ball.
iii) The time taken for blue ball is the same as that for the red ball.
iv) The time taken for blue ball is twice that for the red ball.
v) The time taken for blue ball is four times that for the red ball.

76 Running off a roof

A person runs with speed 8.0 m/s off a flat roof that is 3.0 m above the ground. First suppose that the person travels horizontally at the moment that he leaves the roof. Determine how far horizontally from the edge of the roof the person will land. *(131F2022)*

a) Sketch the situation with the "earlier" instant being that at which the person leaves the roof and the "later" instant being the moment just before the person hits the ground.

List as many of the variables as possible. Use the format:

$$\begin{aligned} t_0 &= & t &= \\ x_0 &= & x &= \\ y_0 &= & y &= \\ v_{0x} &= & v_x &= \\ v_{0y} &= & v_y &= \\ a_x &= & a_y &= \end{aligned}$$

b) Sketch the velocity vector at the earlier moment and use this to determine the components of $\vec{\mathbf{v}}_0$. Enter these in the list above.

c) Identify the variable needed to answer the question of the problem. Select and write down a kinematic equation that contains this variable and attempt to solve it.

You should see to solve the variable describing the horizontal position, you first need the value for another, currently unknown variable. Which variable is this?

d) Use the vertical aspects of the object's motion to solve for this other unknown variable and use this result to answer the question of this problem.

Suppose that the person ran and jumped from the building at an angle of 30° above the horizontal. This will change how far the person travels. Before answering that question, we ask, what is the maximum height above the ground reached by the person for this running jump?

e) Sketch the velocity vector at the earlier moment and use this to determine the components of $\vec{\mathbf{v}}_0$. Reconstruct the list of variables for the problem.

f) Sketch the velocity vector at the instant when the person reaches his highest point. Use this to add additional information to the list of variables for the problem.

g) Use the kinematic equations to determine the maximum height that the person reaches.

h) Determine the speed of the person at the maximum height.

i) Determine how far horizontally from the edge of the roof the person will land.

77 Projectile motion range

A person runs with speed 8 m/s off a flat roof that is 3.0 m above the ground. The person can launch himself at various angles and the purpose of this exercise is to determine the speed with which the person hits the ground and where on the ground the person lands (for various angles of launch). First suppose that the person travels horizontally at the moment that he leaves the roof. It was found that the person lands 6.3 m from the base of the building. *(131F2022)*

a) Sketch the situation with the "earlier" instant being that at which the person leaves the roof and the "later" instant being the moment just before the person hits the ground. List as many of the variables as possible. Use the format

$$\begin{aligned} & & t &= \\ x_0 &= & x &= \\ y_0 &= & y &= \\ v_{0x} &= & v_x &= \\ v_{0y} &= & v_y &= \\ a_x &= & a_y &= \end{aligned} \quad .$$

b) Draw the velocity vector at the earlier instant and use this to determine the components of $\vec{\mathbf{v}}_0$. Enter these in the list above.

c) Draw the velocity vector at the later instant. Describe whether the components are positive, negative or zero.

d) The speed of the object is the magnitude of the velocity vector. So to determine the speed, you will first need to determine the components of the velocity vector. Use the kinematic equations to determine the x and y components of the velocity at the later instant. You must start by writing the equation that you use, before substituting.

e) Sketch the velocity vector at the instant just before the person hits the ground and indicate the values of the x and y components on the sketch. Use this to determine the speed of the person just before hitting the ground.

Now suppose that the person travels with the same speed but launches himself at an angle of 45° from the roof.

f) Using the same "earlier" and later instants as before, list as many of the variables as possible.

g) Draw the velocity vector at the earlier moment and use this to determine the components of $\vec{\mathbf{v}}_0$.

h) Use the kinematic equations to determine the x and y components of the velocity at the later instant.

i) Sketch the velocity vector at the instant just before the person hits the ground and indicate the values of the x and y components on the sketch. Use this to determine the speed of the person just before hitting the ground.

j) Determine the time taken to hit the ground.

k) Determine how far the person lands from the building.

78 Aircraft dropping object

An aircraft flies horizontally with a constant speed of $600\,\mathrm{km/h}$ at a height of $1200\,\mathrm{m}$ above a flat surface. It drops an object from its underside; this object is supposed to hit a particular spot on the ground. How far (horizontally) from the spot must the aircraft be for the object to hit the spot? *(131F2022)*

79 Rifle shot

A rifle fires a bullet. At the moment that the bullet leaves the rifle it travels horizontally with speed $300\,\mathrm{m/s}$. Determine how far the bullet will drop by the time that it reaches a vertical wall that is $100\,\mathrm{m}$ from the end of the rifle that is closest to the wall. *(131F2022)*

80 Jumping over a ditch

A dog attempts to jump over a ditch, which is 2.0 m wide. The dog launches itself from one edge of the ditch with speed 5.0 m/s at an angle of 30° from the horizontal. The aim of this exercise is to determine whether the dog will reach the other side of the ditch. First we will find out whether the dog reaches its maximum height before or after it is above the middle of the ditch. *(131F2022)*

a) Sketch the situation with the "earlier" instant being that at which the dog launches and the "later" instant being the moment when it reaches its highest point. List as many of the variables as possible. Use the format

$$
\begin{array}{ll}
 & t = \\
x_0 = & x = \\
y_0 = & y = \\
v_{0x} = & v_x = \\
v_{0y} = & v_y = \\
a_x = & a_y = \quad .
\end{array}
$$

b) Draw the velocity vector at the earlier instant and use this to determine the components of $\vec{\mathbf{v}}_0$. Enter these in the list above.

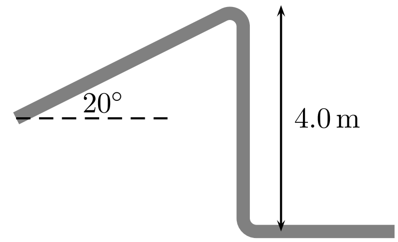
c) Draw the velocity vector at the later instant. Describe whether the components are positive, negative or zero and enter as much information about these in the list above.

d) Determine the horizontal distance traveled by the dog by the time that it reaches it's maximum height.

e) As the dog descends from its maximum height back to the ground, how much further does it travel? Does it reach the other side of the ditch?

81 Launching off a ski ramp

A ski ramp is arranged as illustrated. A skier launches off the ramp with a speed of 15 m/s. Initially the aim of this exercise is to determine the maximum height reached by the skier and the velocity at this point. A later goal is to determine the distance at which the skier lands from the bottom of the ramp. *(131F2022)*



a) Sketch the situation with the "earlier" instant being that at which the skier launches and the "later" instant being the moment when she reaches its highest point. List as many of the variables as possible. Use the format

$$\begin{aligned} t_0 &= & t_1 &= \\ x_0 &= & x_1 &= \\ y_0 &= & y_1 &= \\ v_{0x} &= & v_{1x} &= \\ v_{0y} &= & v_{1y} &= \\ a_x &= & a_y &= \quad . \end{aligned}$$

b) Draw the velocity vector at the earlier instant and use this to determine the components of $\vec{\mathbf{v}}_0$. Enter these in the list above.

c) Draw the velocity vector at the later instant. Describe whether the components are positive, negative or zero and enter as much information about these in the list above.

d) Determine the time taken to reach the maximum height and then the horizontal distance traveled by the skier to reach her maximum height. Determine the velocity at this point.

You will now consider the motion from the highest point back to the ground.

e) Repeat the problem set-up with the"earlier" instant being that at which the skier is at maximum height and the "later" instant being the moment *just before* she reaches hits the ground. Determine the time taken for this portion of the motion and use it to determine the horizontal distance from the base of the ramp to the skier's landing point.

82 Jumping grasshopper

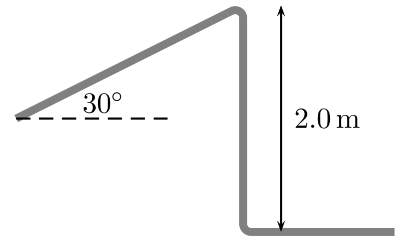
A grasshopper jumps, leaving the ground at an angle of 70° from the horizontal. The grasshopper reaches a height of 0.60 m. *(131F2022)*

a) Determine the speed with which the grasshopper leaves the ground.

b) Determine how far the grasshopper lands from where it jumped.

83 Launching off a ski ramp, 2

A ski ramp is arranged as illustrated. A skier launches off the top of the ramp with a speed of 28 m/s. Determine the horizontal distance at which the skier lands from the bottom of the ramp. *(131F2022)*



84 Jumping lemur

A lemur (a type of primate) jumps, leaving the ground at an angle of 40° from the horizontal with speed 6.0 m/s. *(131F2022)*

a) Determine the maximum height reached by the lemur.

b) Determine the amount of time for which the lemur is airborne.

c) Determine the horizontal distance traveled by the lemur from the moment it leaves the ground until it returns to the ground.

85 Cannonball range

A cannonball is fired from the ground (assume that the ball leaves from the ground level) and must hit a target on the ground a distance of 500 m away. Assume that the ground is horizontal and ignore air resistance. *(131F2022)*

a) Suppose that the cannonball leaves at an angle of 50° from the horizontal. Determine the speed with which it must be fired to hit the target.

b) Suppose that the cannonball is fired with speed 150 m/s. Determine the angle above the horizontal at which it must be fired so that it hits the target.

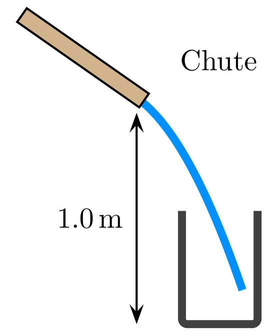
c) *(Challenging)* Determine the minimum speed with which the cannonball must be fired so that it can hit the target if the angle is adjusted correctly.

86 Angry tennis player

An angry tennis player hits a tennis ball into the air toward the fence that surrounds the court. The tennis player is a horizontal distance of 20 m from the fence, which is 10 m high. The tennis player hits the ball with speed 28 m/s at an angle of 70° above the horizontal from a height of 1.2 m above the ground. Does the ball reach the fence? Does it pass over the top of the fence? Explain your answer. *(131F2022)*

87 Water chute and bucket

Water slides down a chute that is at an angle of 35° above the horizontal. It leaves the end of the chute with speed 3.0 m/s. A bucket with sides 30 cm high and diameter 20 cm is placed beyond the chute so that it catches the water. Determine where the left edge of the bucket be should placed so that the water will land in the bucket. Provide the entire range of possible locations. *(131F2022)*



88 Rotating mountain bike wheel

One standard mountain bike wheel has rims with diameter 29in. A cyclist rides the bike with a constant speed of 15 mph. Determine the speed and centripetal acceleration of a point on the rim. *(131F2022)*

89 Ball on a string

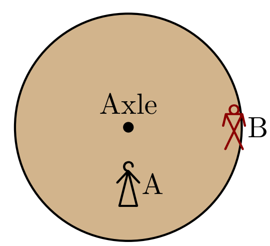
A ball swings with constant speed on the end of a 50 cm long string. Determine the period of orbit (time for one circle) such that the ball's acceleration is $2g$. *(131F2022)*

90 Orbiting object

An object orbits in a circle with constant speed. The radius of the orbit is r and the object completes on orbit in time T (the period of orbit). Determine an expression for the object's acceleration in terms of T and r. *(131F2022)*

91 Rotating dolls

Two dolls sit in fixed places on a disk that rotates about its center. Doll A is halfway from the axle to the rim. Doll B is at the rim. The wheel rotates at a uniform constant rate. Let v_A be the speed of A, v_B be the speed of B, a_A the acceleration of A, etc. In each of the following, explain your answer. *(131F2022)*



a) Which of the following is true?

   i) $v_A = \frac{1}{4} v_B$

   ii) $v_A = \frac{1}{2} v_B$

   iii) $v_A = v_B$

   iv) $v_A = 2v_B$

   v) $v_A = 4v_B$

b) Which of the following is true?

   i) $a_A = \frac{1}{4} a_B$

   ii) $a_A = \frac{1}{2} a_B$

   iii) $a_A = a_B$

   iv) $a_A = 2a_B$

   v) $a_A = 4a_B$

92 Acceleration on Grand Mesa versus Grand Junction

Consider standing in two places: one in Grand Junction and the other on top of Grand Mesa. The altitude of Grand Junction is roughly 1380 m and Grand Mesa 3200 m. The aim of this exercise is to determine the difference in velocity and acceleration between the two locations. Grand Junction's location latitude is about 39° North. Note that all objects rotate about an axis through Earth's poles. *(131F2022)*

a) Determine the speed with which a person in Grand Junction moves as Earth (radius 6400 km at sea level) rotates.

b) Determine the speed with which a person on top of Grand Mesa moves.

c) Determine the acceleration of a person in Grand Junction.

d) Determine the acceleration of a person on the Grand Mesa. Are the accelerations noticeably different?

93 Acceleration on Earth's surface

People stand on Earth's surface and are at rest *relative to Earth.* Earth has a radius of 6.4×10^3 km and spins about its poles at a rate of one revolution every 24 hrs. *(131F2022)*

a) Determine the acceleration of a person at Earth's equator.

b) Another person stands at a location much closer to the North pole. Is this person's acceleration the same as, larger than or smaller than that of a person at the equator? Explain your answer.

94 Centripetal acceleration

The formula for centripetal acceleration is

$$a = \frac{v_t^2}{r}.$$

In this exercise you will use calculus to prove that this is true. *(131F2022)*

a) Consider an object whose position is represented by the vector (from the origin)

$$\vec{\mathbf{r}} = r\cos{(\omega t)}\hat{\mathbf{i}} + r\cos{(\omega t)}\hat{\mathbf{j}}.$$

By considering this at various times, show that it represents the position of a particle traveling in a circle of radius r and with angular velocity ω.

b) Determine the tangential velocity vector

$$\vec{\mathbf{v}}_t = \frac{d\vec{\mathbf{r}}}{dt}$$

and the acceleration vector

$$\vec{\mathbf{a}} = \frac{d\vec{\mathbf{v}}_t}{dt}.$$

c) Show that

$$\vec{\mathbf{a}} = -\omega^2 \vec{\mathbf{r}}$$

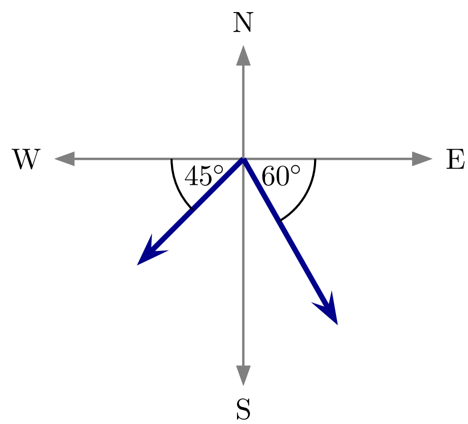
and use this to show that

$$a = \omega^2 r = \frac{v_t^2}{r}.$$

Additional Kinematics Problems

95 Successive displacements

An insect crawls along a horizontal two dimensional surface in two straight stages. First the insect walks 8.0 cm at an angle of 45° south of west. Second, the insect walks 10.0 cm in a straight line at an angle 60° south of east. Determine an expression for the displacement of the insect and how far the insect ends up from its starting point. *(131F2022)*



96 Diver splashdown

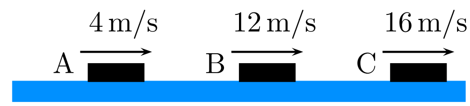
A diver launches off a platform at an angle of 55° above the horizontal and with speed 8.0 m/s. The platform is 3.0 m above the surface of a pool. *(131F2022)*

a) Determine the diver's speed just before hitting the water.

b) Determine the time taken by the diver to hit the water.

Dynamics

97 Hockey pucks sliding horizontally



Three identical hockey pucks slide horizontally across a frictionless sheet of ice and they maintain the indicated speeds during a particular period. Let F_A be the magnitude of the force acting on A during this period, F_B be the magnitude of the force acting on B, etc, ... Which of the following is true? Explain your answer.

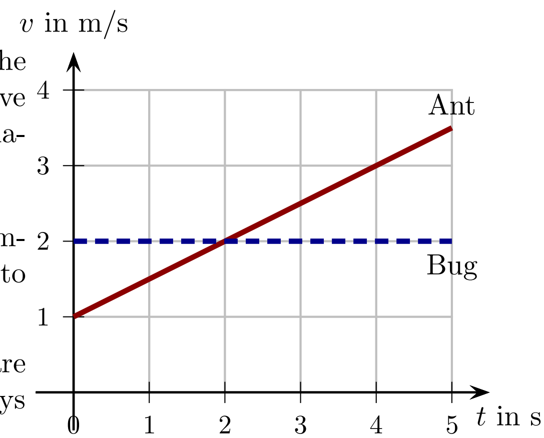
i) $F_B = 2F_A$ and $F_C = 4F_A$

ii) $F_A = 2F_B$ and $F_A = 4F_C$

iii) $F_A = F_B = F_C \neq 0$

iv) $F_A = F_B = F_C = 0$

98 Forces on an ant and a bug



An ant and a bug walk along straight wires. The graph illustrates their velocities vs. time. They have the same mass. Answer the following, giving explanations for each answer.

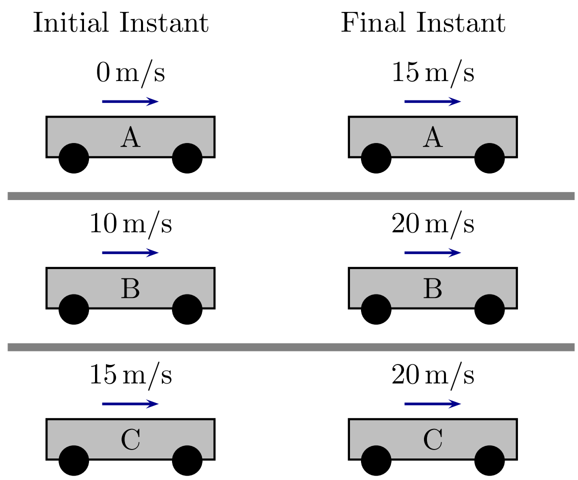
a) How does the net force on the ant at 2.0 s compare (same, larger, four times as large,etc,) to the net force on the ant at 4.0 s?

b) How does the net force on the ant compare (same, always larger, sometimes larger, always smaller,...) to the net force on the bug?

c) Is the net force exerted on the ant ever the same as that exerted on the bug? If so, explain when.

99 Moving carts

Three identical carts move horizontally along tracks. Their speeds at two instants 5.0 s apart are indicated. Let F_A be the magnitude of the net force acting on A during this interval, F_B be the magnitude of the net force acting on B, etc, ... Which of the following is true? Explain your answer.



i) $F_A > F_B > F_C$.

ii) $F_B = F_C > F_A$.

iii) $F_B = F_C < F_A$.

iv) $F_A = F_B = F_C \neq 0$

100 Riding a bicycle

Suppose that you ride a bicycle at constant speed in straight lines across various surfaces. In each of the following, explain your answers.

a) If you ride at a constant speed along a flat horizontal surface, which of the following is true?

   i) The net force on the bicycle is zero.
   ii) The net force on the bicycle is in the direction of motion.
   iii) The net force on the bicycle is opposite to the direction of motion.
   iv) Whether the net force is zero or not depends on the speed.

b) If you ride at a constant speed along a slanted flat uphill surface, which of the following is true?

   i) The net force on the bicycle is zero.
   ii) The net force on the bicycle is in the direction of motion.
   iii) The net force on the bicycle is opposite to the direction of motion.
   iv) Whether the net force is zero or not depends on the speed.

101 Pushing carts

Zog and Geraldine (his wife) each push a cart along a horizontal surface where friction is negligible. Both carts are initially at rest. Zog takes the cart with mass 25 kg and exerts a force of 400 N on it for a period of 4.0 s and he then collapses and stops pushing. Geraldine has to push a cart of mass 50 kg and she is also able to exert a force of 400 N on it. Geraldine claims that it is possible for the speed of her cart to eventually reach the speed of Zog's cart. Is this true? Explain your answer.

102 Forces on a cart sliding horizontally

A cart can slide horizontally left or right.

a) Suppose that the cart slides to the left with increasing speed. Which of the following is true about the net force, $\vec{\mathbf{F}}_{\text{net}}$, acting on the cart? Explain your choice.

   i) $\vec{\mathbf{F}}_{\text{net}} = 0$

   ii) $\vec{\mathbf{F}}_{\text{net}} \neq 0$ and points right.

   iii) $\vec{\mathbf{F}}_{\text{net}} \neq 0$ and points left.

b) Suppose that the cart slides to the left with decreasing speed. Which of the following is true about the net force acting on the cart? Explain your choice.

   i) $\vec{\mathbf{F}}_{\text{net}} = 0$

   ii) $\vec{\mathbf{F}}_{\text{net}} \neq 0$ and points right.

   iii) $\vec{\mathbf{F}}_{\text{net}} \neq 0$ and points left.

103 Force on an accelerating box

A 50 kg box is initially at rest on a horizontal sheet of ice. Subsequently someone pulls on the box with a constant horizontal force. The box moves 15 m during the first 10 s while the force is applied. Determine the magnitude of the force.

104 Moving a sleepy dog

A sleepy 30 kg dog lies on a horizontal surface. The dog is initially at rest. Subsequently a child pushes horizontally on the dog with a 150 N force. There is no friction between the dog and the surface and forces in the vertical direction are irrelevant to its motion.

a) Determine how far the dog moves after the child has pushed for 3.0 s.

b) Determine the speed of the dog after the child has pushed for 3.0 s.

c) If the child continues pushing for twice as long will the speed be twice as much? Will the distance traveled be twice as much? Explain your answers.

105 Pushing a curling stone across a frozen ice sheet

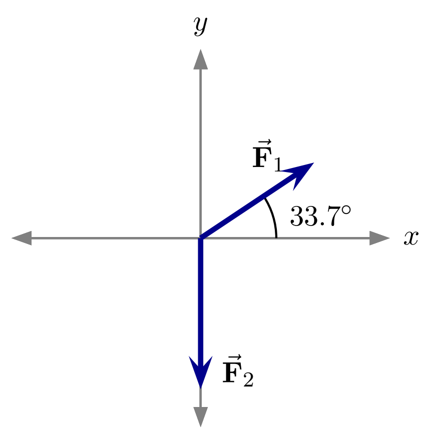
A 20 kg curling (a type of sport) stone lies at rest on a horizontal sheet of ice. The stone is pushed by a player in a straight line with a constant horizontal force for a distance of 3.0 m and is then released. It travels in a straight line for a further distance of 42 m in 20 s. There is no spin on the stone. Determine the magnitude of the force exerted by the player on the stone.

106 Net force vector: two forces

Two forces, $\vec{\mathbf{F}}_1$ and $\vec{\mathbf{F}}_2$ act on an object and are as illustrated. Their magnitudes are $F_1 = 400\,\mathrm{N}$ and $F_2 = 500\,\mathrm{N}$.

a) Determine the x and y components of the net force.

b) Determine the magnitude of the net force acting on the object.

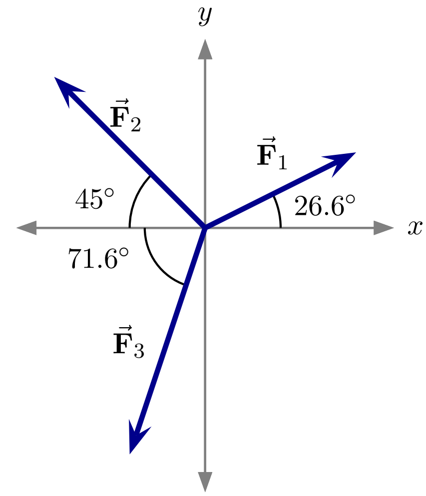


107 Net force vector: three forces

Three forces, $\vec{\mathbf{F}}_1, \vec{\mathbf{F}}_2$ and $\vec{\mathbf{F}}_3$ act on an object and are as illustrated. Their magnitudes are $F_1 = 40\,\text{N}, F_2 = 25\,\text{N}$ and $F_3 = 15\,\text{N}$.

a) Determine the x and y components of the net force.

b) Determine the magnitude of the net force acting on the object.

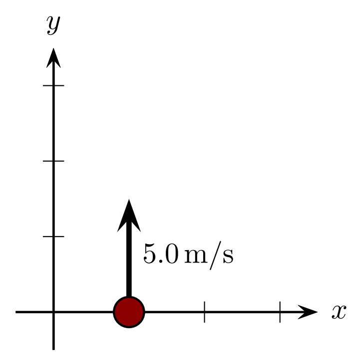


108 Forces and two dimensional motion

A 2.0 kg rock slides along a horizontal surface. At the moment that it passes the $x = 1.0\,\text{m}, y = 0.0\,\text{m}$ mark it is moving with the illustrated velocity. During the next 4.0 s a constant force $8.0\,\text{N}\hat{\mathbf{i}}$ acts on the rock.

a) Determine the rock's position and velocity at the instant 4.0 s later.

b) Describe and sketch, as accurately as possible, the trajectory of the rock while the force acts on it.



109 Ice skaters

Two ice skaters, Alice with mass 55 kg and Bob with mass 85 kg are initially at rest on a frictionless horizontal surface. Bob gently pushes on Alice and while he does this she has a constant acceleration of $0.020\,\mathrm{m/s^2}$.

a) Determine the force exerted by Bob on Alice while she accelerates.

b) Determine the force exerted by Alice on Bob while Alice accelerates.

c) Determine the acceleration of Bob during the period while he is pushing on Alice.

110 Multiple forces and motion

A 20.0 kg box can move along a frictionless horizontal surface. Three people pull horizontally on the box with the indicated forces.

a) Draw a free body diagram for the box.

b) Write Newton's Second Law in its component form, i.e. write

$$\begin{aligned} F_{\text{net } x} &= \Sigma F_x = \cdots \\ F_{\text{net } y} &= \Sigma F_y = \cdots \end{aligned}$$

Insert as much information as possible about the components of acceleration at this stage. You will return to these equations soon; they will generate the algebra that eventually gives you the acceleration and the normal force.

c) List all the components of all the forces, using one of the two formats below.

$F_{1x} = \cdots$
$F_{1y} = \cdots$
$F_{2x} = \cdots$
$F_{2y} = \cdots$
$F_{3x} = \cdots$
$F_{3y} = \cdots$

Force	x comp	y comp
$\vec{\mathbf{F}}_1$		
$\vec{\mathbf{F}}_2$		
$\vec{\mathbf{F}}_3$		

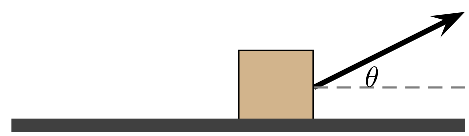
Use these to determine the components of the net force.

d) Use Newton's second law, which you wrote earlier, to determine the components of the acceleration of the box.

e) If the box were moving right while these forces act would it slow down or speed up?

f) If the box were moving left while these forces act would it slow down or speed up?

111 Pulling a box



A 20.0 kg box can move along a frictionless horizontal surface. A person pulls on the box with the indicated force. Initially assume that the force pulls horizontally; later we will consider a general angle.

a) Draw a free body diagram for the box.

b) Write Newton's Second Law in its component form, i.e. write

$$
\begin{aligned}
F_{\text{net } x} &= \Sigma F_x = \cdots \\
F_{\text{net } y} &= \Sigma F_y = \cdots
\end{aligned}
$$

Insert as much information as possible about the components of acceleration at this stage. You will return to these equations soon; they will generate the algebra that eventually gives you the acceleration and the normal force.

c) List all the components of all the forces, using one of the two formats below.

$$
\begin{aligned}
F_{gx} &= \cdots \\
F_{gy} &= \cdots \\
n_x &= \cdots \\
n_y &= \cdots \\
F_{\text{person } x} &= \cdots \\
F_{\text{person } y} &= \cdots
\end{aligned}
$$

Force	x comp	y comp
$\vec{\mathbf{F}}_g$		
$\vec{\mathbf{n}}$		
$\vec{\mathbf{F}}_{\text{person}}$		

Use these to determine expressions for the components of the net force.

d) Use Newton's second law in component form to relate the acceleration components to the forces.

e) Determine the normal force on the box.

f) Determine the acceleration of the box.

g) Now suppose that $\theta = 25°$ and repeat the entire exercise to determine the normal force and the acceleration.

112 Box on the floor of an elevator

A 20 kg box sits on the floor of an elevator.

a) During an initial 1.5 s period the elevator moves upward with a speed that increases steadily from 0 m/s to 7.5 m/s. Determine the normal force exerted by the floor on the box during this period.

b) During an later 2.5 s period the elevator moves upward with a speed that decreases steadily from 7.5 m/s to 0 m/s. Determine the normal force exerted by the floor on the box during this period.

113 Alice in an elevator

Alice, with mass 58 kg stands in an elevator, which moves vertically. The elevator accelerates (at a constant rate) from rest to speed of 4.0 m/s during a period of 1.5 s. It then moves with a constant velocity for a period of 10.0 s. Finally it slows to a stop at a constant rate during a period of 2.0 s.

a) Determine the total distance traveled by Alice during the entire journey.

b) Determine the normal force exerted by the elevator floor on Alice during each of the three stages of motion.

114 Free fall in an elevator

A phone with mass m sits on the floor of an elevator, which is initially at rest. The elevator cable snaps and the elevator and phone then undergo free fall (i.e. both move downward with an acceleration g). While they do this which is true of the magnitude of the normal force, n, acting on the phone? Explain your choice.

i) $n = 0$.

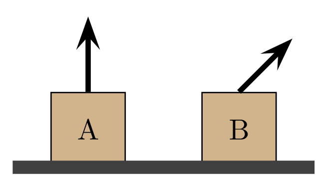
ii) $mg > n > 0$.

iii) $n = mg$.

iv) $n > mg$

115 Normal forces

Two identical boxes are at rest on a rough horizontal surface. A person pulls on each with the same force but in different directions on the boxes. On box A it pulls vertically and on box B it pulls at an angle of 45° from the vertical. Which of the following is true regarding the normal force exerted on A and that exerted on B? Explain your choice.



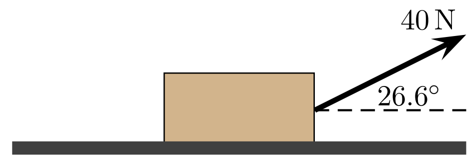
i) $n_A = n_B$.

ii) $n_A < n_B$.

iii) $n_A > n_B$.

116 Dynamics of a single object

A 5.0 kg box can move along a frictionless horizontal surface. A person exerts a force at the illustrated angle. The aim of this exercise is to use Newton's laws to determine the acceleration of the box and the normal force exerted by the surface (provided that the box stays on the surface).



The *entire collection* of these steps is called "applying Newton's laws of mechanics to determine the acceleration of the block."

a) Draw a free body diagram for the block.

b) Write Newton's Second Law in its component form, i.e. write

$$F_{\text{net } x} = \Sigma F_x = \cdots \quad (1)$$
$$F_{\text{net } y} = \Sigma F_y = \cdots \quad (2)$$

Insert as much information as possible about the components of acceleration at this stage. You will return to these equations shortly; they will generate the algebra that eventually gives you the acceleration and the normal force.

c) Determine the magnitude of the gravitational force. Let n be the *magnitude* of the normal force. Do you think that $n = mg$?

d) List all the components of all the forces, using one of the two formats below.

$$F_{gx} = \cdots$$
$$F_{gy} = \cdots$$
$$n_x = \cdots$$
$$n_y = \cdots$$
$$\vdots \vdots$$

Force	x comp	y comp
$\vec{\mathbf{F}}_g$		
$\vec{\mathbf{n}}$		
$\vdots$		

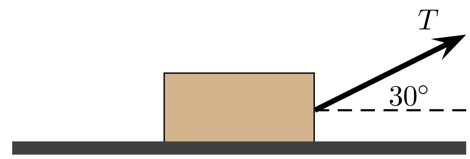
e) Use Eq. (1) to obtain an equation relating various quantities that appear in this problem. Do the same with Eq. (2). Solve these for the acceleration and the magnitude of the normal force. Is $n = mg$?

f) Suppose that rather than pull up, the person pushed down on the box at the same angle from the left and with the same force. Would the acceleration and normal forces differ from the case where the person pulled up?

g) You may have noticed that the acceleration does not depend on the normal force. This is only true if there is no friction. It turns out that when friction is present, the magnitude of friction force increases as the normal force increases. Knowing this, would pulling up or pushing down give a larger acceleration?

117 Accelerating box

A rope pulls on a 30 kg box which slides across a frictionless horizontal surface. The box moves along the surface to the right with acceleration $3.5\,\text{m/s}^2$.

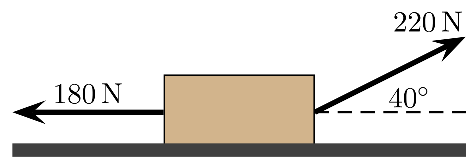


a) Determine the tension in the rope.

b) Determine the normal force exerted by the floor on the box.

118 Multiple forces and motion

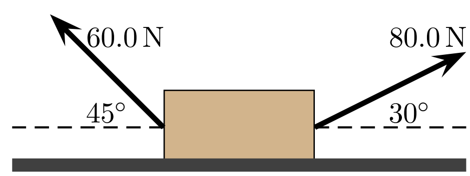
The illustrated forces act on an 80.0 kg box that slides along a frictionless horizontal surface.



a) Determine the acceleration of the box.
b) Suppose that at one moment the box was moving left. Will it slow down, speed up or move with constant velocity in the next moments? Explain your answer.
c) Suppose that at one moment the box was moving right. Will it slow down, speed up or move with constant velocity in the next moments? Explain your answer.

119 Multiple forces on a single object

A 25.0 kg crate can move along a frictionless horizontal surface. Two people exert forces on the crate as illustrated.

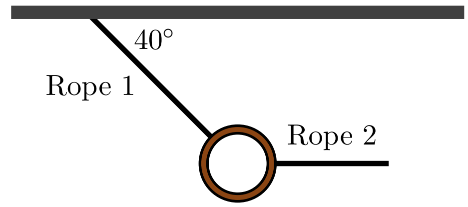


a) Determine the acceleration of the crate.

b) Determine the normal force on the crate.

120 Suspended ring in equilibrium, 1

A 2.50 kg ring is suspended from the ceiling and is held at rest by two ropes as illustrated. Rope 2 pulls horizontally. The aim of this exercise is to use Newton's 2nd Law to determine the tension in each rope. One piece of background information that you will need to answer this is that the magnitude of the gravitational force on an object of mass m is $F_g = mg$.



a) Draw a free body diagram for the ring. Label the tension forces $\vec{\mathbf{T}}_1$ and $\vec{\mathbf{T}}_2$.

b) Write Newton's 2nd Law in its component form, i.e. write

$$F_{\text{net }x} = \Sigma F_{ix} = ma_x \quad (3)$$
$$F_{\text{net }y} = \Sigma F_{iy} = ma_y \quad (4)$$

Insert as much information as possible about the acceleration. You will return to these equations shortly; they will generate the algebra that eventually gives you the tensions.

c) These equations require all components of all forces, including the two unknown tension forces. In order to manage these, you should express the components of each tension force in terms of its magnitude. When doing this denote the magnitude of the tension in rope 1 by T_1 and for rope 2, by T_2.

d) List as much information as possible about each component for each force; each could be a number or an algebraic expression. Use one of the two formats below.

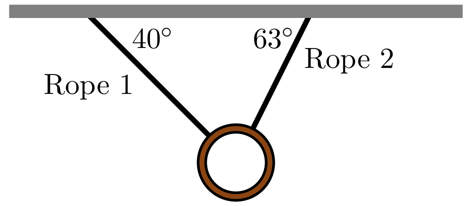
$F_{gx} = \cdots$
$F_{gy} = \cdots$
$T_{1x} = \cdots$
$T_{1y} = \cdots$
$\vdots$

Force	x comp	y comp
$\vec{\mathbf{F}}_g$		
$\vec{\mathbf{T}}_1$		
$\vdots$		

e) Use Eq. (3) to obtain an equation relating various quantities that appear in this problem. Do the same with Eq. (4). You should get two expressions that contain the two unknowns T_1 and T_2. Solve them for the unknowns.

f) If you had one rope that is rated to break when the tension exceeds 30 N and another rated to break when the tension exceeds 40 N, which one would you use to suspend the object as illustrated above?

121 Suspended ring in equilibrium, 2



A 2.50 kg ring is suspended from the ceiling and by two ropes as illustrated. The aim of this exercise is to use Newton's 2nd Law to determine the tension in each rope.

a) Draw a free body diagram for the ring. Label the tension forces $\vec{\mathbf{T}}_1$ and $\vec{\mathbf{T}}_2$.

b) Write Newton's 2nd Law in its component form, i.e. write

$$F_{\text{net } x} = \Sigma F_{ix} = ma_x \qquad (5)$$

$$F_{\text{net } y} = \Sigma F_{iy} = ma_y \qquad (6)$$

Insert as much information as possible about the acceleration. You will return to these equations shortly; they will generate the algebra that eventually gives you the tensions.

c) These equations require all components of all forces, including the two unknown tension forces. In order to manage these, you should express the components of each tension force in terms of its magnitude. When doing this denote the magnitude of the tension in rope 1 by T_1 and for rope 2, by T_2.

d) List as much information as possible about each component for each force; each could be a number or an algebraic expression. Use one of the two formats below.

$$F_{gx} = \cdots$$
$$F_{gy} = \cdots$$
$$T_{1x} = \cdots$$
$$T_{1y} = \cdots$$
$$\vdots$$

Force	x comp	y comp
$\vec{\mathbf{F}}_g$		
$\vec{\mathbf{T}}_1$		
$\vdots$		

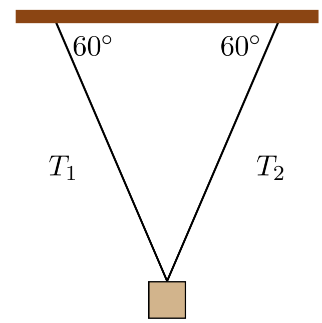
e) Use Eq. (5) to obtain an equation relating various quantities that appear in this problem. Do the same with Eq. (6). You should get two expressions that contain the two unknowns T_1 and T_2. Solve them for the unknowns.

122 Object suspended at rest

A 0.20 kg block is suspended by two ropes as illustrated. The tension in the left rope is T_1 and in the right rope it is T_2.

a) Is T_1 the same as or different to T_2? Explain your answer.

b) Determine the magnitude of the tension in each rope.



123 Stretched clothesline

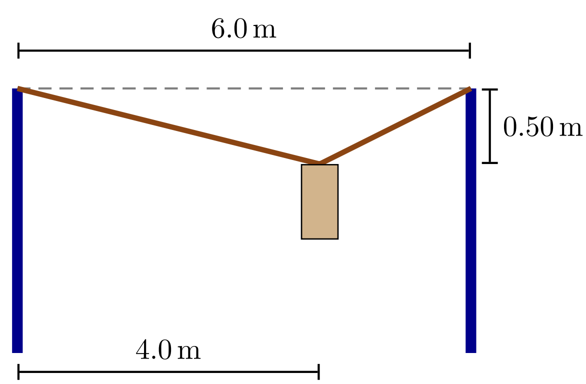
A clothesline (rope) initially droops approximately horizontally between two poles. A hanger is suspended at rest from the midpoint of the clothesline.

a) Is it possible to stretch the clothes line so that it is perfectly horizontally while the hanger is suspended? Explain your answer using Newton's laws.

b) The hanger is removed. Is it possible to stretch the clothes line so that it is perfectly horizontally? Explain your answer using Newton's laws.

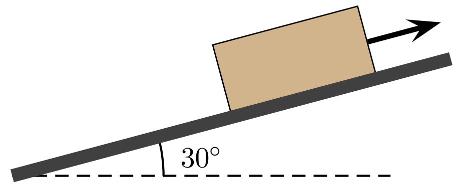
124 Dangling monkney

A 15.0 kg monkey hangs from a rope stretched between the tops of two equally tall supports in the illustrated configuration. Determine the tension in the rope left of the monkey and the tension in the rope right of the monkey.



125 Object pulled along a ramp

A 4.0 kg box can move along a frictionless ramp angled 30° from the horizontal. A person pulls on a rope which exerts a force of 15 N up the ramp parallel to its surface. The object of this exercise is to determine the acceleration of the box.



a) Draw a free body diagram for the box.

b) Describe the x and y axes that you will use.

c) Write Newton's Second Law in vector form and also in its component form, i.e. write

$$F_{\text{net } x} = \Sigma F_x = \cdots \tag{7}$$

$$F_{\text{net } y} = \Sigma F_y = \cdots \tag{8}$$

Insert as much information as possible about the components of acceleration at this stage. The resulting equations will generate much of the algebra that follows.

d) Determine the magnitude of the gravitational force.

e) List all the components of all the forces, using one of the two formats below.

$$F_{gx} = \cdots$$
$$F_{gy} = \cdots$$
$$n_x = \cdots$$
$$n_y = \cdots$$
$$\vdots$$

Force	x comp	y comp
$\vec{\mathbf{F}}_g$		
$\vec{\mathbf{n}}$		
$\vdots$		

f) Use Eq. (7) to obtain an equation relating various quantities that appear in this problem. Do the same with Eq. (8).Use the resulting equations to determine the acceleration of the box.

g) Is it possible to say with certainty whether the box is moving up the ramp or down the ramp? Is either direction possible in this situation? If only one direction is possible, which is it?

h) Suppose that the box is initially at rest. With the indicated applied force, how long will it take for the box to slide a distance of 2.0 m along the ramp?

126 Bathroom scale in a train

A bathroom scale reads the normal force that it exerts on the object on the scale. Suppose that a bathroom scale is fixed to the floor of a train and a person stands on the scale. The train travels at a constant speed along horizontal sections of track and then up and down inclined sections (the slopes of the inclined sections are the same). In the following explain your answers.

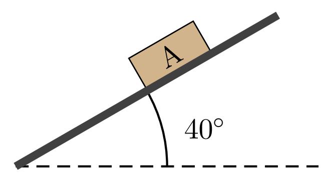
a) Is the reading on the scale when traveling up the inclined section the same as, smaller than or larger than when traveling along the horizontal section?

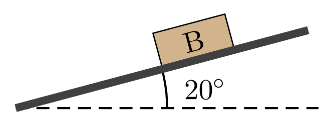
b) Is the reading on the scale when traveling down the inclined section the same as, smaller than or larger than when traveling up the inclined section?

c) Would the reading on the scale while the train travels up the inclined section depend on the speed with which it travels?

127 Blocks on ramps

Two blocks with the same mass are at rest on the illustrated inclined surfaces. Which of the following is true about the magnitudes of the normal forces that act on the blocks? Explain your answer.





i) $n_{\mathrm{A}} > n_{\mathrm{B}}$.

ii) $n_{\mathrm{A}} = n_{\mathrm{B}}$.

iii) $\frac{1}{2}\, n_{\mathrm{B}} < n_{\mathrm{A}} < n_{\mathrm{B}}$.

iv) $n_{\mathrm{A}} = \frac{1}{2}\, n_{\mathrm{B}}$.

v) $n_{\mathrm{A}} < \frac{1}{2}\, n_{\mathrm{B}}$.

128 Different boxes on the same ramp

Two boxes, one red (mass 3.0 kg) and the other blue (mass 6.0 kg) are each on frictionless ramps inclined at an angle of 10° from the horizontal. They are released from rest. Let a_{red} be the acceleration of the red box and a_{blue} that of the blue box. Which of the following is true? Explain your answer.

i) $a_{\mathrm{blue}} = \frac{1}{2}\, a_{\mathrm{red}}$

ii) $a_{\mathrm{blue}} = a_{\mathrm{red}}$

iii) $a_{\mathrm{blue}} = 2a_{\mathrm{red}}$

iv) $a_{\mathrm{blue}} > 2a_{\mathrm{red}}$

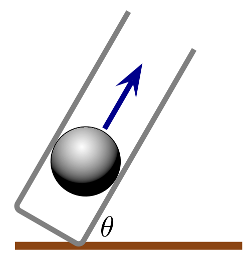
129 Snowboarder sliding up a ramp

An 80 kg snowboarder slides along a horizontal surface with a speed of 25 m/s and approaches a surface inclined at 10° above the horizontal. Both surfaces are frictionless and you can ignore air resistance.

a) Determine the acceleration of the snowboarder along the inclined surface.
b) Determine how far along the inclined surface the snowboarder slides before stopping.
c) Determine the maximum vertical height ascended by the snowboarder along the ramp.

130 Launch force on a cannonball

A 40 kg cannonball is launched at an angle of θ above the horizontal. The cannonball is initially at rest at the ground level and reaches height h. The length of the cannon tube is L. The aim of this exercise is to determine the launching force exerted on the cannonball, assuming that it is constant and that it points parallel to the tube.



a) Show that the launch speed is

$$v_{\text{launch}} = \frac{\sqrt{2g\,(h - L\sin\theta)}}{\sin\theta}.$$

b) Show that the magnitude of the acceleration of the cannonball, while in the cannon tube is

$$a = g\frac{h - L\sin\theta}{L\sin^2\theta}.$$

c) Show that the launching force exerted by the cannon has magnitude

$$F = \frac{mg}{L\sin^2\theta}\left(h - L\sin\theta\cos^2\theta\right).$$

131 Blow dart

A toy blow dart gun fires a 60 g dart through a tube. The tube has length 40 cm and is angled at 75° from the horizontal. The dart is propelled from rest by air which exerts a constant force and it reaches a height of 6.0 m above the upper end of the tube. Ignore air resistance.

a) Determine the launch velocity of the dart.
b) Determine the magnitude of the acceleration of the dart while in the tube.
c) Determine the force exerted by the propelling air while the dart is in the tube.

132 Towing a car up a ramp

A rope pulls a 2500 kg car up an icy ramp which is tilted at angle 15° above the horizontal. The rope pulls with a constant force. The car is at rest at the bottom of the ramp and while the rope pulls it travels a distance 54 m along the ramp in 6.0 s. Determine the tension in the rope. Ignore friction and air resistance.

133 Lowering a box with ropes

Two ropes are attached to the top of a 75 kg box. They both pull vertically up with the same tension. The box moves downwards with constant downward acceleration of $2.5\,\mathrm{m/s^2}$. Determine the tension in each rope.

134 Sledding on a slope

A person in a sled is at rest at the top of a slope that is angled 15° above the horizontal. The length of the slope is an 800 m (about 0.5 mi). The combined mass of the person and sled is 90 kg. They are released from the top of the slope and slide straight down without pushing. While this happens the air exerts a constant force of 150 N exactly opposite to the direction in which they move. Ignore friction between the sled and the slope.

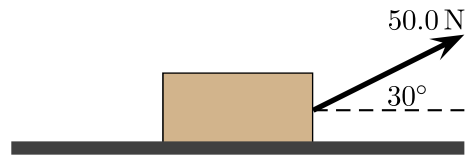
a) Determine the acceleration of the person and sled. *You must solve this by starting with a FBD, using Newton's second law, finding components,.... Simply looking up a formula is not adequate.*

b) Determine the time taken for the person and sled to reach the bottom of the slope.

c) Determine the speed of the person and sled at the bottom of the slope.

135 Dynamics of a single object with friction

A 15.0 kg box moves rightward along a horizontal surface. A rope pulls with a force at the illustrated angle. The coefficient of kinetic friction is 0.250. The primary aim of this exercise will be to determine the acceleration of the box.



a) Draw a free body diagram for the block.

b) Write Newton's Second Law in its component form, i.e. write

$$F_{\text{net } x} = \Sigma F_x = \cdots \tag{9}$$
$$F_{\text{net } y} = \Sigma F_y = \cdots \tag{10}$$

Insert as much information as possible about the components of acceleration at this stage. Can you describe in words what these equations are telling you to do?

c) Determine the magnitude of the gravitational force. Let n be the *magnitude* of the normal force. Using this write an expression for the magnitude of the friction force. Do you know the exact number for the friction force at this point?

d) List all the components of all the forces, using one of the two formats below.

$$w_x = \cdots$$
$$w_y = \cdots$$
$$n_x = \cdots$$
$$n_y = \cdots$$
$$\vdots$$

Force	x comp	y comp
$\vec{\mathbf{w}}$		
$\vec{\mathbf{n}}$		
$\vdots$		

e) Use Eq. (9) to obtain an equation relating various quantities that appear in this problem. Do the same with Eq. (10). Does either give the acceleration immediately? Can one of then at least give the normal force immediately?

f) Determine the normal force and use this result to find the acceleration.

g) What tension would be required for the box to have acceleration $4.00\,\text{m/s}^2$ to the right?

136 Pushing a box at constant speed

A 10 kg box can move along a rough horizontal surface. You discover that when you push horizontally with a force of 50 N that the box moves with constant speed. Which of the following is true about the magnitude of the friction force? Explain your answer.

i) $f = 10\,\mathrm{N}$

ii) $f = 50\,\mathrm{N}$

iii) $f = 98\,\mathrm{N}$

iv) f is more than 50 N but less than 98 N.

v) f is more than 98 N.

137 Crate in a truck

A crate lies on the flat, horizontal bed of a truck. The truck moves along a horizontal surface. In the following the truck moves so that the crate does not slip along the bed of the truck.

a) Is there a friction force between the crate and the truck when they both move north at the same constant speed along a straight horizontal road? Explain your answer.

b) Suppose that the truck speeds up while heading North. In which direction does the friction force point when it does this? Explain your answer.

c) Suppose that the truck slows down while heading North. In which direction does the friction force point when it does this? Explain your answer.

Explain your answers. *Hint: Consider applying Newton's second law to the crate.*

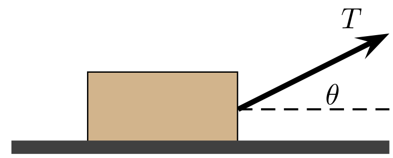
138 Braking car

A 2000 kg car moves along a horizontal concrete road with speed 24 m/s. At one moment the driver applies the brakes sharply and the tires slide without rotating across the concrete surface. The coefficient of static friction in this case is 0.90 and the coefficient of kinetic friction is 0.60. Air resistance provides a 3500 N force acting opposite to the car's motion.

a) Determine the acceleration of the car.

b) Determine the distance which the car travels while the brakes are applied and it skids.

139 Dragging a crate



A crate with mass m is dragged along a rough horizontal surface by a rope that pulls with tension T. The rope can pull at various angles. Suppose that you want to produce the largest acceleration for a given tension.

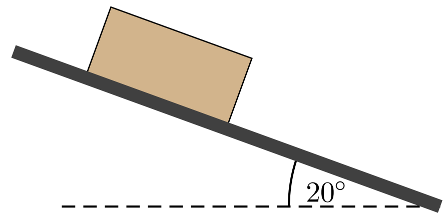
a) Explain what the drawbacks, in terms of attaining higher acceleration, would be of pulling at a larger angle.

b) Explain what the benefits, in terms of attaining higher acceleration, would be of pulling at a larger angle.

c) Determine an expression for the acceleration in terms of T, m, g, θ, and the coefficient of kinetic friction. Explain how you could use this to find the angle that would give the optimal acceleration.

140 Speed at the bottom of a rough ramp

A 10 kg box can move along a 4.0 m long rough ramp angled 20° from the horizontal. The coefficient of kinetic friction between the box and the ramp is 0.25 and the coefficient of static friction is 0.30. The box is released from rest at the top of the ramp and moves down the ramp. The aim of this exercise is to determine the speed of the box at the bottom of the ramp.



a) Draw a free body diagram for the box.

b) Describe your choice of x and y axes.

c) Write Newton's Second Law in vector form and also in its component form, i.e. write

$$F_{\text{net }x} = \Sigma F_x = \cdots \quad (11)$$
$$F_{\text{net }y} = \Sigma F_y = \cdots \quad (12)$$

where x and y refer to your specially chosen axes. Insert as much information as possible about the components of acceleration at this stage. The resulting equations will generate much of the algebra that follows.

d) Determine expressions for the *magnitudes* of the gravitational and the friction forces.

e) List all the components of all the forces, using one of the two formats below.

$$F_{gx} = \cdots$$
$$F_{gy} = \cdots$$
$$n_x = \cdots$$
$$n_y = \cdots$$
$$\vdots$$

Force	x comp	y comp
$\vec{\mathbf{F}}_g$		
$\vec{\mathbf{n}}$		
$\vdots$		

f) Use Eq. (11) to obtain an equation relating various quantities that appear in this problem. Do the same with Eq. (12). Use the resulting equations to find the acceleration of the box.

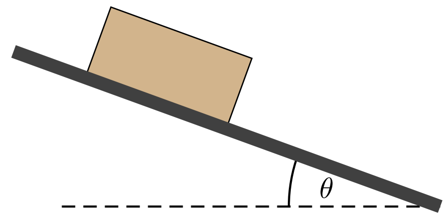
g) Determine the speed of the box when it reaches the bottom of the ramp.

h) Do these results depend on the mass of the box?

i) What would be the minimum force, pushing parallel to the ramp, required to keep the box at rest?

141 Perfect friction on a rough ramp

A box can move along a rough ramp which makes an angle θ from the horizontal and which has length L. The box is launched with speed v from the top of the ramp. The aim of this exercise is to determine the coefficient of friction needed to bring the box to a stop at the bottom of the ramp.



a) The first part of the solution uses kinematics to assess the acceleration of the box. Using kinematics, and eventually dynamics, is greatly simplified by choosing an appropriate "x" and a "y" axis. These do not have to be along the usual vertical and horizontal directions. Regardless of the axes that you choose, the usual general kinematics and dynamics equations will be valid. Describe the "x" and "y" axes that you will use.

b) Determine an expression for the magnitude of the acceleration of the box, a, in terms of variables relevant to this problem, such as L, θ, v, and possibly the mass of the box, m.

c) Draw a free body diagram for the box.

d) Write Newton's Second Law in vector form and also in its component form, i.e. write

$$F_{\text{net } x} = \Sigma F_{ix} = \cdots \tag{13}$$

$$F_{\text{net } y} = \Sigma F_{iy} = \cdots \tag{14}$$

where x and y refer to your specially chosen axes. Insert as much information as possible about the components of acceleration at this stage. The resulting equations will generate much of the algebra that follows.

e) Determine expressions for the *magnitudes* of the gravitational and the friction forces.

f) List all the components of all the forces, using one of the two formats below.

$$F_{gx} = \cdots$$
$$F_{gy} = \cdots$$
$$n_x = \cdots$$
$$n_y = \cdots$$
$$\vdots$$

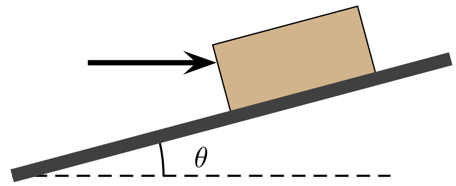
Force	x comp	y comp
$\vec{\mathbf{F}}_g$		
$\vec{\mathbf{n}}$		
$\vdots$		

g) Use Eq. (13) to obtain an equation relating various quantities that appear in this problem. Do the same with Eq. (14). Use the resulting equations to find an expression for the coefficient of kinetic friction. Does the result depend on the mass of the box?

h) Suppose that the ramp is a roof whose length is 5.0 m and which is angled at 15° from the horizontal. If the box is pushed with speed 4.0 m/s, determine the coefficient of friction needed to stop the box at the bottom of the roof.

142 Box pushed up a rough ramp

A block with mass m slides up a ramp at angle θ from the horizontal. The coefficient of kinetic friction between the surfaces is μ_{k}. A person pushes horizontally with a force F_{p}. The object of this exercise is to determine an expression for the acceleration of the block



$$a = \text{formula involving } m, \theta, F_{\mathrm{p}}, \mu_{\mathrm{k}}, g \text{ and constants.}$$

The *entire collection* of these steps is called "applying Newton's laws of mechanics to determine the acceleration of the block."

a) Draw a free body diagram for the block.

b) Describe the x and y axes that you will use.

c) Write Newton's Second Law in vector form and also in its component form, i.e. write

$$F_{\text{net } x} = \cdots \tag{15}$$

$$F_{\text{net } y} = \cdots \tag{16}$$

Insert as much information as possible about the components of acceleration at this stage. The resulting equations will generate much of the algebra that follows.

d) Determine expressions for the magnitudes of all the friction and gravitational forces. Do you think that $n = mg$?

e) List all the components of all the forces, using one of the two formats below.

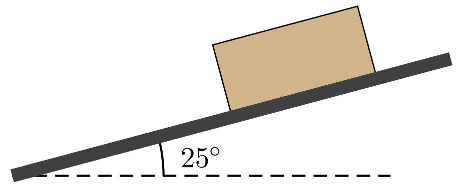
$$F_{gx} = \cdots$$
$$F_{gy} = \cdots$$
$$n_x = \cdots$$
$$n_y = \cdots$$
$$\vdots$$

Force	x comp	y comp
$\vec{\mathbf{n}}$		
$\vdots$		
$\vdots$		

f) Note that $F_{\text{net } x} = \sum_i F_{ix}$ (i.e. the x component of the net force is the sum of the x components of individual forces). Use this and Eq. (15) to obtain an equation relating various quantities that appear in this problem . Do the same with Eq. (16). Use the resulting algebraic expressions to get an expression for n. Is this mg? Use the resulting equations to get an expression for a.

143 Crate sliding along a rough ramp

A 15 kg crate can slide up or down a ramp at angle 25° from the horizontal. The coefficient of kinetic friction between the crate and the ramp is 0.30.



a) Determine the crate's acceleration if it slides up the ramp.

b) Determine the crate's acceleration if it slides down the ramp.

144 Brick on a slope

A 1.50 kg brick is at rest on an inclined surface. The angle between the surface and the horizontal is 10°.

a) Determine the friction force that the surface exerts on the brick.

b) Determine the minimum coefficient of static friction between these surfaces that allows for the brick to stay at rest.

145 Car on a slope

A car with mass 1500 kg is at rest on an incline. The coefficient of static friction between dry asphalt and rubber here is 0.90 and the coefficient of static friction between wet asphalt and rubber is 0.40.

a) Determine the maximum angle of the incline so that the car will stay at rest when the surface is dry.

b) Determine the maximum angle of the incline so that the car will stay at rest when the surface is wet.

146 Launching a box up a ramp

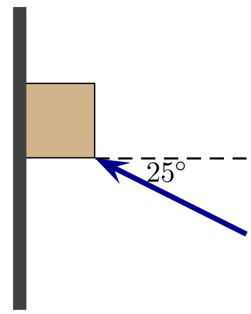
A ramp with length 2.0 m is inclined at an angle of 15° above the horizontal. A tiny box with mass 0.25 kg is launched with a very brief kick imparting speed 2.75 m/s at the base of the ramp. The coefficient of kinetic friction between the box and slope is 0.20.

a) Determine the acceleration of the box as it slides up the ramp.

b) Determine whether the box reaches the other end of the ramp or not.

147 Book held against a wall

A 10.0 kg book lies against a vertical wall and a hand pushes on it as illustrated. The coefficient of static friction between the book and wall is 0.30. The coefficient of kinetic friction between the book and wall is 0.20.

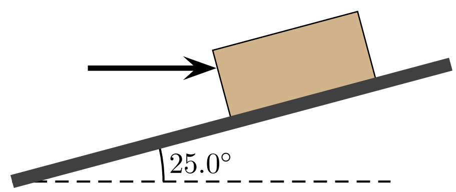


a) Determine the minimum force needed so that the book stays at rest on the wall.

b) Determine the magnitude of the force exerted by the hand so that the book slides down the wall with constant speed.

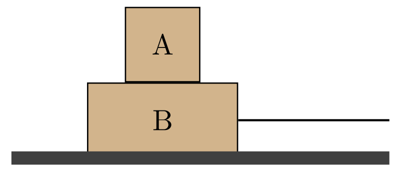
148 Box pushed up a rough ramp

A 6.00 kg box slides up a ramp at angle 25.0° from the horizontal. The coefficient of kinetic friction between the surfaces is 0.450. A person pushes horizontally with a 80.0 N force as illustrated. Determine the acceleration of the box.



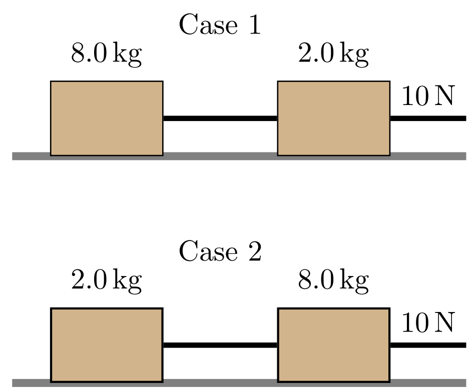
149 Slipping stacked objects

Two boxes are stacked and move along a frictionless horizontal surface as illustrated. Block A has mass 2.0 kg and block B has mass 3.0 kg. A rope is attached to block B and pulls horizontally with a 50 N force. The coefficient of friction between block A and block B is 0.25. Determine the acceleration of each block, assuming that they both move right and that B moves faster than A.



150 Connected objects: tension and acceleration

Two objects on a frictionless horizontal surface are connected by a massless rope. They are connected in different orders and pulled by another massless rope.



a) Let a_1 be the acceleration for case 1 and a_2 the acceleration for case 2. Which of the following is true? Explain your choice.

   i) $a_1 = a_2$

   ii) $a_1 > a_2$

   iii) $a_1 < a_2$

b) Let T_1 be the tension in the rope connecting the blocks for case 1 and T_2 that for case 2. Which of the following is true? Explain your choice.

   i) $T_1 = T_2 = 10\,\mathrm{N}$

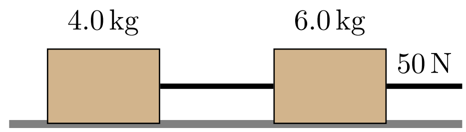
   ii) $T_1 < T_2 < 10\,\mathrm{N}$

   iii) $T_2 < T_1 < 10\,\mathrm{N}$

   iv) $T_1 = T_2 < 10\,\mathrm{N}$

151 Connected objects: tension and acceleration

Two boxes can move along a horizontal surface. There is no friction between either box and the surface. The boxes are connected by a rope. A hand pulls on the other rope with force 50 N.

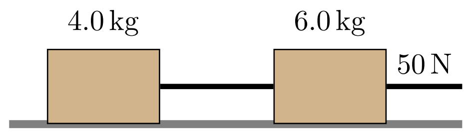


a) Determine the acceleration of each box.

b) Determine the tension in the rope connecting the boxes.

152 Connected objects: friction

Two boxes can move along a horizontal surface. There is no friction between the 6.0 kg box and the surface. There is friction for the other box: the coefficient of static friction is 0.70 and the coefficient of kinetic friction is 0.50. The boxes are connected by a rope. A hand pulls on the other rope with force 50 N.

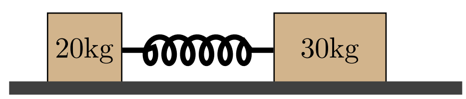


a) Determine the acceleration of each box.

b) Determine the tension in the rope connecting the boxes.

153 Connected objects separated by a spring

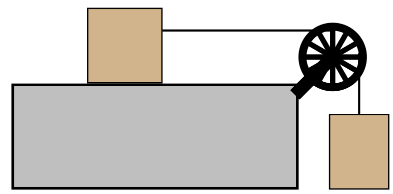
Two boxes can move along a horizontal surface. They are connected by a spring with spring constant 600 N/m. A person exerts a constant 100 N force pointing right on the box on the left. The boxes eventually move so that they maintain a fixed distance between them.



a) Determine the distance by which the spring is compressed when they move like this.

b) Suppose that the situation is repeated but a constant 100 N force is now exerted on the box on the right; this force points left. Is the compression of the spring the same as before? Explain your answer.

154 Connected objects: level/suspended blocks without friction



Two blocks are connected by a string, which runs over a massless pulley. One block, with mass m_1, is suspended and the other block, with mass m_2, can move along a frictionless horizontal surface. The string connected to the block on the surface runs horizontally. A hand exerts a constant force on the block on the surface. This force has magnitude F_{hand} and points horizontally to the left. Determine an expression for the magnitude of acceleration of the blocks, a. This should be of the form

$a =$ expression with only $m_1, m_2, g, F_{\text{hand}}$ and constants.

a) Consider the block on the horizontal and carry out the following.
   i) Draw a free body diagram for this block.
   ii) Write Newton's second law in *vector form* for this block. Rewrite this in vertical and horizontal component form. *Note: Just writing $F = ma$ is not completely correct and is too imprecise to eventually give a correct answer.*
   iii) Use the free body diagram to rewrite the component form of Newton's second law in terms of the individual forces acting on this block. Can you manipulate this to obtain

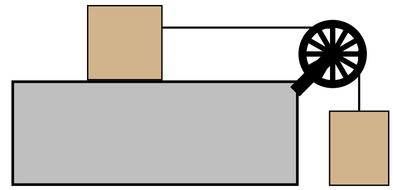
$$a = \text{formula involving only } m_1, m_2, g \text{ and constants?}$$

b) Repeat part a) for the suspended block.

c) Combine the expressions obtained for each block to obtain a single expression for the acceleration of the block on the horizontal.

155 Connected objects: Level/Suspended blocks with friction

A 6.0 kg crate is suspended from a rope which runs over a massless pulley and is connected to a 4.0 kg box, which moves right along a rough horizontal surface. The coefficient of friction between the box and surface is 0.25. The string connected to the box on the surface runs horizontally. The aim of this exercise will be to determine the acceleration of the objects, ignoring any air resistance.



a) Draw a free body diagram for the *box on the surface.*

b) Write Newton's Second Law in component form for the *box on the surface,* i.e. write

$$F_{\text{net }x} = \Sigma F_x = \cdots \quad (17)$$

$$F_{\text{net }y} = \Sigma F_y = \cdots \quad (18)$$

Insert as much information as possible about the components of acceleration at this stage. The resulting equations will generate much of the algebra that follows.

c) List all the components of all the forces for the box on the surface.

$$F_{gx} = \cdots$$
$$F_{gy} = \cdots$$
$$n_x = \cdots$$
$$n_y = \cdots$$
$$\vdots$$

Force	x comp	y comp
$\vec{\mathbf{F}}_g$		
$\vec{\mathbf{n}}$		
$\vdots$		

d) Use Eqs. (17) and (18) and the components to obtain an equation relating the tension in the rope and the acceleration of the box. Can you solve this for acceleration at this stage?

e) Repeat parts a) to d) for the *suspended crate.* Be careful about the acceleration!

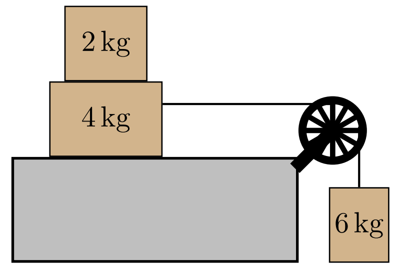
f) Combine the equations for the two objects to obtain the acceleration and the tension in the rope.

The analysis can be performed for objects of any mass. Let m_1 be the mass of the block on the surface, m_2 the mass of the suspended block and μ_k be the coefficient of friction between the block and the surface.

g) Determine an expression for the magnitude of acceleration of the blocks, a. This should be of the form

$$a = \text{formula with only } m_1, m_2, g, \mu_k \text{ and constants.}$$

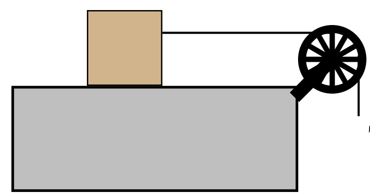
156 Stacked objects on a surface connected to a suspended object

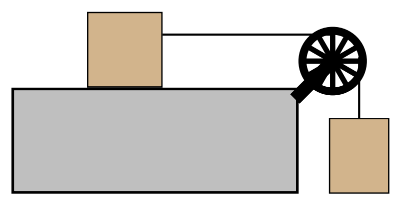


Various boxes are arranged as illustrated. The 4 kg block lies on a table with a horizontal surface.

a) Suppose that all the blocks are at rest. Is there a friction force between the 4 kg block and the table? If so, in which direction? Explain your answer.
b) Suppose that all the blocks are at rest. Is there a friction force between the 2 kg block and the 4 kg block? If so, in which direction? Explain your answer.
c) Suppose that the block on the table accelerates to the right and the 2 kg block does not slip relative to the 4 kg block. Is there a friction force between the 2 kg block and the 4 kg block? If so, in which direction? Explain your answer.

157 Connected objects: block dragged along a surface

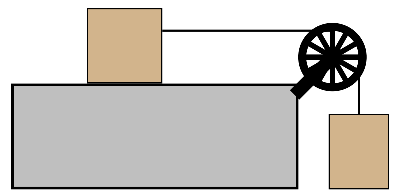




A block on a surface can be dragged along a frictionless surface by a connecting rope in two ways. Either a person exerts a force on the rope or else a suspended block exerts a force on the rope. Suppose that the person exerts a 50 N tension force on the rope and that the weight (gravitational force on) of the suspended block is exactly 50 N. In which case is the acceleration of the block on the horizontal surface largest? Explain your answer.

158 Dynamics of connected objects; level/suspended blocks without friction

Two blocks are connected by a string, which runs over a massless pulley. A 10 kg block is suspended and a 5.0 kg block can slide along a frictionless horizontal surface. The string connected to the block on the surface runs horizontally. The blocks held at rest and then released. They move, constantly speeding up. Which of the following is true regarding the tension in the connecting string, T, while they move? Explain your choice.



i) $T = 0$.

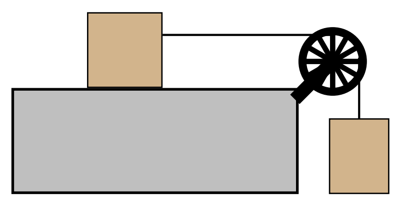
ii) $98\,\mathrm{N} > T > 0$.

iii) $T = 98\,\mathrm{N}$.

iv) $T > 98\,\mathrm{N}$

159 Dynamics of connected objects; box dragged along a rough surface

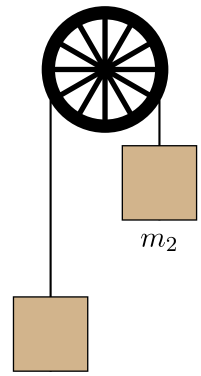
A small box, with mass m, is connected to a suspended mass, with mass $3m$, by a string, which runs over a massless pulley. The box can slide along a rough horizontal surface. The coefficient of static friction is μ_s and the coefficient of kinetic friction is μ_k, where $\mu_k < \mu_s$.



a) Determine an expression for the minimum coefficient of static friction such that the box does not move.

b) The box is given a brief push to the left and it begins to move. Determine an expression for the acceleration of the box *after* this brief push and while it is moving.

160 Atwood's machine



Two blocks, with masses indicated, are connected by a string which runs over a massless pulley. Use the following steps to determine an expression for the magnitude of acceleration of the blocks, a. This should be of the form

$$a = \text{formula involving only } m_1, m_2, g \text{ and constants.}$$

The *entire collection* of these steps is called "applying Newton's laws of mechanics to determine the acceleration of the blocks."

a) Consider the block on the left and carry out the following.
   i) Draw a free body diagram for the block on the left.
   ii) Write Newton's second law in *vector form* for the block on the left. Rewrite this in vertical and horizontal component form. *Note: Just writing $F = ma$ is not completely correct and is too imprecise to eventually give a correct answer.*
   iii) Use the free body diagram to rewrite the component form of Newton's second law in terms of the individual forces acting on the block on the left. Can you manipulate this to obtain

$$a = \text{formula involving only } m_1, m_2, g \text{ and constants?}$$

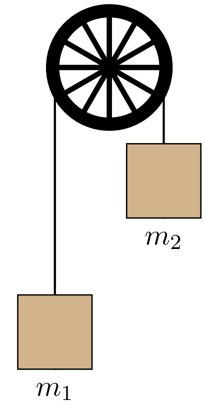
b) Repeat part a) for the block on the right. Is the acceleration of the two blocks exactly the same? If not, how are the accelerations related? Convert this into a simple algebraic relationship. *Note: You should be convinced that it cannot be correct to use the same symbol to represent the vertical component of acceleration for each block.*

c) Combine the expressions obtained for each block to obtain a single expression for the vertical component of the acceleration of the block on the left. Use this to obtain an expression for the magnitude of acceleration of each block.

161 Atwood's machine variation

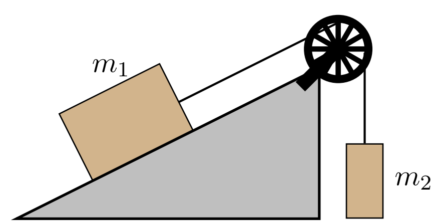
Two blocks, with masses indicated, are connected by a string which runs over a massless pulley. A hand exerts a constant downward force with magnitude F_{hand} on the block on the left. Determine an expression for the magnitude of acceleration of the blocks, a. This should be of the form

$$a = \text{formula involving only } m_1, m_2, g, F_{\text{hand}} \text{ and constants.}$$



162 Connected objects: ramp

A block on a rough ramp is connected via a string to another suspended block. At one instant the block on the ramp is sliding up the ramp.



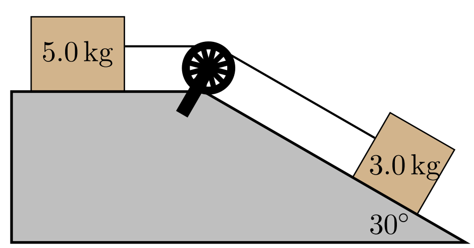
a) Determine an expression for the acceleration of the block on the ramp if the ramp is inclined at an angle of 65° above the horizontal, the mass of the block on the ramp is 8.0 kg, the mass of the suspended block is 9.0 kg and the coefficient of kinetic friction is 1.2. Does the block on the ramp speed up or slow down?

b) Determine a general expression for the acceleration of the block moving up the ramp if the ramp is inclined at an angle of θ above the horizontal and the coefficient of kinetic friction is μ_k.

c) What condition must the masses satisfy for the block to speed up as it ascends the ramp?

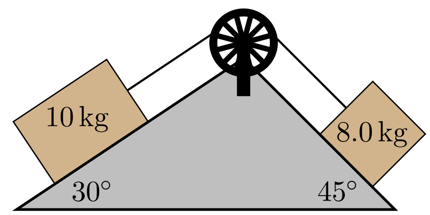
163 Connected objects: horizontal and a ramp

Blocks connected by a massless string are able to slide on the illustrated frictionless surfaces. The strings run parallel to the surfaces. Determine the acceleration of the block on the ramp.



164 Connected objects: two ramps

Blocks connected by a massless string are able to slide on two frictionless ramps.

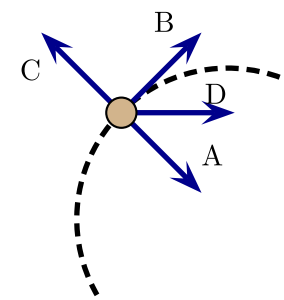


a) Determine the acceleration of the blocks.

b) Suppose that the block on the right were replaced by another block so that the two blocks slide with constant speed. What would the mass of the block on the right be?

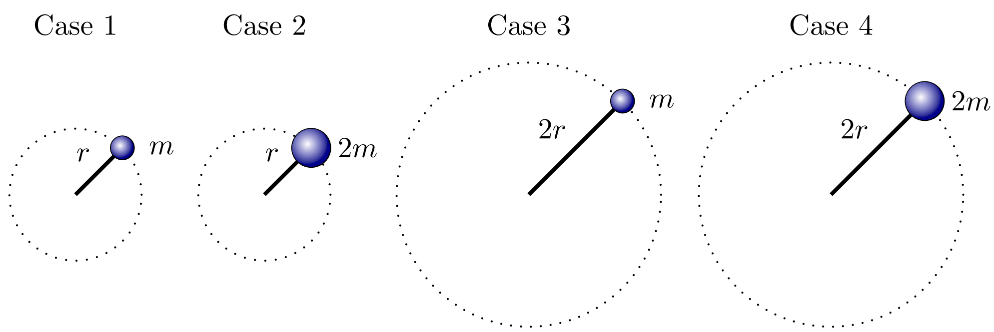
165 Bug walking in a circle

A bug walks at a constant speed in a circular path on a horizontal surface. Which vector best illustrates the net force on the bug at the illustrated moment? Explain your choice.



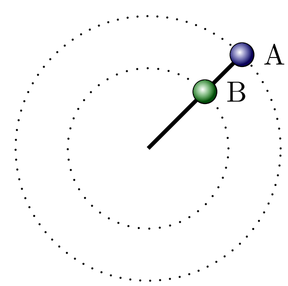
166 Balls swinging on the end of strings

Various balls at the end of strings swing in circles, with the same speed, on a horizontal frictionless surface. The diagram illustrates this as viewed from above. Rank the cases in order of increasing tension in the string. Explain your answer.



167 Connected balls swinging in horizontal circles, 1

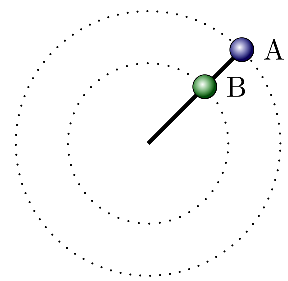
Two balls are connected by strings. They are on a horizontal frictionless surface and swing in horizontal circles about a central point; both strings point radially outward from the center as the balls move. The diagram illustrates this as viewed from above.



a) Draw a free body diagram, as viewed from the side, for ball B at the moment when the balls are at the leftmost location of their motion.
b) Draw the direction of the net force on the ball B at the moment when the balls are at the leftmost location of their motion.
c) How does the tension in the inner string compare (larger, smaller, same) to that in the string connecting the two balls? Explain your answer.

168 Connected balls swinging in horizontal circles, 2

Two balls are connected by strings. They are on a horizontal frictionless surface and swing in horizontal circles about a central point; both strings point radially outward from the center as the balls move. The diagram illustrates this as viewed from above.



a) Suppose that A has a larger mass than B. Is the tension in the inner string the same as, larger than or equal to the tension in the outer string? Explain your answer.

b) Suppose that A has a smaller mass than B. Is the tension in the inner string the same as, larger than or equal to the tension in the outer string? Explain your answer.

c) In which arrangement (larger mass on the outside, smaller mass on the outside) will the tension in the outer string be larger? Assume that both arrangements swing with the same speed. Explain your answer.

169 Child swinging on ice

A parent and child are each on a horizontal sheet of ice. The parent is fixed to the ice and swings the child, who is connected by a horizontal rope to the parent. The child slides without any friction with constant velocity. Determine an expression for the tension in the rope in terms of the mass of the child, the length of the rope and the angular velocity of the child.

170 Particle accelerator

The Large Hadron Collider (LHC) accelerates subatomic particles and then lets them collide with a target. During this trip the particles move through a circular tunnel with radius 2.80 km. One type of particle use in the LHC is a proton. Suppose that a proton travels this circle at 10% of the speed of light. Determine the net force on the proton. *Note: to be strictly correct this needs to include the effects of special relativity. The approach here will give an approximate force.*

171 Rotating Earth

Earth rotates, completing one rotation in a day (86400 s). Suppose that you stand on a scale at sea level at Earth's equator; the scale measures the normal force that it exerts and converts it into a reading in kilograms by dividing by $9.81\,\mathrm{m/s^2}$. In the following ignore air resistance.

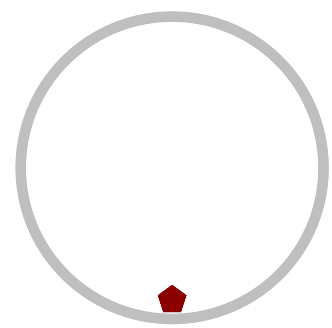
a) Explain why the force measured by the scale will not equal the gravitational force exerted by Earth.

b) Assuming that your mass is 70.0 kg, determine the normal force and the scale reading.

c) Suppose that Earth's rotation were to speed up. How will this affect the scale reading?

d) If Earth were able to speed up determine the time for one rotation such that the scale would read zero. What would happen to you if you were standing on the scale and Earth continued to speed up beyond this threshold?

172 Science fiction space station



A science fiction movie features a space station which is essentially a giant circular hoop. People and objects reside on the inside of the hoop. The hoop rotates at a constant rate.

a) Consider an object with mass m at rest relative to the surface of the space station floor. Determine an expression for the normal force exerted by the floor in terms of the radius and the time taken to complete one orbit.

b) The floor will feel the same as Earth's surface if the normal force equals mg. Determine an expression for the time taken to complete one orbit so that this is true.

c) Image a space station with a radius of 5.0 km. Determine the time it should take to complete one rotation so that the space station floor feels like Earth's surface.

173 Car turning

A 3000 kg car travels along a flat (horizontal) road. The road curves with a radius of 350 m. The maximum speed with which the car can do the turn is 18 m/s.

a) Determine the net force on the car. What force provides the net force?

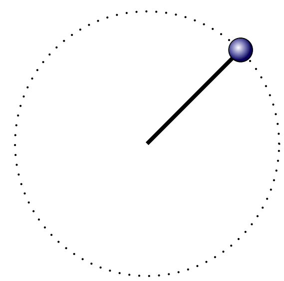
b) Determine the (minimum) coefficient of static friction that allows the car to follow this curve at the given speed.

174 Coin on a turntable

A coin with mass m sits on a horizontal turntable with radius R. The distance from the turntable axle to the coin is d. The coefficient of static friction between the coin an the turntable is μ_s and the coefficient of kinetic friction is μ_k. The turntable is initially at rest and slowly speeds up. Determine an expression for the maximum angular velocity of the turntable so that the coins does not slip.

175 Ball swinging in a vertical circle

A 0.20 kg ball swings with in a vertical circle at the end of a 0.50 m long string.



a) Draw a free body diagram for the ball at the highest point of the circle. Draw a free body diagram at the lowest point.

b) Suppose that the speed of the ball is constant throughout its motion. How does net force at the highest point of the circle compare (larger, smaller, same) to that at the lowest point of the circle? Use you answer to compare (larger, smaller, same) the tension in the string at the lowest point of the circle to the tension at the highest point of the circle.

c) Suppose that the string will break if the tension in it exceeds 5.0 N. Use Newton's second law to analyze the situation where the tension is largest (i.e. highest or lowest point) and determine the maximum speed with which the ball can move so that the string does not break.

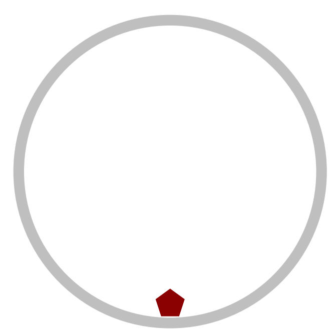
d) In general the speed of the ball can vary as it swings. As the speed decreases does the tension at the top of the circle increase, decrease or stay constant? Determine the minimum speed so that the tension is not zero. Describe what happens if the speed drops beneath this.

176 Monkey on a rope

A monkey with mass m_{monkey} swings from a rope. Is the tension in the rope at the bottom of the swing larger than, smaller than or the same as $m_{\text{monkey}}g$? Explain your answer.

177 Sliding inside a hoop

A small 0.10 kg object slides around the inside a frictionless vertical hoop with radius 0.25 m.



a) The speed of the object at the top of the hoop is 2.0 m/s. Determine the normal force exerted by the hoop on the object at the top of the loop.

b) The object reaches the bottom of the hoop with speed 3.71 m/s. Determine the normal force exerted by the hoop on the object at the bottom of the loop.

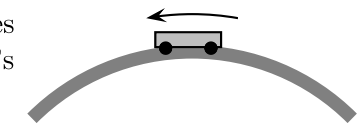
c) Determine the minimum speed at the top of the loop so that the object stays on the inside surface of the loop.

178 Loop-the-loop

A 50 g ball slides, without rolling, inside a vertically oriented circular loop with radius 80 cm. In two different situations, the ball is set into motion so that its speed is i) 4.0 m/s and the top of the loop and ii) 4.0 m/s and the bottom of the loop. Determine the normal force exerted by the loop on the ball in each case.

179 Roller coaster on circular tracks

A roller coaster with mass m moves along a track that makes a vertically oriented circle with radius R. At one moment it passes along the outside of the track at the top, as illustrated. The cart's speed at the top of the track is $v > 0$.



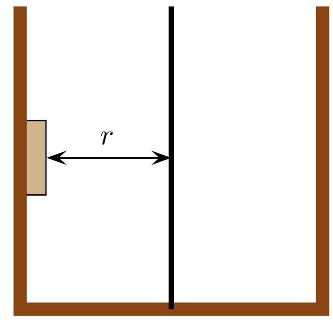
a) Determine an expression for the normal force exerted by the track on the cart at the top of the loop. Assume that the cart has no mechanism for "grabbing" the track.

b) Determine an expression for the maximum speed which the cart can have so that it will stay on the track without a "grabbing" mechanism that keeps it on the track.

c) For an actual roller coaster, use this analysis to estimate the maximum speed so that the cart will stay on the track without a "grabbing" mechanism. Provide any data that you need to supply to do the estimate.

180 Block inside a revolving drum

A spinning drum has vertical wooden sides. A wooden block block is placed inside the drum and the drum is eventually made to spin with a constant angular velocity. This is done is such a way that the block does not slide relative to the drum; it rotates at the same rate as the drum. In the first part of the problem suppose that the mass of the block is 2.0 kg, the coefficient of static friction is 0.60 and the radius of the drum is 0.80 m.



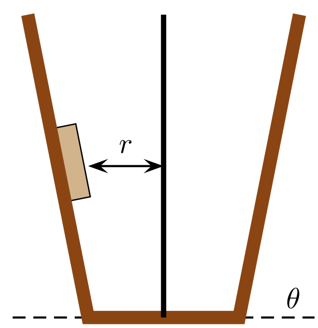
a) Draw a free body diagram for the block, identify the direction of the acceleration and write Newton's 2nd law in component form. Is $n = mg$ in this case?

b) Determine an expression for the minimum angular velocity with which the drum must rotate so that the block does not slip.

Now consider the more general case where the drum has radius r and the coefficient of static friction is μ_s.

c) Determine an expression for the minimum angular velocity (in terms of g, r and μ_s) so that the block does not slip. Does it depend on the mass of the block?

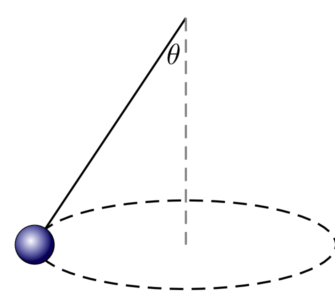
Now suppose that the spinning drum has tilted sides. A block is placed inside the drum and the drum is eventually made to spin with a constant angular velocity ω. This is done is such a way that the block does not slide relative to the drum; it rotates at the same rate as the drum. Let r be the distance from the block to the axle of the drum.



d) Determine the minimum angular velocity required for the block not to slip when $\theta = 75°$, $r = 2.5$ m and the coefficient of static friction is 0.2.

181 Conical pendulum

A ball with mass m swings with a constant speed at the end of a string with length L. The angle between the string and the vertical, θ, is constant.



a) Determine an expression for the tension in the string in terms of m, θ and constants.

b) Determine an expression for the speed of the ball in terms of m, θ, L and constants.

c) Determine an expression for the angular velocity of the ball in terms of m, θ, L and constants.

d) Determine an expression for the period of orbit of the ball in terms of m, θ, L and constants.

182 Banked turn on a road

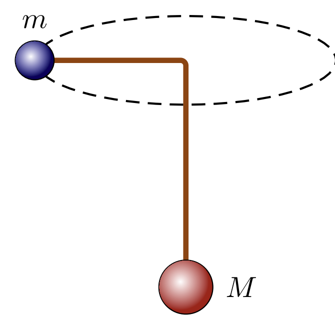
A road is constructed with a turn of radius 300 m. The surface of the road is banked at an angle in order to assist cars to make the turn. A car travels through this turn with constant speed of 35 m/s (about 80 mph).

a) Suppose that there is no friction between the tires and road. Determine the angle at which the road must be banked so that the car can complete the turn without slipping.

b) There usually is friction between the tires and road. For wet concrete and rubber the coefficient of static friction is 0.30 and the coefficient of kinetic friction is 0.20. Determine the minimum angle at which the road must be banked so that the car completes the turn without slipping.

183 Connected balls

A ball with mass m swings at the end of a string on a horizontal frictionless surface. The string runs through a hole in the surface and another ball with mass M is connected to it. Determine an expression for mass of the suspended ball such that the ball on the table swings in a circle with constant speed v and constant radius R.



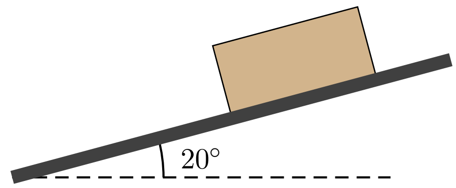
a) Determine an expression (in terms of m, R, v and g) for mass of the suspended ball such that the ball on the table swings in a circle with constant speed v and constant radius R.

b) Determine an expression for the time for one orbit (in terms of m, R, M and g) such that the ball on the table swings in a circle with constant speed and constant radius R.

Additional Dynamics Questions

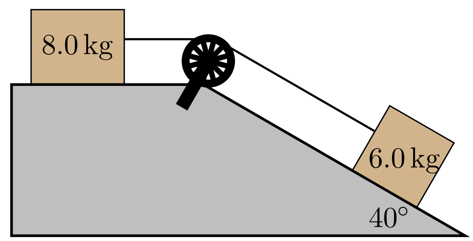
184 Crate pushed up a rough ramp

A 12 kg crate can slide up or down a ramp at angle 20° from the horizontal. The coefficient of kinetic friction between the crate and the ramp is 0.40. A hand pushes with a 120 N force parallel to the ramp in the uphill direction. Determine the crate's acceleration if it slides up the ramp.



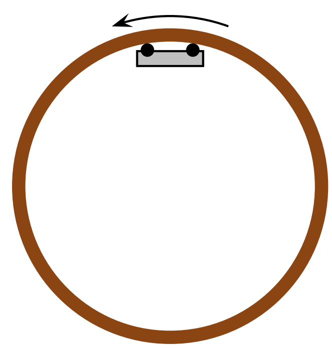
185 Connected objects: horizontal and a rough ramp

Blocks connected by a massless string are able to slide on the illustrated surfaces. The strings run parallel to the surfaces. The horizontal surface is frictionless and the ramp has coefficient of kinetic friction 0.50. Determine the acceleration of the block on the ramp if it descends.



186 Roller coaster inside a circular loop

Two identical roller coasters cars, A and B, each move along a track that makes a vertically oriented circle with radius R. Each passes along the inside of the track at the top and is in contact with the track at this point. The speed of A is larger than the speed of B. Determine whether the normal force on A is the same as, smaller than or larger than the normal force on B.



Work and Energy

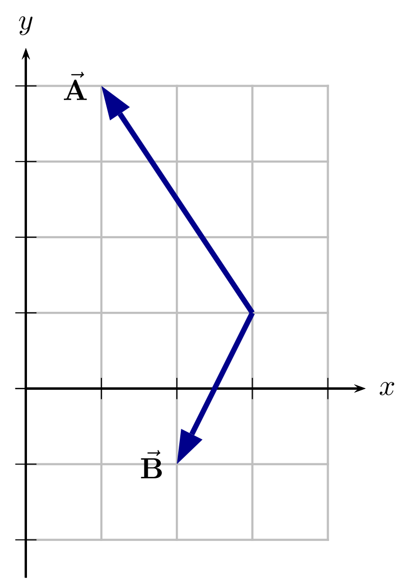
187 Vectors: dot products, algebraic

For each of the following, determine A_x, A_y, B_x, B_y and A_z and B_z (if applicable) and determine the dot product, $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}}$. *Note: If your answer for the dot product contains* $\hat{\mathbf{i}}$ *and* $\hat{\mathbf{j}}$ *then it is very incorrect! (131F2022)*

a) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$.
b) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}}$.
c) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$.
d) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}}$.
e) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}} + 3\hat{\mathbf{k}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$.
f) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}} + 3\hat{\mathbf{k}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}}$.
g) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}} + 3\hat{\mathbf{k}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}} + 3\hat{\mathbf{k}}$.
h) $\vec{\mathbf{A}} = 1\hat{\mathbf{i}} - 2\hat{\mathbf{j}} + 3\hat{\mathbf{k}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} + 1\hat{\mathbf{j}} - 3\hat{\mathbf{k}}$.

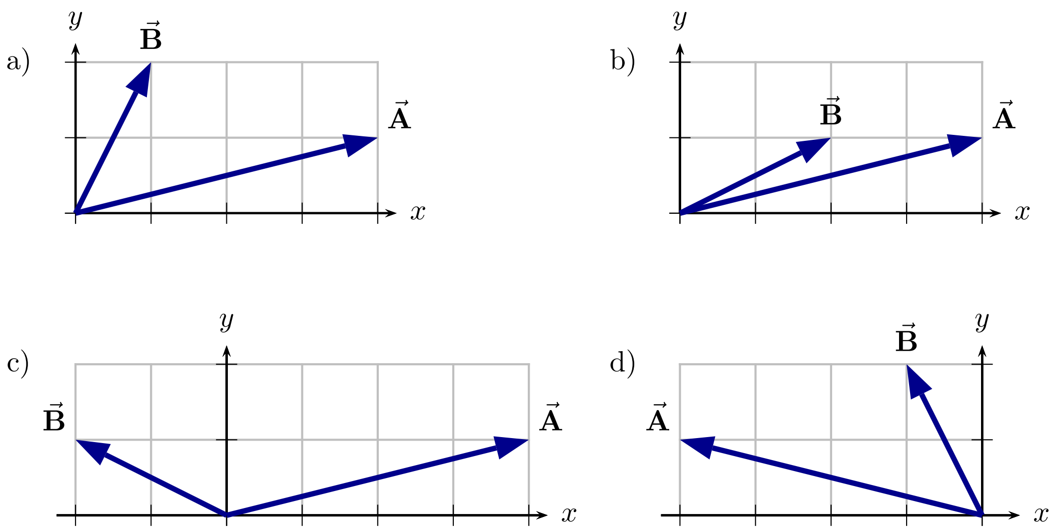
188 Dot product of two vectors, graphical

Determine $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}}$ for the illustrated vectors. *(131F2022)*



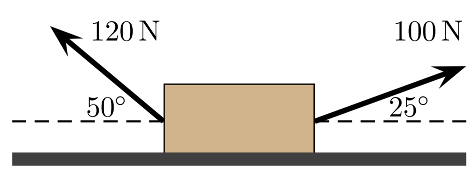
189 Vectors: dot products, graphical 2

For each of the following, express $\vec{\mathbf{A}}$ in component form $\vec{\mathbf{B}}$ using unit vectors and determine the dot product, $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}}$. *Note: If your answer for the dot product contains* $\hat{\mathbf{i}}$ *and* $\hat{\mathbf{j}}$ *then it is very incorrect! (131F2022)*



190 Work done on a crate

A 20 kg crate moves along a horizontal frictionless surface. One person pulls up on the crate from the right and another pulls up on the left as illustrated. The crate is initially at rest and subsequently slides right for 5.0 m. *(131F2022)*



a) Determine the work done by each of the following forces: gravity, normal force, and the forces exerted by the two people.

b) Determine the net work done on the crate.

191 Raising an elevator

An elevator is raised by a cable and slows to a stop. *(131F2022)*

a) While the elevator slows is the work done by the tension in the cable positive, negative or zero? Explain your answer.

b) While the elevator slows is the magnitude of the work done by tension larger than, smaller than or the same as the magnitude of the work done by gravity? Explain your answer.

192 Object sliding down a ramp

A 4.0 kg box slides down a ramp that makes and angle of 20° from the horizontal. The length of the ramp is 3.0 m. *(131F2022)*

a) Determine the work done by gravity as the box slides all the way down the ramp from the top to the bottom.

b) Determine the work done by the normal force as the box slides all the way down the ramp from the top to the bottom.

193 Cart sliding up and down a ramp

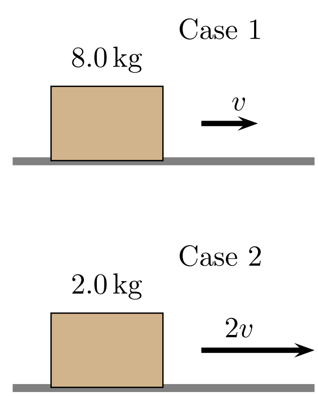
A cart approaches a ramp. The cart slides up the ramp, reverses direction and then slides down. *(131F2022)*

a) Consider the segment of the motion where the cart slides up the ramp. Is the work done by gravity positive, negative or zero? Explain your answer.

b) Consider the segment of the motion where the cart slides down the ramp. Is the work done by gravity positive, negative or zero? Explain your answer.

194 Kinetic energy

Two boxes on move on a frictionless horizontal surface. The speed of the box in case 2 is twice the speed of the box in case 1. Let K_1 be the kinetic energy of the block in Case 1 and K_2 be the kinetic energy of the block in Case 2. Which of the following is true? Explain your answer. *(131F2022)*



i) $K_1 = \dfrac{1}{4} K_2$

ii) $K_1 = \dfrac{1}{2} K_2$

iii) $K_1 = K_2$

iv) $K_1 = 2K_2$

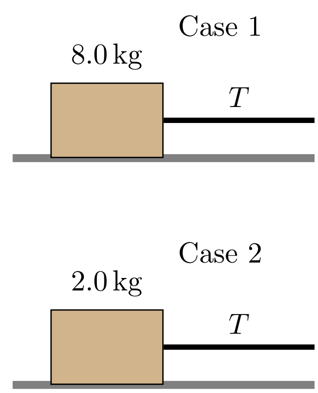
v) $K_1 = 4K_2$

195 Molecular kinetic energy

The average kinetic energy of molecules in a gas only depends on the temperature of the gas *(side note: this is about translational kinetic energy only)*. Consider a gas of helium molecules (each Helium molecule consists of just one Helium atom) and a gas of Neon molecules (each Neon molecule consists of one Neon atom). Suppose that these gases are both at the same temperature. For these gases how does the typical speed of the Helium molecules compare (same, smaller, larger, . . .) to that of the Neon molecules. *(131F2022)*

196 Pulling a box: energy and speed

Two boxes on a frictionless horizontal surface are initially at rest. Both are pulled by a rope with the same tension for the same distance. *(131F2022)*



a) Let K_1 be the kinetic energy of the block in Case 1 after it has been pulled through distance d. Let K_2 be the kinetic energy of the block in Case 2 after it has been pulled through distance d. Which of the following is true? Explain your answer.

i) $K_1 = \frac{1}{4} K_2$

ii) $K_1 = \frac{1}{2} K_2$

iii) $K_1 = K_2$

iv) $K_1 = 2K_2$

v) $K_1 = 4K_2$

b) Let v_1 be the speed of the block in Case 1 after it has been pulled through distance d. Let v_2 be the speed of the block in Case 2 after it has been pulled through distance d. Which of the following is true? Explain your answer.

i) $v_1 = \frac{1}{4} v2$

ii) $v_1 = \frac{1}{2} v_2$

iii) $v_1 = v_2$

iv) $v_1 = 2v_2$

v) $v_1 = 4v_2$

197 Energy, distance and speed

A rock is initially at rest on a horizontal sheet of ice. Alice pushes the rock with a constant horizontal force. The rock moves in a straight line, first passing Bob who is 5.0 m from the initial location and then Carol, who is 5.0 m from Bob. *(131F2022)*

a) Let ΔK_1 be the change in the rock's kinetic energy from its initial location until it reaches Bob. Let ΔK_2 be the change in the rock's kinetic energy from the moment it passes Bob until it reaches Carol. Which of the following is true? Explain your answer.

   i) $\Delta K_2 < \Delta K_1$

   ii) $\Delta K_2 = \Delta K_1$

   iii) $\Delta K_2 > \Delta K_1$

b) Let v_1 be the rock's speed as it reaches Bob. Let v_2 be the rock's speed as it reaches Carol. Which of the following is true? Explain your answer.

   i) $v_2 = v_1$

   ii) $\sqrt{2}v_1 > v_2 > v_1$

   iii) $v_2 = \sqrt{2}v_1$

   iv) $v_2 = 2v_1$

   v) $v_2 > 2v_1$

198 Barge in a canal

A barge can move along a straight canal. The barge is pulled by a donkey that walks along the bank of the canal. A rope connects the donkey to the barge. The donkey pulls the barge in a straight line for a distance of 750 m. *(131F2022)*

a) Suppose that the rope makes an angle of 15° from the forwards direction of the barge's motion and the the donkey exerts a constant force of 275 N on the barge. Determine the work done by the donkey.

b) Now suppose that the rope length is changed and the result is that the rope makes an angle of 8.0° from the forwards direction of the barge's motion. Determine the force that must be exerted by the donkey so that it does the same work as it had done previously.

199 Crate sliding down a frictionless ramp

A 6.00 kg crate is at rest at the top of a frictionless ramp that is inclined at 25° from the horizontal. The length of the ramp is 3.00 m. Use work and energy to answer the following questions. *(131F2022)*

a) The crate is released. Determine the net work done on the crate as it moves from the top to the bottom of the ramp.

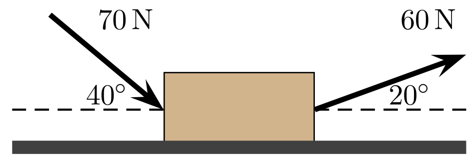
b) Use the net work to determine the speed of the block as it reaches the bottom of the ramp.

200 Crate lowered down a frictionless ramp

A 20.0 kg crate is at rest at the top of a frictionless ramp that is inclined at 30° from the horizontal. The length of the ramp is 5.00 m. A rope pulls on the crate with a 70.0 N force parallel to and up the ramp. Use work and energy to determine the speed of the crate when it reaches the bottom of the ramp. *(131F2022)*

201 Pushing a crate across a rough floor

A 10 kg crate can move across a rough horizontal floor. One person pulls up on the crate from the right and another pushes down as illustrated. The crate is initially at rest and subsequently slides right for 5.0 m. The coefficient of kinetic friction between the crate and floor is 0.20. *(131F2022)*



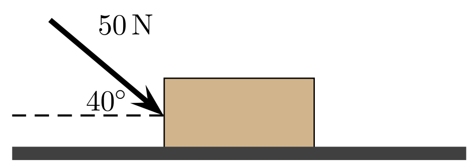
a) Determine the friction force on the crate.

b) Determine the work done by each of the following forces: gravity, normal force, friction force and the forces exerted by the two people.

c) Determine the speed of the crate at the moment that it has moved 5.0 m from its original location.

202 Pushing a crate at a constant speed along a rough floor

A worker pushes a crate a distance of 6.0 m along a rough horizontal surface. The crate moves with a constant speed. *Use work* to determine the frictional force acting on the cart. *(131F2022)*



203 Sliding hockey puck

A 0.150 kg hockey puck slides along a horizontal surface. Initially the surface is frictionless and the puck slides with speed 18 m/s. The puck then hits a rough section of floor which provides a constant friction force. The puck stops a distance of 2.5 m after hitting the rough section. *(131F2022)*

a) Determine the net work done on the puck as it moves across the rough section. *Hint: consider kinetic energy.*

b) Use the net work to determine the magnitude of the friction force acting on the puck.

c) Determine the coefficient of kinetic friction between the puck and the floor.

204 Work done by a string

A ball swings in a circle at the end of a string. Which of the following is true? Explain your answer. *(131F2022)*

i) The string does positive work on the ball whenever the ball speeds up and negative work on the ball whenever it slows down.
ii) The string does positive work on the ball regardless of its speed.
iii) The string does negative work on the ball regardless of its speed.
iv) The string does zero work on the ball regardless of its speed.

205 Spring forces

A 5.0 kg bag is suspended by a spring from the ceiling of an elevator. The spring constant is 4000 N/m. *(131F2022)*

a) The elevator and spring move up with a constant speed of 0.50 m/s. Determine the amount by which the spring is stretched.
b) The elevator and bag accelerate upwards with an acceleration of $3.0\,\mathrm{m/s^2}$. Determine the amount by which the spring is stretched.

206 Monkey on a vertical spring

A monkey hangs from a spring which is attached to the ceiling of a building. The spring hangs vertically and the monkey bounces up and down without touching the floor. *(131F2022)*

a) As the monkey ascends toward and nears its highest point, the spring is compressed. Which of the following is true while this happens?
    i) The spring does positive work, gravity does positive work.
    ii) The spring does positive work, gravity does negative work.
    iii) The spring does negative work, gravity does positive work.
    iv) The spring does negative work, gravity does negative work.
b) As the monkey begins to descend away its highest point, the spring is still compressed. Which of the following is true while this happens?
    i) The spring does positive work, gravity does positive work.
    ii) The spring does positive work, gravity does negative work.
    iii) The spring does negative work, gravity does positive work.
    iv) The spring does negative work, gravity does negative work.

207 Oscillating block

A 6.0 kg block can slide along a frictionless table. It is attached to a spring with spring constant 30 N/m. The block is pulled 0.20 m from the spring's equilibrium position. The block oscillates. *(131F2022)*

a) Describe whether you can use constant acceleration kinematics to predict the block's speed as it passes the equilibrium point.

b) Determine the speed of the box as it passes the equilibrium point.

208 Work done by a spring

A 20 kg box on a rough horizontal floor is pushed against a spring with constant 800 N/m. The spring is compressed by 0.10 m. The coefficient of kinetic friction between the box and floor is 0.15. The box departs from the spring when the spring reaches its equilibrium state. *(131F2022)*

a) Determine the work done by the friction force on the box from the point of release until the box departs.

b) Determine the work done by spring on the box from the point of release until the box departs.

c) Determine the speed of the box at the point of departure.

d) Is the acceleration of the box constant during this process? Could you use constant acceleration kinematics and Newton's second law to determine the speed of the box at the point of departure.

209 Power delivered by engines

Two engines pull identical objects along horizontal surfaces. Engine A delivers 2000 W of power and engine B delivers 4000 W. Engine A pulls for 5 min and engine B for 2 min. Which of the following is true? Explain your answer. *(131F2022)*

i) Engine A delivers more work than engine B.

ii) Engine A delivers less work than engine B.

iii) Engine A delivers the same work as engine B.

iv) There is not enough information to decide.

210 Hoisting fish

King Zog and Queen Geraldine are fishing from a bridge and they catch identical twin fish, each with mass 5.0 kg. They hoist the fish at constant speeds to the bridge 8.0 m about the water. Zog takes 10 s to hoist his fish and Geraldine 7.5 s to hoist her fish. *(131F2022)*

a) Which of the following is true? Explain your answer.

   i) Zog and Geraldine do the same work.
   ii) Zog does more work than Geraldine.
   iii) Zog does less work than Geraldine.

b) Which of the following is true? Explain your answer.

   i) Zog and Geraldine expend the same power.
   ii) Zog expends less power.
   iii) Zog expends more power.

211 Solar energy

The Sun delivers energy in the form of electromagnetic waves to Earth. At the outer edge of Earth's atmosphere, the total power per square meter *(the solar irradiance)* is $1360\,\mathrm{W/m^2}$. This is diminished at Earth's surface by the atmosphere and depends on the angle of the Sun. At some location it is reduced to $1050\,\mathrm{W/m^2}$. *(131F2022)*

a) A satellite uses solar panels to gather energy. If the satellite requires 10 kW of power, what would the necessary area of its solar panels be (assuming that the panels are 100% efficient)?

b) Suppose that a solar plant on Earth is required to provide 5.0×10^9 J of energy per hour. Determine the area of the Earth's surface that the solar panels would have to cover if they are only 25% efficient.

212 Raising an elevator

An 2000 kg elevator is lifted by a cable attached to a motor. It moves at a constant speed through a vertical distance of 25 m. It takes 75 s to do this. *(131F2022)*

a) Determine the work done by gravity as the elevator is lifted.

b) Determine the work done by the cable as the elevator is lifted.

c) Determine the power delivered by the motor as it raises the elevator.

d) Suppose that the elevator were raised through the same distance and starting at the same speed but with the speed decreasing at a constant rate as it ascends. How would the magnitude of the work done by the cable compare (larger, smaller,...) to that done by gravity? Explain your answer using physics. What would this imply for the power delivered by the motor compared to the situation where the elevator is raised at a constant speed?

213 Cannonball energy

Two identical cannonballs are fired from the ground with the same speed. Cannonball Y is fired vertically upward while cannonball Z is fired at an angle of 60° above the horizontal. Consider the highest points reach by the cannonballs. *(131F2022)*

a) Explain which cannonball has the largest kinetic energy at its highest point.

b) Explain which cannonball has the largest gravitational potential energy at its highest point.

214 Energy and Projectiles

A 15 kg cannonball is fired, leaving the ground with speed 30 m/s. We aim to determine the speed of the cannonball when it reaches a height of 25 m above the ground. *(131F2022)*

a) Sketch the situation showing the trajectory of the cannonball. Indicate an "initial" and a "final" moment.

b) Determine the total energy at the moment that the cannonball is launched.

c) Determine the total energy when the cannonball is 25 m above the ground.

d) Determine the kinetic energy of the cannonball when it is 25 m above the ground.

e) Determine the speed of the cannonball when it is 25 m above the ground.

215 Cart and ramp

A 20 kg cart is launched with speed 4.0 m/s at the base of a frictionless ramp. Determine the maximum vertical height that the cart ascends as it moves up the ramp. *(131F2022)*

216 Sledding

King Zog, with mass 160 kg, and Queen Geraldine, with mass 80 kg, sled down an icy hill. They start from rest at the same point above the bottom of the hill. Ignore friction and air resistance. Which of the following is true regarding their speeds at the bottom of the hill? Explain your answer. *(131F2022)*

i) Same speeds.

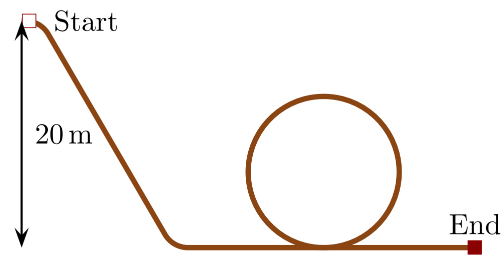
ii) Geraldine's speed is twice that of Zog.

iii) Geraldine's speed is four times that of Zog.

iv) Zog's speed is larger than Geraldine's speed.

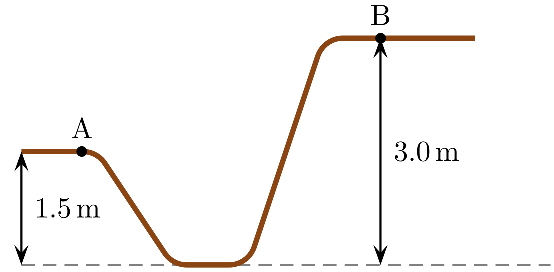
217 Loop-the-loop rollercoaster

A 100 kg rollercoaster starts from rest at the top of the illustrated track. The rollercoaster completes the loop. Determine speed of the rollercoaster at the end of the track. Ignore friction and air resistance. *(131F2022)*



218 Skate park

A skater approaches point A with speed 10 m/s. The skater slides along the illustrated track. Ignore friction and air resistance. *(131F2022)*



a) Suppose that the mass of the skater is 60 kg. Determine the speed of the skater at point B.

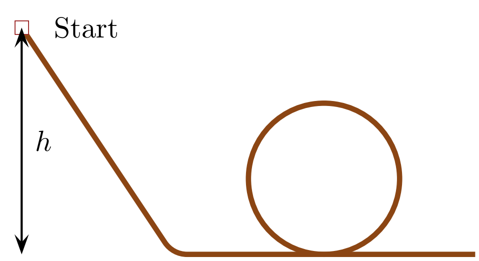
b) Determine the maximum speed of the 60 kg skater along the track.

c) Determine the minimum speed that the 60 kg skater should have at A so that she reaches B.

d) Would any of your results to the previous parts be different if the mass of the skater were different? Explain your answer.

219 Completing the loop

A cart slides down a frictionless track toward a circular loop with radius R. The cart is released from rest. *(131F2022)*

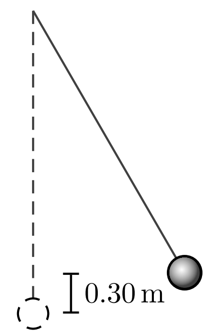


a) Determine an expression for the minimum speed for the cart at the top of the loop such that it completes the loop.

b) Determine an expression for the minimum height at which the cart should be released so that it completes the loop.

220 Pendulum

A pendulum consists of a ball that swings from a string. A 1.4 m long pendulum is raised so that it is released from rest 0.30 m above its lowest point. Determine the maximum speed of the pendulum. *(131F2022)*



221 Swinging monkey

A monkey grabs a 3.0 m rope and swings in a circular arc. The monkey reaches a maximum speed of 8.0 m/s. Determine the maximum angle (from the vertical) reached by the monkey as it swings. *(131F2022)*

222 Tarzan

Tarzan, with mass 80 kg, grabs a 5.0 m rope and swings in a circular arc. As Tarzan begins to swing the rope is at an angle of 35° from the vertical. Determine Tarzan's maximum speed. *(131F2022)*

223 Spring bumper

Two walruses (named X and Y), with the same masses, slide along horizontal sheets of ice. Each collides with a horizontal spring mounted to a wall; the springs are identical. Prior to hitting the spring, walrus X moved with speed twice that of walrus Y. The springs compress, bringing each walrus to a stop. Which of the following is true regarding the distances by which the springs compress? Explain your answer. *(131F2022)*

i) Springs compress by the same distance.
ii) X compresses spring by twice as much Y.
iii) X compresses spring by four times as much Y.
iv) X compresses spring by half as much Y.
v) X compresses spring by a quarter of what Y compresses.

224 Bungee jumper

A 100 kg person is attached to a bungee cord and, starting at rest, jumps off a bridge that is 120 m above a river. The bungee cord behaves like a spring and the length of the cord when it is unstretched is 100 m. The spring constant of the cord needs to be such that person stops just above the river. *(131F2022)*

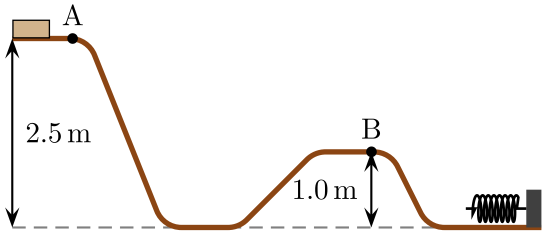
a) Determine the total energy of the system at the moment that the person jumps.

b) Determine the total energy of the system at the moment that the person stops just above the river and use the result to determine the spring constant of the bungee cord.

c) Determine the maximum force that the bungee cord exerts on this person.

d) Now suppose that a person with mass 70 kg jumps from the same bridge using the same cord. Determine the maximum stretch in the spring, the height above the river at which the person reverses direction and the maximum force exerted on the person.

225 Sled and spring bumper



A 100 kg sled moves along the illustrated track. At point A it moves right with speed 5.0 m/s. While it moves friction and air resistance can be ignored. *(131F2022)*

a) Determine the energy of the sled at point A.

b) Determine the kinetic energy of the sled when it is at point B.

c) Determine the speed of the sled at point B.

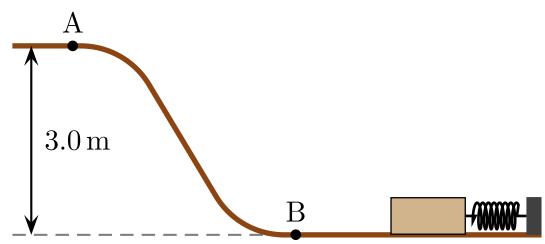
The sled approaches a spring with spring constant 5000 N/m.

d) Determine the speed of the sled just before it hits the spring.

e) Determine the maximum distance by which the spring is compressed.

f) Determine the maximum force exerted by the spring as the sled compresses it.

226 Spring-launched sled



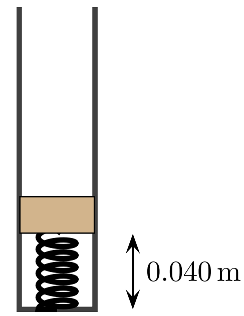
A 10.0 kg sled is pushed against a spring with spring constant 4000 N/m. The sled is held at rest while the spring is compressed by 0.45 m. It is released and then travels along the illustrated frictionless surface. *(131F2022)*

a) By the time that the sled passes point B it has left the spring. Determine the speed of the sled at point B.

b) Determine the speed of the sled at point A.

227 Spring gun

A spring gun consists of a vertical pipe with frictionless walls. A 30 g block is pushed against a spring, which is attached to the base of the pipe. In equilibrium the top of the spring is 0.050 m above the base of the pipe. The block is pushed against the spring and released from the indicated location while the pipe points vertically. *(131F2022)*



a) Determine the spring constant so that the maximum height above the base of the pipe that the block reaches is 12.00 m.

b) Determine the maximum velocity of the block.

228 Crate and ramp

A 10 kg crate is launched with speed 16 m/s at the base of a frictionless ramp that is inclined at 25° from the horizontal. Use work and energy to answer the following questions. *(131F2022)*

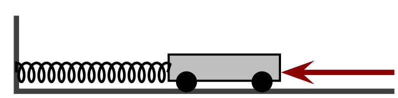
a) Ignoring air resistance, determine the distance along the ramp that the crate travels before stopping (briefly at its highest point).

b) Ignoring air resistance, determine the vertical height gained by the crate at the highest point that it reaches.

c) Suppose that the crate only travels 20 m because of air resistance that results in a force opposite to the crate's motion. Assuming that the air resistance is constant, determine the magnitude of the air resistance force.

229 Spring, cart and hand

A 5.0 kg cart can slide along a frictionless horizontal surface. A spring, with spring constant 400 N/m connects the cart to a wall. The spring is initially compressed by 0.25 m and the cart is held at rest. It is released and subsequently a hand pushes with a constant 30 N force against the spring as the spring relaxes. Determine the speed of the cart when the spring reaches its equilibrium position. *(131F2022)*



230 Spring-launched cart

A 40 kg cart can move along a horizontal surface. The cart is pushed against a spring, with spring constant 3000 N/m, compressing it by 0.35 m. It is released and begins to move right across a frictionless surface, eventually leaving the spring. After it has left the spring it enters section where there is friction. The coefficient of friction between the cart and the surface is 0.20. The cart eventually stops in this section. *(131F2022)*

a) Determine the speed of the cart at the moment that it leaves the spring.

b) Determine the distance which the cart travels from the moment that it encounters the friction until it stops. *Hint: use work and energy.*

231 Bumper cart

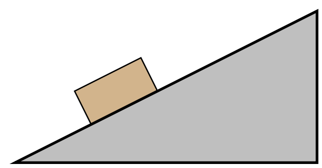
A 200 kg bumper cart can move on a rough horizontal surface. The cart is pushed against a spring, with spring constant 6000 N/m, compressing it by 0.25 m. It is released and begins to move right. The coefficient of friction between the cart and the surface is 0.20. *(131F2022)*

a) Determine the speed of the cart at the moment that it leaves the spring.

b) Suppose that while the cart moves right it is also pulled with a rope that pulls with constant tension 600 N to the right. Determine the speed of the cart when it leaves the spring.

232 Box on a rough ramp

A 5.0 kg box approaches a rough ramp, inclined at an angle of 20° above the horizontal. The box's speed at the base of the ramp is 16 m/s. The coefficient of kinetic friction between the box and ramp is 0.28. *(131F2022)*



a) Use *work and energy* to determine the distance along the ramp which the box slides before returning back down the ramp.

b) Use *work and energy* to determine the speed of the box when it reaches the bottom of the ramp again.

c) *(Challenging)* Suppose that the angle between the ramp and the horizontal is θ. Determine an expression for the minimum coefficient of friction so that the box does not reach the bottom of the ramp.

233 Work along various trajectories

A force $\vec{\mathbf{F}} = 40\,\mathrm{N}\hat{\mathbf{i}} - 30\,\mathrm{N}\hat{\mathbf{j}}$ acts on a particle. The particle could move along one of the following three trajectories given in Cartesian coordinates (x, y):

i) Path A: $(0,0) \rightarrow (2,0) \rightarrow (2,3)$

ii) Path B: $(0,0) \rightarrow (0,3) \rightarrow (2,3)$

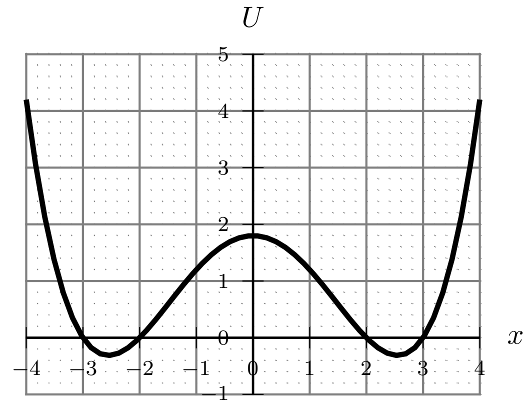
iii) Path C: $(0,0) \rightarrow (2,3)$

a) Determine the work done along each trajectory. *(131F2022)*

b) Could the force be conservative?

234 Potential and motion, 1

A particle that can move along the x axis is subjected to the potential whose graph is as illustrated (vertical axis units are J and horizontal axis units are m). *(131F2022)*

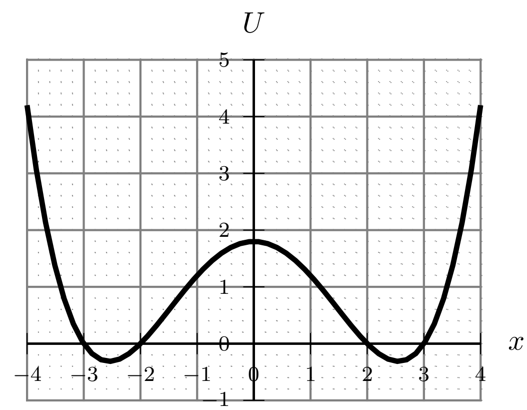


a) The particle is released from rest at $x = 1.0\,\text{m}$. Describe the direction of the force acting on the particle at this moment. Describe the subsequent motion of the particle (left, right, slowing , speeding up, ...). Approximately what is the furthest right that this particle reaches?

b) The particle is released from rest at $x = 4.0\,\text{m}$. Describe the direction of the force acting on the particle at this moment. Describe the subsequent motion of the particle (left, right, slowing , speeding up, ...). Approximately what is the furthest left that this particle reaches?

235 Potential and motion, 2

A particle that can move along the x axis is subjected to the potential whose graph is as illustrated. *(131F2022)*



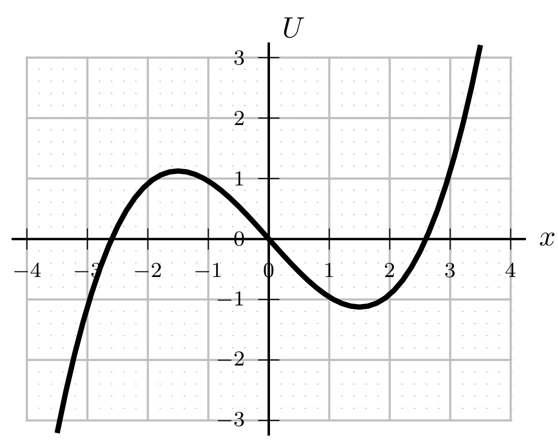
a) Suppose that the potential energy of the particle is zero. Use the plot to explain whether the force on the particle is also zero in this situation.

b) Suppose that the force on the particle is zero. Use the plot to explain whether the potential energy of the particle is also zero in this situation.

236 Motion under a complicated potential

A particle that can move along the x axis is subjected to the potential

$$U(x) = (x^3 - 6.75x)/5.$$



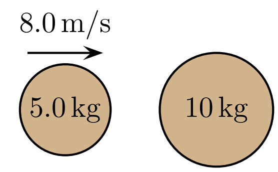
a) Determine an expression for the horizontal component of the force on the object.

b) Determine locations where the object is in equilibrium and for each describe whether the equilibrium is stable or not. *(131F2022)*

Momentum

237 Colliding balls, 1

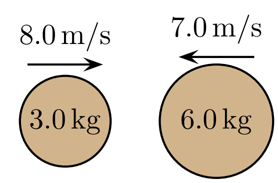
Two balls, isolated from all other objects, are initially as illustrated. The 5.0 kg ball moves directly toward the 10 kg ball. They collide and subsequently the 10 kg ball moves right with speed 3.0 m/s. The aim of this exercise will be to determine the speed and direction of motion of the smaller ball after the collision.



a) Determine the momentum of the smaller ball before the collision.
b) Determine the momentum of the larger ball before the collision.
c) Determine the momentum of the system before the collision.
d) Determine the momentum of the larger ball after the collision.
e) Determine the momentum of the smaller ball after the collision.
f) Determine the velocity of the smaller ball after the collision.
g) Suppose that the construction of the balls was different and that after the collision the larger ball moves right with speed 5.0 m/s. Determine the velocity of the smaller ball after the collision.

238 Colliding balls, 2

Two balls, isolated from all other objects, initially move toward each other as illustrated. The 3.0 kg ball moves directly toward the 6.0 kg ball. The balls collide and subsequently the 3.0 kg ball moves left with speed 4.0 m/s. Determine the velocity of the larger ball after the collision.



239 Space collision

A 100 kg astronaut is at rest in space. A 0.0050 kg fleck of paint moves toward the astronaut with speed 15×10^3 m/s. It collides with and sticks to the astronaut.

a) Write an expression for the total momentum of the system before the collision in terms of the masses and speeds of the astronaut and paint. Determine the total momentum of the system before the collision (assume that the paint fleck initially moves along the positive x axis).
b) Write an expression for the total momentum of the system after the collision in terms of the masses and speeds (after collision) of the astronaut and paint.
c) Use momentum conservation to determine the speed of the astronaut after the collision.
d) Now suppose that the paint fleck bounced off the astronaut and reverses direction with speed 8.0×10^3 m/s. Determine the speed of the astronaut after the collision.

240 Railroad car carrying sand

An empty 3000 kg rail car has an open top and moves right with speed 5.0 m/s (it slides along the tracks without a locomotive pulling it) It passes beneath a chute that pours sand into the car. The sand hits the car vertically and after it has passed the car moves with speed 3.0m/s. Determine the mass of the sand delivered to the car.

241 Sledder catching a ball

A person sits at rest on a sled on a sheet of ice; the combined mass of the person and sled is 95.0 kg. A 5.0 kg bowling ball is launched horizontally rightwards toward the person with speed 20 m/s. The person catches the ball and the person, sled and ball slide together at the same speed.

a) Determine their velocity after the ball has been caught.

b) Is kinetic energy conserved in this process?

Suppose that the person and sled had been moving left with speed 2.0 m/s prior to catching the ball.

c) Determine their velocity after the ball has been caught.

242 Bumper carts on ice

A parent slides in a cart (mass of both 100 kg) to the right with speed 6.0 m/s. A child on another cart (mass of both 60 kg) also slides to the right, initially ahead of the parent with speed 4.0 m/s. When they collide the parent holds onto the other cart. Both slide together. Determine their velocity after the collision.

243 Dropping a rock on a planet

An astronaut stands on a planet, holding a rock at rest above the surface of the planet. The planet, astronaut and rock are initially at rest. The astronaut releases the rock and it falls toward the planet.

a) While the rock falls is the total momentum of the planet/astronaut/rock system zero or not? Explain your answer.

b) While the rock falls does the planet remain at rest or not? Explain your answer.

244 Rebounding subatomic particles

A subatomic particle, labeled 1, with mass m_1 travels with speed v_1 directly toward another subatomic particle, labeled 2, with mass m_2 and initially at rest. The particle with mass m_1 rebounds, traveling left with speed $0.80v_1$ and the other particle travels right with speed v_2. Determine an expression for the mass of particle 2 in terms of the speeds and the mass of particle 1.

245 Jumping crowd

A crowd of 100000 people, each with mass 80 kg are at rest on Earth's surface. They all jump up simultaneously, leaving Earth's surface with speed 3.0 m/s (relative to the background). Determine Earth's recoil speed.

246 Separating carts

Two carts are at rest on a frictionless horizontal track. The mass of cart A is exactly four times the mass of cart B. A spring between the carts is released, the carts separate and cart A moves left with speed v.

a) Which of the following is true for cart B after they separate? Explain your answer.

   i) B moves left with speed v.
   ii) B moves left with speed $2v$.
   iii) B moves left with speed $4v$.
   iv) B moves right with speed v.
   v) B moves right with speed $2v$.
   vi) B moves right with speed $4v$.

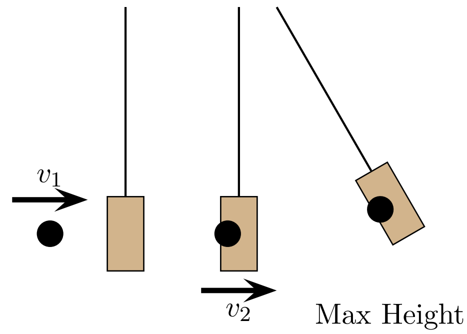
b) Which cart gains the most kinetic energy? Explain your answer.

247 Ball launched from a moving cart

A 400 g cart slides along a laboratory bench with velocity 10.0 m/s to the right. A 100 g ball is initially at rest relative to the cart and is fired to the left. Subsequently the velocity of the ball relative to the laboratory is 10.0 m/s to the left. Determine the velocity of the cart after this occurs.

248 Ballistic pendulum

A ballistic pendulum consists of a 1.5 kg wooden block suspended at rest from a cord. A 0.0080 kg bullet is fired horizontally into the block. It embeds itself causing the block to swing upward, reaching a point 0.20 m above its lowest point. The idea is to use the maximum height reached by the pendulum to determine the speed of the bullet immediately before hitting the block. The process is illustrated at three instants. Let instant 1 be the moment just before the bullet hits, instant 2, the moment just after it embeds and instant 3, the moment at which it reaches its highest point.



a) Is momentum conserved from instant 1 to instant 2? Is mechanical energy, $E = K + U_{\text{grav}}$, conserved from instant 1 to instant 2?

b) Is momentum conserved from instant 2 to instant 3? Is mechanical energy, $E = K + U_{\text{grav}}$, conserved from instant 2 to instant 3?

c) Consider the period from instant 2 to instant 3 and use this to determine the speed of the bullet and block just after it embeds.

d) Consider the period from instant 1 to instant 2 and use this to determine the speed of the bullet and block just before it embeds.

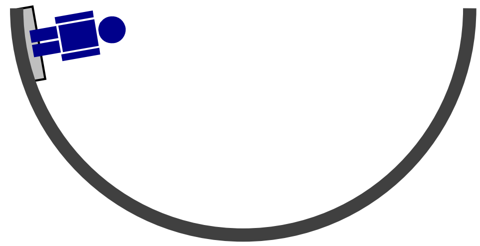
249 Ballistic pendulum

A 0.010 kg bullet is fired horizontally into a 2.0 kg block that is suspended at rest from a string just above the ground. The bullet collides with the block and sticks. The two then swing in a circle and the block reaches a height of 0.30 m above the ground.

a) Determine the speed of the bullet and block just after the bullet has stuck to the block.

b) Determine the speed of the bullet just before the bullet hits the block.

250 Half pipe



A 60 kg person rides a 5.0 kg skateboard. Both are at rest at the top of a half-pipe of radius 10 m. Ignore any friction and the rotation of the wheels.

a) Determine the speed of the skateboarder at the bottom of the half pipe.
b) Suppose that there was another skateboarder, of mass 80 kg on a 5.0 kg skateboard at rest at the bottom of the pipe. The two skateboarders collide, hold each other and move together. Determine their speed moments after they collide.
c) Determine how high up the pipe the combined pair of skateboarders move.

251 Pool ball collision

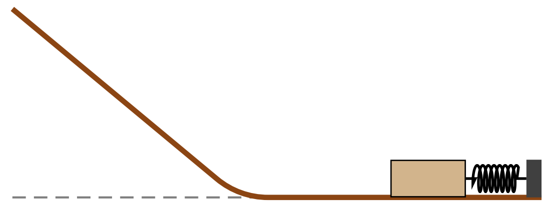
A ball rolls right along a horizontal surface toward another ball, initially at rest. The diagram illustrates the approximate configuration of the balls. The balls collide and this collision is not necessarily head-on. Explain whether each of the following is a possible trajectory afterwards.

i) Both balls are at rest.
ii) One ball moves ↑ and the other moves →.
iii) One ball moves ↑ and the other moves ↓.
iv) One ball moves ↗ and the other moves →.
v) One ball moves ↗ and the other moves ↘.

Additional Energy Questions

252 Spring-launched crate

An 8.0 kg crate is held at rest against a spring with spring constant 1600 N/m compressing it by by 0.25 m. It is released and then travels along the illustrated surface. The lower 0.50 m long horizontal portion of the surface is rough with coefficient of friction 0.35. The rest of the surface is frictionless. Ignoring air resistance determine the maximum vertical height reached by the crate. *(131F2022)*



253 Force for a quadratic potential

A particle moves subject to an interaction described by the potential

$$U(x) = ax^2 + bx + c$$

where $a = -4.0\,\mathrm{J/m^2}$, $b = 10.0\,\mathrm{J/m}$ and $c = 5.0\,\mathrm{J}$ are constants.

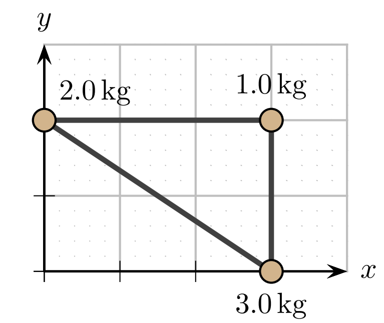
a) Determine any locations where the force on the particle is zero.

b) Suppose that the particle is held at rest at $x = 0.0\,\mathrm{m}$. In which direction will it begin to move? Explain your answer.

Rotational Motion

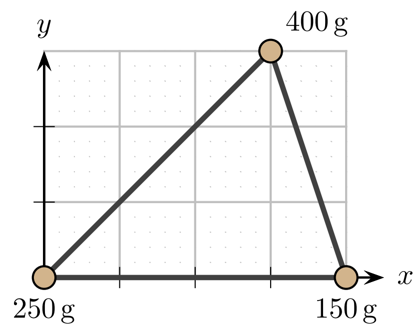
254 Center of mass of three balls, 1

Three small balls are connected via massless rods in the illustrated configuration. Each grid block is 2.0 cm long. Determine the center of mass of the system. *(131F2022)*



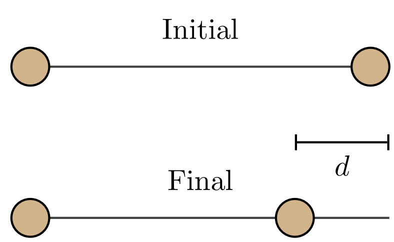
255 Center of mass of three balls, 2

Three small balls are connected via massless rods in the illustrated configuration. Each grid block is 5.0 cm long. Determine the center of mass of the system. *(131F2022)*



256 Center of mass

Two identical balls are attached to a rigid rod with negligible mass. The ball on the right is shifted left by distance d. Which of the following is correct about the center of mass (ignore the rod) after the ball has been shifted? *(131F2022)*



i) The c.o.m. has remained where it was before the mass was shifted.

ii) The c.o.m. moved less than $d/2$ to the left.

iii) The c.o.m. moved exactly $d/2$ to the left.

iv) The c.o.m. moved between $d/2$ and d to the left.

v) The c.o.m. moved exactly d to the left.

257 Jumping crowd and Earth displacement

A crowd of 100000 people each with mass 80 kg is initially at rest on Earth's surface. They all jump upward simultaneously and their maximum height from their starting point is 0.50 m. Determine the maximum displacement of Earth from its starting point. *(131F2022)*

258 Rotating bar bell

A rigid barbell rotates about the axle at O. The distance from the end labeled B to O is three times the distance from the end labeled A to O. *(131F2022)*

a) Which of the following is true? Explain your answer.

  i) The linear speed of B is nine times that of A.
  ii) The linear speed of B is three times that of A.
  iii) The linear speed of B is the same as that of A.
  iv) The linear speed of B is one third that of A.
  v) The linear speed of B is one ninth that of A.

b) Explain as precisely as possible how the centripetal acceleration of A is related (e.g. same, four times, ...) to that of B.

259 Bugs on a rotating disk

The PhET animation

http://phet.colorado.edu/en/simulation/rotation

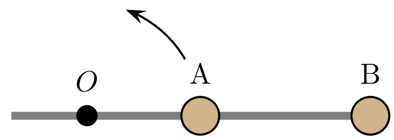
illustrates bugs on a rotating disk. Use the link to run the animation. Once the animation has opened, use the Intro tab (this is the default tab). The two bugs can be moved to various parts of the disk and the disk can be made to rotate. Place one bug a quarter of the way from the center to the edge. Place the other half way from the center to the edge. *(131F2022)*

a) Predict how many times larger (or smaller) the velocity of the bug that is closer to the center is than that of the bug further from the center. Explain your prediction.

b) Predict how many times larger (or smaller) the centripetal acceleration of the bug that is closer to the center is than that of the bug further from the center. Explain your prediction.

c) Run the animation by entering various angular velocities. It should display the velocity and acceleration vectors. Do your results for the previous parts agree with the observed acceleration vectors? Do your predictions from the previous parts depend on the angular velocity?

260 Rotating masses on a rod



Two masses are fixed as illustrated on a 0.50 m long rigid rod that rotates about the axis at O. The distance from O to the left end of the road is 0.10 m, the distance from A to the left end of the rod is 0.25 m and B is at the right end of the rod. *(131F2022)*

a) Suppose that the rod rotates at a constant rate of 720 rpm. Determine the speed of each mass.

b) Suppose that the rod rotates in such a way that the angle from the horizontal is $\theta = \left(10\,\mathrm{rad/s^2}\right)\, t^2$. Determine an expression for the angular velocity and angular acceleration of each ball. Determine the total distance traveled by each mass from $t = 0.0\,\mathrm{s}$ to $t = 60.0\,\mathrm{s}$.

261 Hard drive rotation

A hard drive in a computer contains a disk that rotates at a rate of 7200 rpm. The diameter of the disk is 6.25 cm. *(131F2022)*

a) Determine the speed of a point at the edge of the disk while it is rotating at 7200 rpm.

b) Assume that the disk is initially at rest and accelerates at a constant rate reaching 7200 rpm in 200 ms. Determine the magnitude of the angular acceleration of the disk.

262 Slowing turntable

A turntable (circular disk with an axle perpendicular to the disk through its center) initially rotates counterclockwise about the axle at 4800 rpm (revolutions per minute) and subsequently slows at a constant rate. It stops after exactly 30 revolutions. *(131F2022)*

a) Determine the angular acceleration of the turntable.

b) Determine the speed of a point 0.15 m from the turntable axle at the instant when it has completed 15 revolutions.

263 Rotating bicycle wheels

A bicycle travels with speed 6.5 m/s (about 15 mph). The diameter of the bicycle wheels is 0.700 m. Determine the angular velocity of the wheel. *(131F2022)*

264 Rotating frisbee

A 30cm frisbee rotates about an axis through its center with a constant angular acceleration of $20\pi\,\mathrm{rad/s^2}$ starting from rest. *(131F2022)*

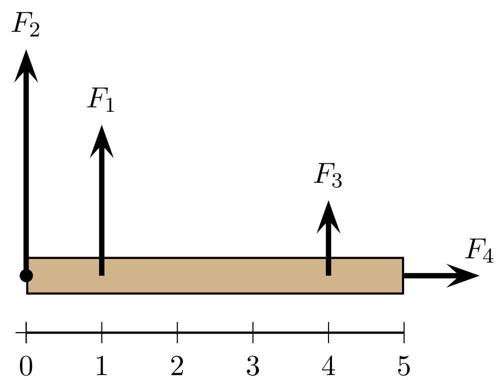
a) Determine the angular velocity of a point on the rim of the frisbee 20s after it starts rotating.
b) Determine the angular velocity of a point halfway from the axis to the rim of the frisbee 20s after it starts rotating.
c) Determine the total distance traveled by a point on the rim of the frisbee in the first 20s after it starts rotating.
d) Determine the total distance traveled by a point halfway from the axis to the rim of the frisbee in the first 20s after it starts rotating.

265 Rotation on Earth

Two people stand on Earth's surface. One is in Houston (latitude 29.8° N) and the other in Seattle (latitude 47.6° N). Assuming that Earth is a perfect sphere and rotates at a constant angular rate, determine the speed, the angular velocity and the acceleration of each person. *(131F2022)*

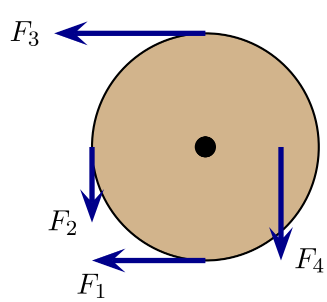
266 Torques on a beam

A beam can pivot about its left end. Various forces act on the beam as illustrated. An axis is provided for scale. The magnitudes of the forces are related via $F_1 = 2F_3$, $F_2 = 3F_3$, and $F_4 = F_3$. Rank the torques produced by the forces about the left end of the beam in order of increasing torque. Explain your answer. *(131F2022)*



267 Torques on a disk

A disk, with diameter 60 cm can rotate about an axle through its center and perpendicular to the disk. The illustrated forces act on the disk. The magnitudes of the forces are $F_1 = 15\,\mathrm{N}, F_2 = 10\,\mathrm{N}, F_3 = 20\,\mathrm{N}$ and $F_4 = 15\,\mathrm{N}$. The force F_4 acts at a point 2/3 of the distance from the center of the disk to the rim. *(131F2022)*

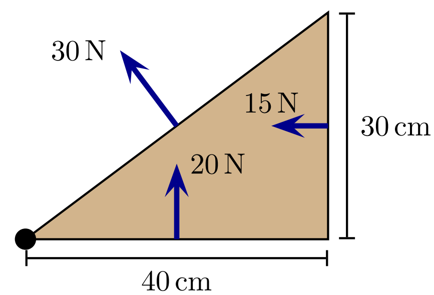


a) Determine the torque exerted by each force about the axle.

b) Determine the net torque on the disk.

268 Torques on a plywood triangle

Three forces act on a triangular piece of plywood as illustrated. Each acts midway along the edge. The plywood can pivot about the axle at the bottom left corner. *(131F2022)*

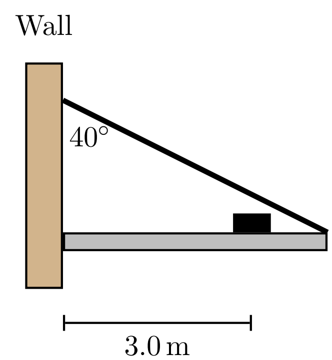


a) Determine the torque exerted by each force about the axle.

b) Determine the net torque on the plywood.

269 Beam perpendicular to a wall

A 4.0 m long, 80 kg beam is anchored to a wall and held at rest horizontally by a rope at the illustrated angle. A 10 kg box rests on the beam at the illustrated point. The aim of this exercise is to determine the tension in the rope. This would enable one to decide on the breaking strength of the rope. *(131F2022)*



a) State the conditions for equilibrium.

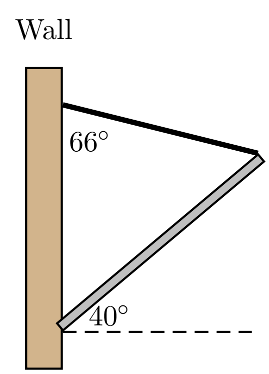
b) Draw all the force vectors on the beam.

c) Identify a pivot point (there are many correct possibilities – one is much more useful than the others) and determine expressions for the torque exerted by each force about the pivot.

d) Substitute the individual torques into one of the conditions for equilibrium and obtain an expression for the tension in the rope.

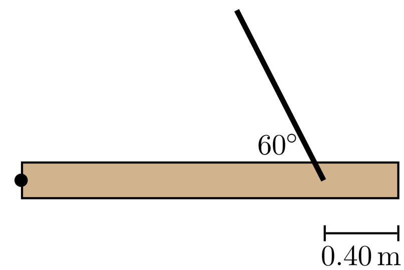
270 Raised drawbridge

A 5.0 m long, 600 kg drawbridge is anchored to a castle wall. A rope holds the drawbridge at rest at the illustrated angle. While this happens a 120 kg knight in armor dangles vertically downward from the right end of the drawbridge. Determine the tension in the rope. *(131F2022)*



271 Beam in equilibrium, 1

A 10 kg beam with length 2.0 m can pivot about its left end. A rope is attached as illustrated. *(131F2022)*



a) State the conditions for equilibrium.

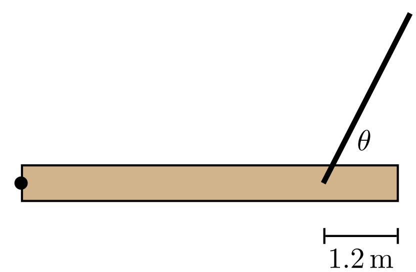
b) Draw all the force vectors on the beam.

c) Identify a pivot point (there are many correct possibilities – one is much more useful than the others) and determine expressions for the torque exerted by each force about the pivot.

d) Substitute the individual torques into one of the conditions for equilibrium and determine the tension in the rope.

272 Beam in equilibrium, 2

A 50 kg beam with length 6.0 m can pivot about its left end. A rope is attached as illustrated. *(131F2022)*

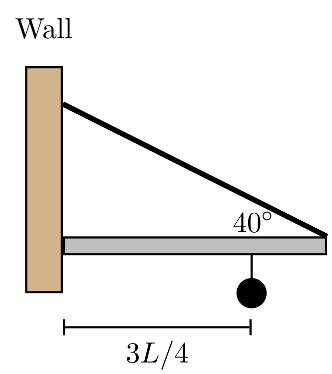


a) Determine an expression for the tension so that the beam stays at rest horizontally.

b) Does the tension needed stay constant, increase or decrease as the angle $0^\circ \leqslant \theta \leqslant 90^\circ$ increases? Explain you answer.

273 Beam supporting a ball

A beam with mass M and length L is anchored to a wall and held at rest horizontally by a rope as illustrated. A ball with mass m is suspended from the beam at the illustrated point. The aim of this exercise is to determine the tension in the rope. This would enable one to decide on the breaking strength of the rope. *(131F2022)*



a) State the conditions for equilibrium.

b) Draw all the force vectors on the beam.

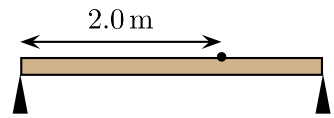
c) Identify a pivot point (there are many correct possibilities – one is much more useful than the others) and determine expressions for the torque exerted by each force about the pivot.

d) Substitute the individual torques into one of the conditions for equilibrium and obtain an expression for the tension in the rope.

e) What must be the minimum required breaking tension for the rope if it is to support a 40 kg beam with length 3.0 m while there is a 8.0 kg ball suspended as illustrated?

274 Balance beam, 1

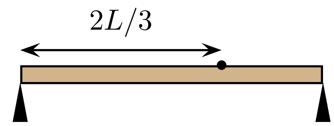
A 60 kg person stands on a 20 kg horizontal beam, with length 3.0 m, at the point illustrated by the dot. The beam is supported by stands at either end and is in equilibrium. Each support exerts an upward force. *(131F2022)*



a) Determine the force provided by the support on the right. *Hint: Consider torques about the left support and don't forget the mass of the beam.*
b) Determine the force provided by the support on the left. *Hint: Consider torques about the right support and don't forget the mass of the beam.*

275 Balance beam, 2

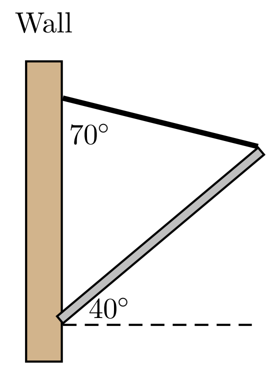
An person with mass m_p stands on a horizontal beam, with mass m_b and length L, at the point illustrated by the dot. The beam is supported by stands at either end and is in equilibrium. Each support exerts an upward force. *(131F2022)*



a) Determine an expression for the force that each support provides. Does this depend on the length of the beam?
b) Determine the force that each support provides if the beam has mass 40 kg and the person 90 kg.

276 Raising a drawbridge

A 5.0 m long, 400 kg drawbridge is anchored to a castle wall. A rope with tension 2000 N raises the drawbridge at the illustrated angle. Determine the net torque on the drawbridge about the point where the drawbridge is attached to the wall. *(131F2022)*

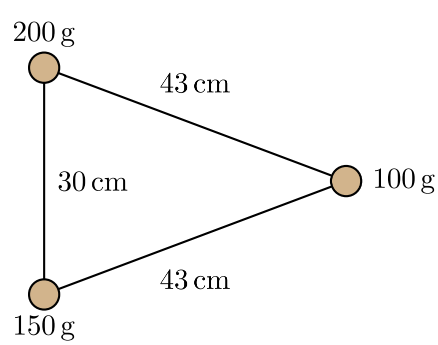


277 Moment of inertia for point masses

Three point masses are connected by massless rods. Determine the moment of inertia about an axis perpendicular to the page and that passes through:

a) the 150 g mass,
b) the 100 g mass, and
c) the 200 g mass.

(131F2022)



278 Moments of inertia

Two circular disks are made of the same material. Disk A has a radius three times that of disk B; their thicknesses are the same. Let I_A be the moment of inertia of A and I_B be the moment of inertia of B (each about an axis perpendicular to the page). Which of the following is true? Explain your answer. *(131F2022)*

i) $I_A = I_B$

ii) $I_A = \frac{9}{2} I_B$

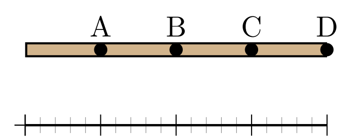
iii) $I_A = 9\, I_B$

iv) $I_A = \frac{81}{2} I_B$

v) $I_A = 81\, I_B$

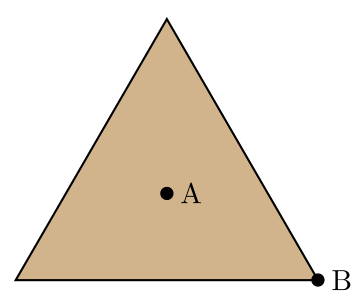
279 Moment of inertia of a rod about different axes

A thin rod can rotate about any of the illustrated four axes. The mass is uniformly distributed along the rod. Let I_A be the moment of inertia about point A, I_B be the moment of inertia about point B, etc. Rank the moments of inertia from smallest to largest, indicating any equality. Explain your answer. *(131F2022)*



280 Moment of inertia of a triangle about different axes

A flat equilateral triangular plate can rotate about one of two axes. Point A is at the center and point B is at one of the corners. Let I_A be the moment of inertia about A and I_B be the moment of inertia about B (each about an axis perpendicular to the page). Which of the following is true? Explain your answer. *(131F2022)*



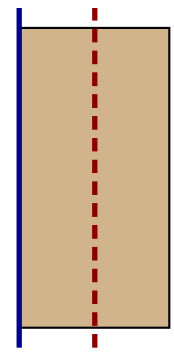
i) $I_A = I_B$

ii) $I_A > I_B$

iii) $I_A < I_B$

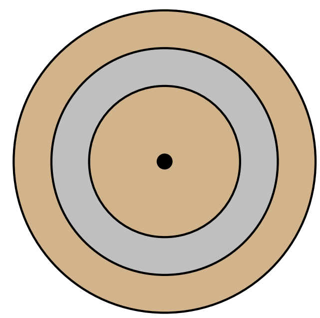
281 Moment of inertia of a door

A door could rotate about one of two axes. One axis (solid dark blue in the illustration) passes along the long edge of the door. The other axis (dashed dark red in the illustration) passes parallel to the long edge and through the center of the door. Estimate the mass and dimensions of a door in your room, state what your estimates are and use these to calculate the moment of inertia about each axis. *Note: The moment of inertia of a rectangular object about an axis parallel to the edge is the same as that for a rod rotating about the same axis. (131F2022)*



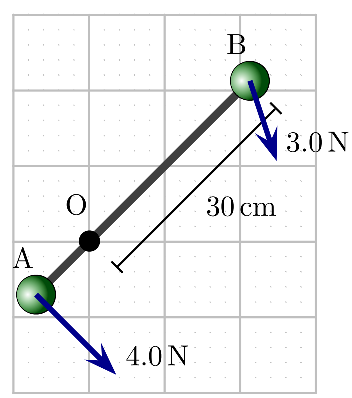
282 Moment of inertia of rotating objects

A turntable with mass M and radius R can rotate about an axis through its center and perpendicular to the disk. A ring with mass m, inner radius $R/4$ and outer radius $R/2$ is fixed to the disk concentrically. Determine an expression for the total moment of inertia of the system. *(131F2022)*



283 Rotational dynamics of a barbell

A rigid barbell consists of two heavy balls mounted at the ends of a light rigid 40 cm long rod. The barbell can rotate about an axle (pointing perpendicular to the board/page) at O. The mass of A is 600 g, the mass of B is 300 g and the mass of the rod is negligible. One force acts on each ball and the force on ball A is perpendicular to the rod. The angle between the force on B and the rod is 63°. The set-up is such that gravitational forces are irrelevant. At an indicated moment the rod makes a 45° angle with respect to the usual x axis. *(131F2022)*



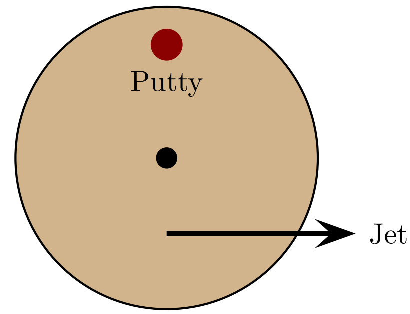
a) Determine the net torque on the barbell (about O).

b) Determine the moment of inertia of the barbell (about O).

c) Determine the angular acceleration of the barbell (about O).

284 Rotating turntable and putty

A 2.0 kg turntable (disk) has radius 0.10 m and can rotate horizontally about a frictionless axle through its center. A 1.2 kg blob of putty is stuck to a point on the disk three quarters of the distance from the center to the edge. A jet attached halfway from the center to the edge of the disk exerts a 4.0 N tangential force as illustrated. The aim of this exercise is to determine the angular acceleration of the disk. *(131F2022)*



a) Write the rotational version of Newton's second law.

b) Determine the moment of inertia of the disk plus putty.

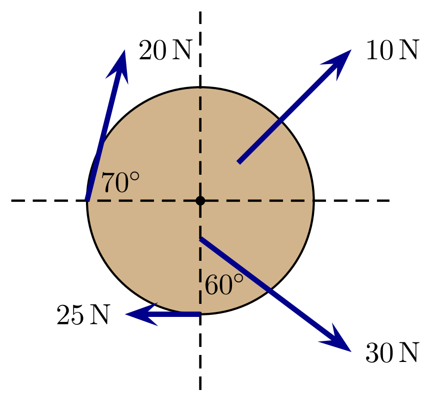
c) Determine the net torque acting on the disk.

d) Determine the angular acceleration of the disk.

e) Suppose that a brake pad presses on the rim of the disk, producing a frictional force with magnitude 1.5 N while the jet is operating. If the wheel is rotating counterclockwise, determine the angular acceleration of the disk in this situation.

285 Rotating disk

An 8.0 kg disk with radius 0.15 m can rotate about an axle through its center and perpendicular to the disk. The illustrated forces act on the disk. The 30 N force acts at a point 0.10 m from the axle. The 10 N force acts at a point 0.08 m from the axle. *(131F2022)*



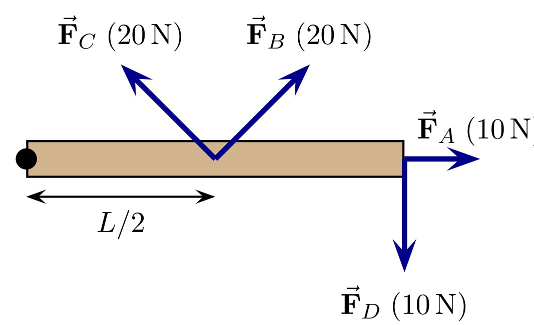
a) Determine the torque about the axle produced by each force on the disk.

b) Determine net torque on the disk.

c) Determine the angular acceleration of the disk.

286 Rotating rod

A rod with length L lies on a frictionless horizontal surface and can rotate about an axle at its left end. *In separate instances* one force is applied to the rod as illustrated. The angles between forces B and C and the rod are the same. Rank the magnitude of the angular accelerations in order from largest to smallest. Explain your answer. *(131F2022)*



287 Rod rotating in a vertical plane

A thin long rod with uniformly distributed mass M and length L can rotate in a vertical plane (i.e. up and down) about an axis through one end. A hand pushes vertically upward at the other end of the rod with force F. Consider the instant at which the rod is horizontal. For each of the following situations explain whether the rod is speeding up, slowing down, maintaining a constant velocity or the situation is impossible. *(131F2022)*

a) The rod rotates counterclockwise and $F = Mg$.

b) The rod rotates counterclockwise and $F = Mg/2$.

c) The rod rotates counterclockwise and $F = Mg/4$.

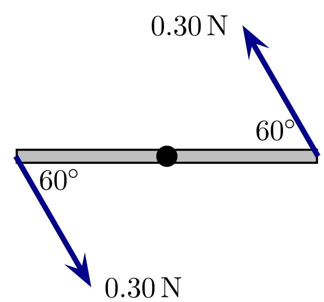
d) The rod rotates clockwise and $F = Mg$.

e) The rod rotates clockwise and $F = Mg/2$.

f) The rod rotates clockwise and $F = Mg/4$.

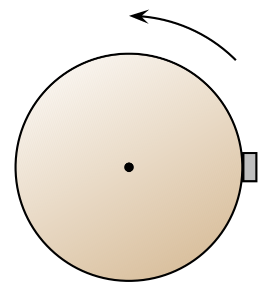
288 Spinning rod

A thin 0.25 kg, 0.50 m long rod can rotate about an axis through its center. Two jets are attached to the end of the rod and each exerts the same force at the same angle relative to the rod as illustrated. Suppose that the rod was initially at rest. Determine the time taken for the rod to rotate at 2000 rpm. *(131F2022)*



289 Braking wheel

An wheel with mass M and radius R can rotate about an axle through its center and perpendicular to the wheel. The wheel is a solid disk with uniform mass distribution. The wheel initially rotates with angular velocity ω_i. A brake pushes against perpendicularly against the edge of the rim, exerting a (normal) force F. The coefficient of kinetic friction between the rim and brake is μ_k. *(131F2022)*



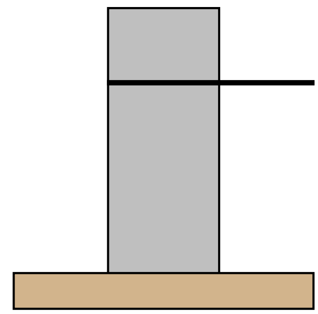
a) Show that the time taken to stop the wheel is

$$T = \frac{MR\omega_i}{2\mu_k F}.$$

b) Determine the time taken to stop a 2.5 kg wheel with radius 0.40 m that is initially rotating at 100 rpm. The force acting on the wheel is 35N and the coefficient of kinetic friction is 0.40.

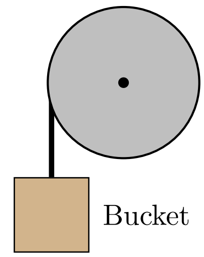
290 Flywheel and axle

A particular flywheel is a solid disk with mass 0.150 kg and radius 0.075 m. This is mounted to an 0.400 kg axle which is a hollow cylinder with radius 0.020 m. The entire arrangement is initially at rest and is subsequently pulled with constant tension by a string that is wound around the axle. It reaches an angular velocity of 40 rad/s in 5.0 s. A side view is illustrated. Determine the tension in the string. *(131F2022)*



291 Bucket suspended from a rotating pulley

A bucket with mass M is suspended from a massless string that is wrapped around a pulley. The pulley has with radius, R, and uniformly distributed mass, m and rotates about a frictionless axle through its center. The bucket is held at rest 1.5 m above the ground. The aim of this exercise is to find the time taken for the bucket to reach the ground. *(131F2022)*



a) Apply Newton's second law to the bucket and determine an expression for the acceleration of the bucket in terms of the tension in the string and other problem variables.

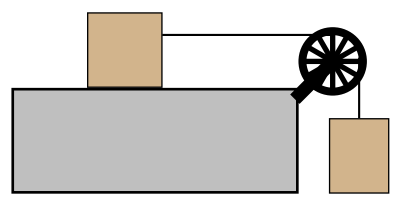
b) Apply the rotational version of Newton's second law to the pulley and use this to determine an expression for the angular acceleration of the pulley in terms of the tension in the string and other problem variables.

c) Relate the angular acceleration of the pulley to the acceleration of the bucket and use this and the previous expressions to find an expression for the acceleration of the bucket in terms of the masses, the pulley radius and g.

d) Determine the time taken for the bucket to reach the ground if its mass is 3.0 kg, the pulley's mass is 2.0 kg and the radius is 0.20 m.

292 Dynamics of connected objects: level/suspended blocks with a massive pulley

A box, with mass m_b, can slide along a horizontal frictionless surface. It is connected to a suspended object, with mass m_s, by a massless string. The string runs horizontally over a pulley, which is a solid disk with uniformly distributed mass m_p and radius R. These objects are held at rest and are then released. *(131F2022)*



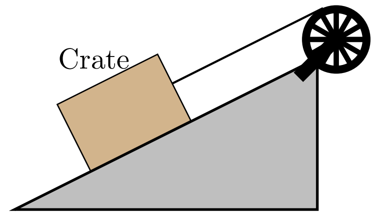
a) Is the angular acceleration of the pulley after the objects are released zero or not? Explain your answer.

b) How does the tension in the vertical part of string compare (smaller, larger, same) to that in the horizontal part of the string as the objects move after they are released? Explain your answer.

c) Determine an expression for the acceleration of the objects after they are released.

293 Crate sliding down a ramp while connected to a heavy pulley

A crate on a rough ramp is connected to a string which is wrapped around a pulley. The string runs parallel to the ramp. At one instant the crate slides down the ramp. *(131F2022)*

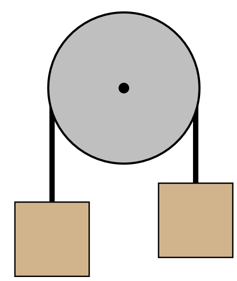


a) Determine the acceleration of the crate if the ramp is inclined at an angle of 35° above the horizontal, the mass of the crate is 4.0 kg, the mass of the pulley is 2.0 kg and the coefficient of kinetic friction is 0.40. Does the crate speed up or slow down?

b) Determine a general expression for the acceleration of the crate sliding down the ramp if the ramp is inclined at an angle of θ above the horizontal and the coefficient of kinetic friction is μ_k. Check that your expression is correct in the limit as the mass of the pulley approaches zero or the limit as the ramp becomes horizontal or vertical.

294 Blocks suspended from a rotating disk, 1

A pulley, with moment of inertia I, can rotate about a frictionless axle through its center. Two blocks are suspended from a string, which runs, without slipping, over the pulley. The block on the left has mass m_1 and that on the right has mass $m_2 < m_1$. The system is held at rest and then released. *(131F2022)*



a) Write the rotational version of Newton's second law for the pulley.

b) Determine the net torque acting on the pulley, assuming that the tension in the string on the left might be different from that on the right.

c) Determine an expression for the angular acceleration of the pulley in terms of the tensions in the strings.

d) If the moment of inertia of the pulley is non-zero and the pulley is accelerating, can the two tensions be equal?

e) Apply Newton's second law to each of the suspended masses, in each case relating the magnitude of the acceleration to the tension in the string.

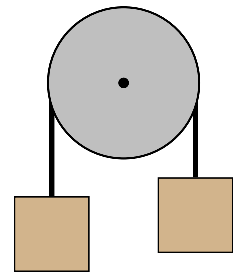
f) Combine the results from the previous parts to show that the magnitude of the acceleration of the blocks is

$$a = \frac{m_1 - m_2}{m_1 + m_2 + I/R^2}\, g$$

where R is the radius of the pulley.

295 Blocks suspended from a rotating disk, 2

A pulley, with moment of inertia I, can rotate about a frictionless axle through its center. Two blocks are suspended from a string, which runs, without slipping, over the pulley. The block on the left has mass m_1 and that on the right has mass $m_2 < m_1$. The system is held at rest and then released. *(131F2022)*



a) If the moment of inertia of the pulley is non-zero and the pulley is accelerating, can the tension in the string on the left equal that on the right? Explain your answer.

b) Show that the magnitude of the acceleration of the blocks is

$$a = \frac{m_1 - m_2}{m_1 + m_2 + I/R^2}\, g$$

where R is the radius of the pulley.

296 Rotational kinetic energy

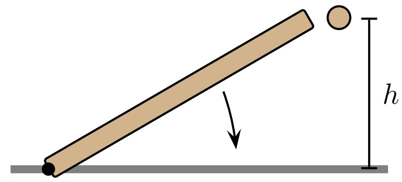
Various spheres have the same mass and rotate about a diametrical axis with different angular velocities as listed in the table.

Object	type	radius	ω
A	Solid sphere	1.0 m	8 rad/s
B	Solid sphere	2.0 m	4 rad/s
C	Hollow sphere	2.0 m	4 rad/s
D	Hollow sphere	3.0 m	2 rad/s

Rank these in order of increasing rotational kinetic energy. Explain your answer. *(131F2022)*

297 Toppling rod versus freely falling ball, 1

A rigid rod with uniformly distributed mass M and length L can pivot about a frictionless axle in a horizontal surface. The rod is held at rest with one end height h above the surface. A ball with mass m is also held at rest alongside the tip of the rod. Both are released at the same time. *(131F2022)*



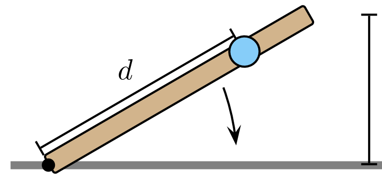
a) Determine the speed of the ball just before it hits the horizontal surface.

b) Determine the speed of the tip of the rod just before it hits the horizontal surface.

c) Which hits first?

298 Rotating versus freely falling ball, 2

A rigid rod with uniformly distributed mass M and length L can pivot about a frictionless axle in a horizontal surface. The rod is held at rest with one end height h above the surface. A ball with mass m is also held at rest alongside the rod at a point distance d along the rod from the pivot point. Both are released at the same time. *(131F2022)*



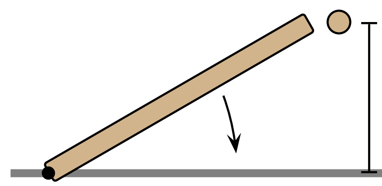
a) Determine the speed of the ball just before it hits the horizontal surface.

b) Determine the speed of the tip of the rod just before it hits the horizontal surface.

c) Show that there is a special distance d such that the ball will hit the surface at the same time as the rod. Provide an expression for this and show that it does not depend on the masses or the release height.

299 Rotating versus freely falling ball, 3

A rigid rod with uniformly distributed mass M and length L can pivot about a frictionless axle in a horizontal surface. The rod is held at rest with one end height h above the surface. A ball with mass m is also held at rest alongside the rod. Both are released at the same time. *(131F2022)*



a) Consider any level at height $y < h$ above the horizontal surface. Show that when the ball reaches this level its speed is lower than that of the the tip of the rod at the same level.

b) Show that when the rod is at an angle θ from the surface, the tangential acceleration of the tip has magnitude

$$a_t = \frac{3}{2} g \cos\theta.$$

Show that the centripetal acceleration is

$$a_c = 3g\left(\frac{h}{L} - \sin\theta\right).$$

Show that the vertical component of the acceleration of the tip is

$$a_y = g\left(\frac{3}{2} + 3\frac{h}{L}\sin\theta - \frac{9}{2}\sin^2\theta\right).$$

300 Rotating dropping rod

A rod with mass M and length 1.5 m can pivot about a frictionless axle at one end. The rod is held at rest horizontally and is then released. *(131F2022)*

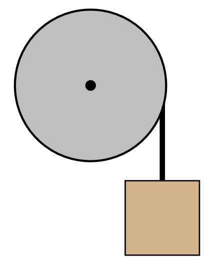
a) Is the angular acceleration of the rod constant? Explain your answer.

b) Determine the angular velocity of the rod when it reaches its lowest point.

c) Determine the speed of the tip of the rod when it reaches its lowest point.

301 Block suspended from a rotating wheel

A 10 kg solid wheel with radius 0.40 m can rotate about a frictionless axle through its center. A 5.0 kg block is suspended from a string which is wrapped around the wheel. The system is held at rest with the block 2.0 m above the ground. The block is then released, causing the wheel to rotate (its axle does not drop). *(131F2022)*



a) Determine the total energy of the system at the moment that the block is released. What type of energy is this?

b) What type of energy does the system have at the instant just before the block hits the ground? Determine an expression for the total energy of the system at this instant; the expression should include the speed of the block, v, and the angular velocity of the wheel ω.

c) If the string does not slip along the wheel the speed of the block v satisfies $v = \omega r$ where r is the radius of the wheel. Substitute this into the result of the previous part to show that the total energy just before the block hits the ground is

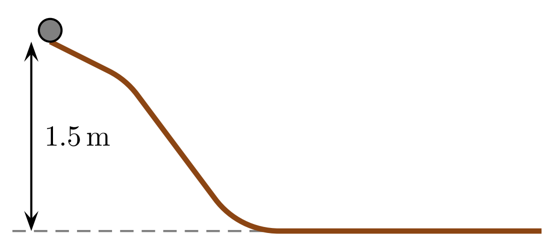
$$E = \frac{1}{2}\, m_{\text{block}} r^2 \omega^2 + \frac{1}{2}\, I_{\text{wheel}} \omega^2.$$

Use this to determine the angular velocity of the wheel just before the block hits the ground.

d) Determine the speed of the block just before it hits the ground.

302 Rolling cylinder

A cylinder with mass M and radius R is released from the top of a track with height 1.5 m. It rolls without slipping. Determine the speed of the cylinder at the bottom of the track. *(131F2022)*



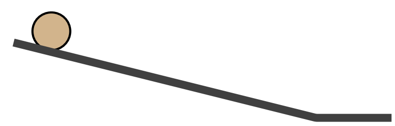
303 Rolling cylinders

Two solid cylinders, A and B, can roll along a ramp without slipping. Each cylinder has a uniform mass distribution and both are released from rest at the same height on the ramp. *(131F2022)*

a) Suppose the radii of the cylinders are the same but A has a larger mass than B. Is the speed of A at the bottom of the ramp the same, larger than or smaller than that of B at the bottom of the ramp? Explain your answer.

b) Suppose the masses of the cylinders are the same but A has a larger radius than B. Is the speed of A at the bottom of the ramp the same, larger than or smaller than that of B at the bottom of the ramp? Explain your answer.

304 Rolling and sliding cylinders



Two identical cylinders can roll along a ramp. Both cylinders roll without slipping along the horizontal section at the base of the ramp. Along the sloped portion of the ramp, cylinder A encounters no friction and slips, but cylinder B rolls without slipping. *(131F2022)*

a) Both cylinders are released from rest at the top of the ramp. Is the speed of A at the bottom of the ramp the same, larger than or smaller than that of B at the bottom of the ramp? Explain your answer.

b) The cylinders are launched along the horizontal surface so that they arrive at the bottom of the ramp with the same velocity and the same angular velocity. Is the maximum height attained by A the same, larger than or smaller than that of B? Explain your answer.

305 Rolling ball

A 0.250 kg hollow ball with radius 0.10 m is held at rest at the top of a ramp that is 3.0 m long. The ramp is inclined at an angle of 15° above the horizontal. The ball is released and rolls without slipping. *(131F2022)*

a) Determine the angular velocity of the ball at the base of the ramp.

b) Determine the speed of the ball at the base of the ramp.

c) Does the speed of the ball at the base of the ramp depend on the mass of the ball? Explain your answer.

d) Does the speed of the ball at the base of the ramp depend on the radius of the ball? Explain your answer.

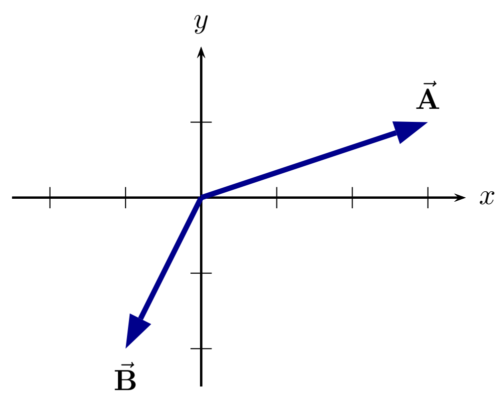
306 Vector cross products: algebraic

For each of the following, determine A_x, A_y, B_x, B_y and A_z and B_z (if applicable) and determine the cross product, $\vec{\mathbf{A}} \times \vec{\mathbf{B}}$. *Note: If your answer for the cross product does not contain* $\hat{\mathbf{i}}, \hat{\mathbf{j}}$ *or* $\hat{\mathbf{k}}$ *then it is very incorrect!*

a) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$
b) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}}$
c) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$
d) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}}$
e) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}} + 3\hat{\mathbf{k}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}}$
f) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}} + 3\hat{\mathbf{k}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} - 2\hat{\mathbf{j}}$
g) $\vec{\mathbf{A}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}} - 3\hat{\mathbf{k}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} + 2\hat{\mathbf{j}} + 3\hat{\mathbf{k}}$
h) $\vec{\mathbf{A}} = 1\hat{\mathbf{i}} - 2\hat{\mathbf{j}} + 3\hat{\mathbf{k}}$ and $\vec{\mathbf{B}} = 2\hat{\mathbf{i}} + 1\hat{\mathbf{j}} - 3\hat{\mathbf{k}}$

307 Vector cross product

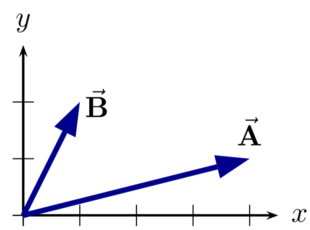
Two vectors $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$ are illustrated. Determine $\vec{\mathbf{A}} \times \vec{\mathbf{B}}$.



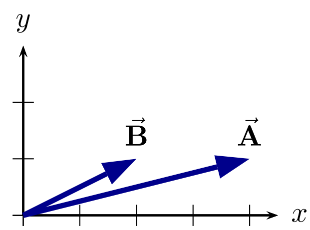
308 Vector cross products: geometric

For each of the following, express $\vec{\mathbf{A}}$ in component form $\vec{\mathbf{B}}$ using unit vectors and determine both cross products, $\vec{\mathbf{A}} \times \vec{\mathbf{B}}$ and $\vec{\mathbf{B}} \times \vec{\mathbf{A}}$. *Note: If your answer for the cross product does not contain* $\hat{\mathbf{i}}, \hat{\mathbf{j}}$ *or* $\hat{\mathbf{k}}$ *then it is very incorrect! (131F2022)*

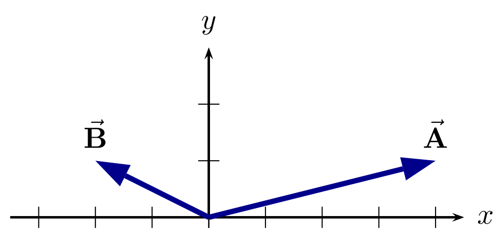
a)



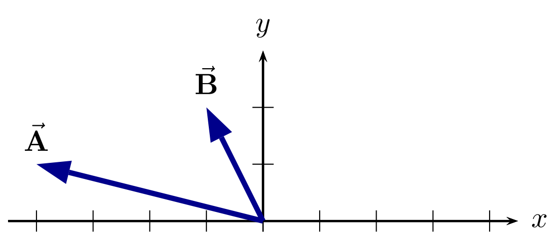
b)



c)

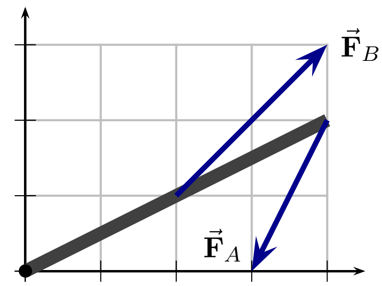


d)



309 Torques via cross product

A beam lies as illustrated; the grid units are meters. The beam can pivot about a point at the origin. Two forces that act on the beam are illustrated. *(131F2022)*



a) Determine the torque about the origin produced by $\vec{\mathbf{F}}_A = -100\,\mathrm{N}\hat{\mathbf{i}} - 200\,\mathrm{N}\hat{\mathbf{j}}$

b) Determine the torque about the origin produced by $\vec{\mathbf{F}}_B = 200\,\mathrm{N}\hat{\mathbf{i}} + 200\,\mathrm{N}\hat{\mathbf{j}}$

310 Rotational collision

A 0.150 kg solid disk with radius 0.050 m rotates at 180 revolutions per minute. A 0.400 kg ring with radius 0.030 m is held at rest and then gently dropped onto the disk so that its center coincides with the center of the disk. It sticks. Determine the angular velocity of the combination after the ring sticks to the disk. *(131F2022)*

311 Rotating disk and hoop

A disk with mass M and radius R rotates in a horizontal plane with constant angular velocity, ω_i. A hoop with mass M and radius R is gently lowered onto the disk so that the center of the hoop coincides with the center of the disk. The hoop sticks to the disk and the two rotate with angular velocity ω_f. Which of the following is true? *(131F2022)*

i) $\omega_f = \omega_i$

ii) $\omega_f = \frac{1}{2}\,\omega_i$

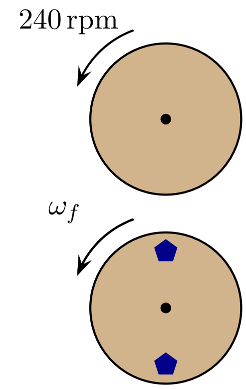
iii) $\omega_f = \frac{1}{\sqrt{2}}\,\omega_i$

iv) $\omega_f = \frac{1}{3}\,\omega_i$

v) $\omega_f = \frac{1}{\sqrt{3}}\,\omega_i$

Explain your answer.

312 Turntable and blocks



A circular 20 kg turntable with radius 0.50 m rotates at 240 rpm in a horizontal plane about an axle through its center. The mass of the turntable is uniformly distributed. Two small blocks, each with mass 5.0 kg are gently lowered onto the turntable and eventually stick at locations that are 3/4 of the distance from the axle to the rim. *(131F2022)*

a) Determine the angular velocity of the turntable after the blocks have settled on the turntable.

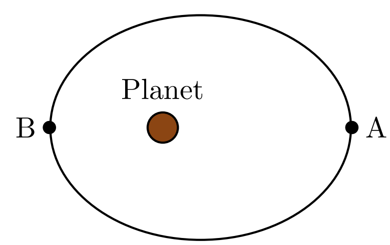
b) Determine the change in kinetic energy of the system from the moment before the blocks hit the turntable until they settle.

313 Merry-go-round

A merry-go-round is a large circular turntable which rotates horizontally about an axle through its center. Children can stand and move about on the merry-go-round. A particular merry-go-round has radius 2.0 m and moment of inertia 600 kgm^2. A 50 kg child stands at the edge of the merry-go-round and her parent pushes it so that it rotates at a constant rate of 40 rpm. The child then walks toward the center of the merry-go-round. Approximating the child as a point particle, determine the angular velocity of the merry-go-round when she is 0.30 m from the axle. *(131F2022)*

314 Elliptical orbit of a satellite

A satellite moves around a planet in an elliptical orbit. At all times the force exerted by the planet on the satellite points directly toward the planet. The satellite's motion can be analyzed by thinking of it as a point particle in a rotational orbit about the point where the planet is located. *(131F2022)*



a) Is the net torque (about the planet's location) on the satellite zero or not at all times? Explain your answer.

b) Is the angular momentum (about the planet's location) of the satellite constant at all times? Explain your answer.

c) Determine an expression for the angular momentum of the satellite in terms of its mass, speed and distance from the planet.

d) Using angular momentum, describe whether the satellite moves faster or slower at location A in comparison to location B.

Gravitation

315 Ordinary objects and gravitational forces

A 100 kg person stand near 4000 kg elephant. Their centers of mass are 1.8 m apart. Determine the gravitational force exerted by the person on the elephant. *(131F2022)*

316 Scale of gravitational forces

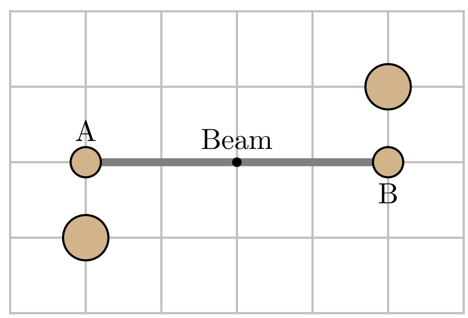
Celestial objects are much larger than a typical person with mass 90 kg and may be expected to exert much larger gravitational forces than the person. Suppose that this person stands 0.50 m away from a 20 kg dog. *(131F2022)*

a) Determine the ratio of the gravitational force exerted by Earth's Moon on the dog to the gravitational force exerted by the person on the dog.

b) Determine the ratio of the gravitational force exerted by Jupiter on the dog to the gravitational force exerted by the person on the dog. The nearest approach of Jupiter is about 6.3×10^{11} m. Are either of the forces exerted by celestial objects very much bigger?

317 Gravitational forces in a Cavendish balance

The Cavendish experiment involves two 400 g balls attached to a beam that can pivot about its center. Two other 1.50 kg balls are placed near to this in the illustrated configuration, where the grid units are each 2.0 cm. *(131F2022)*



a) Determine the next gravitational force exerted by the two larger balls on ball A.

b) Determine the net torque exerted on the beam by both balls.

318 Moons of a planet

A planet has two moons. Moon B has twice the mass of Moon A. Moon B has an orbit with twice the radius of the orbit of Moon A. *(131F2022)*

a) Let F_A be the force exerted by the planet on Moon A and F_B be the force exerted by the planet on Moon B. Which of the following is true? Explain your answer.

   i) $F_B = 4F_A$
   ii) $F_B = 2F_A$
   iii) $F_B = F_A$
   iv) $F_B = \frac{1}{2} F_A$
   v) $F_B = \frac{1}{4} F_A$

b) Let a_A be the acceleration of Moon A and a_B be the acceleration of Moon B. Which of the following is true? Explain your answer.

   i) $a_B = 4a_A$
   ii) $a_B = 2a_A$
   iii) $a_B = a_A$
   iv) $a_B = \frac{1}{2} a_A$
   v) $a_B = \frac{1}{4} a_A$

319 Acceleration due to Earth's gravity

Assume that Earth is a perfect sphere and that at sea-level the acceleration due to Earth's gravity is 9.81 ms. *(131F2022)*

a) Determine the altitude (above Earth's surface) at which the acceleration due to gravity is 10% less than at sea-level. Is it essential to know G and Earth's mass to answer this?

b) Determine fractional change in Earth's gravity at the top of Mount Everest (approximately 8900 m above sea-level).

320 Newton's cannonball

Newton's cannonball was a thought experiment in which a cannonball is fired from the top of a mountain and eventually orbits Earth. Suppose that a cannonball with mass m is fired horizontally from a mountain with altitude h above sea level, which is distance R_E from Earth's center. *(131F2022)*

a) **Starting with and using** Newton's Second Law, determine an expression for the cannonball's launch velocity, v so that it follows a circular orbit at height h above Earth's sea level.

b) Determine the speed with which the cannonball should be launched from the altitude of 8000 m above sea level to orbit as described above.

321 Mars' orbit

Mars orbits the Sun in an approximately circular orbit with radius 2.28×10^{11} m. The period of orbit is 1.88 years and Mars' mass is 6.42×10^{23} kg. *(131F2022)*

a) Use the data to determine the acceleration of Mars and the net force on Mars.

b) Use the result of the previous part and gravitational force exerted by the Sun on Mars to determine the mass of the Sun.

322 Planets orbiting a star

Two planets are observed orbiting a distant star. The orbital period of planet A is 2.5 yr and that of planet B is 12.5 yr. Let r_A be the orbital radius for planet A and r_B be that for planet B. *(131F2022)*

a) **Starting with and using** Newton's Second Law, determine an expression for the ratio of the orbital radii, r_B/r_A. Is it necessary to know the mass of the star in order to determine the ratio?

b) A third planet C has orbital period 40 yr and has a orbital radius 20 times that of Earth about the Sun. Determine the mass of the star.

323 Orbiting satellite

A satellite orbits a planet with mass M_p in a circular orbit with radius r. The satellite's speed is constant. *(131F2022)*

a) **Starting with and using** Newton's Second Law, derive an expression for the satellite's speed in terms of M_p and r.

b) Determine the speed of a satellite in a uniform circular orbit 60000 m above the surface of the dwarf planet Ceres (mass 9.4×10^{20} kg and radius 4.7×10^5 m).

324 Extended free fall above the Moon

An object is dropped from rest above the Moon's at a height (above the surface equal to twice the Moon's radius). Determine the speed of the object at the instant before it hits the Moon's surface. *(131F2022)*

325 Ball launch on Phobos

Phobos, a moon of Mars has mass $1.06 \times 10^{16}\,\mathrm{kg}$ and mean radius $11.3 \times 10^{3}\,\mathrm{m}$. A ball is launched vertically from the surface of Phobos. *(131F2022)*

a) Suppose that the ball is launched with speed $8.00\,\mathrm{m/s}$. Determine the maximum distance, from the center of Phobos, that it reaches.
b) Determine the minimum speed with which the ball must be launched to escape Phobos.

326 Escape velocity from an asteroid

The first space mission to land a craft on an asteroid was the Hayabusa mission that landed on the asteroid 25143 Itokawa, whose mass is $3.5 \times 10^{10}\,\mathrm{kg}$. The asteroid is not spherical. However, if it were spherical, its diameter would be about $330\,\mathrm{m}$. Consider an object launched from the asteroid surface, assuming that it is spherical. Determine the minimum speed that it should have to escape the asteroid completely. What does this imply about the difficulty of landing a spacecraft on the surface? *(131F2022)*