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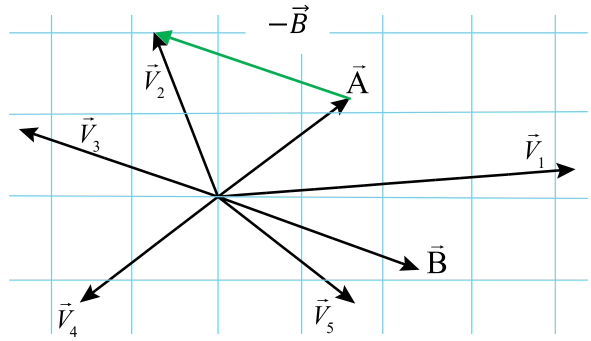
I. [45 pts] Multiple Choice (5 pts each): Mark your answer on BOTH the bubble sheet and this page.



1. [5 pts] The vector in the figure that could represent the vector $\vec{A} - \vec{B}$ is:

   A. $\overrightarrow{V_5}$

   B. $\overrightarrow{V_4}$

   C. $\overrightarrow{V_3}$

   D. $\overrightarrow{V_2}$

   E. $\overrightarrow{V_1}$

   The vector $-\vec{B}$ is shown in the diagram above and vector $\vec{V}_2$ represents the addition of vector $\vec{A}$ and $-\vec{B}$. $\vec{V}_2 = \vec{A} + (-\vec{B})$

2. [5 pts] A sandbag is dropped from a rising air balloon and hits the ground 7.00 seconds later. From what height was the sandbag released if at the moment it was released, the balloon was traveling upward at 3.00 m/s?

   A. 54.0 m

   B. 219 m

   C. 240 m

   D. 439 m

   E. 480 m

   We can use constant acceleration kinematics to solve this problem.

$$\Delta y = v_{iy}\Delta t - \frac{1}{2}g(\Delta t)^2$$

$$\Delta y = (3\text{ m/s})(7\text{ s}) - \frac{1}{2}\left(9.8\frac{\text{m}}{\text{s}^2}\right)(7\text{ s})^2 = -219\text{ m}$$

   The answer above shows that the sandbag falls 219 m, which means that it must have been released 219 m above the ground.

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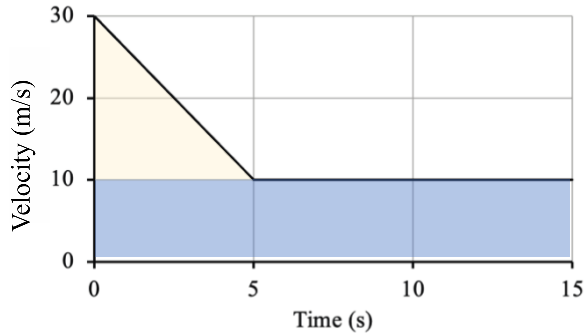
3. [5 pts] The graph shows the instantaneous velocity of a car during 15 s of its motion. The distance traveled by this car during this 15-s interval is:



A. 50 m

B. 100 m

C. 150 m

D. 200 m

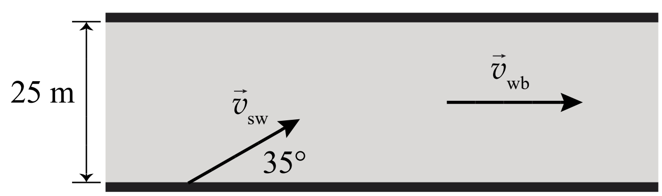
E. 250 m

The displacement is equal to the area under the velocity-time curve.

$$\Delta x = area = area_{triangle} + area_{rectangle}$$

$$\Delta x = \frac{1}{2}(5\text{ s})(20\text{ m/s}) + (15\text{ s})(10\text{ m/s}) = 200\text{ m}$$

4. [5 pts] A student swims across a 25-m wide river at an angle of 35° with respect to the riverbank. She swims at a speed of 1.5 m/s ($|\vec{v}_{sw}|$) with respect to the water. The water is flowing at 0.50 m/s with respect to the bank ($\vec{v}_{wb}$) as shown. How far downstream of her starting point is the student when she reaches the other side of the river?



A. 28 m

B. 31 m

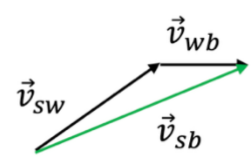
C. 33 m

D. 42 m

E. 50 m

We can find the swimmer's velocity with respect to the Earth/riverbank (b) as follows:

$$\vec{v}_{sb} = \vec{v}_{sw} + \vec{v}_{wb}$$



From the diagram at right, we can see that the vertical component of $\vec{v}_{sb}$ is the same as the vertical component of $\vec{v}_{sw}$, and the horizontal component of the $\vec{v}_{sb}$ is the sum of the horizontal component of $\vec{v}_{sw}$ and $\vec{v}_{wb}$.

If we call the vertical direction y, and the horizontal component x, we can write the following equations.

$$v_{sb,y} = v_{sw} \sin 35°$$

$$v_{sb,x} = v_{sw} \cos 35° + v_{wb}$$

The time to cross the river is equal to the width of the riverbank divided by the y-component of the swimmer's velocity.

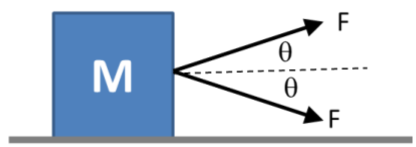
$$\Delta t = \frac{\Delta y}{v_y} = \frac{25 \text{ m}}{v_{sw} \sin 35°}$$

And the distance that the swimmer travels in the x-direction is the product of their horizontal velocity and the time traveling across the river.

$$\Delta x = v_x \Delta t = (v_{sw} \cos 35° + v_{wb}) \frac{25 \text{ m}}{v_{sw} \sin 35°}$$

$$\Delta x = \left((1.5 \text{ m/s}) \cos 35° + 0.5 \text{ m/s}\right) \frac{25 \text{ m}}{(1.5 \text{ m/s}) \sin 35°} = 50 \text{ m}$$

5. [5 pts] A block of mass $M = 4.0$ kg is at rest on a surface. The coefficient of static friction between the floor and block is 0.45. A pair of symmetrically oriented cables, as shown, each applies a 12 N force on the block. What is the largest angle θ that will just begin to make the block move? (That is, for larger angles, the block remains at rest.)



A. 42.7°

B. 24.3°

C. 18.7 °

D. 47.3°

E. Cannot determine from provided information

At the point of where the box slips, the external horizontal force is equal to the maximum static friction force.

$$F_{ext,x} = f_{s,max}$$

$$F_{pc,x} = \mu_s n_{fc}$$

The applied forces have equal x-components pointing in the same direction and y-components pointing in opposite directions. The y-components thus sum to zero and the normal force on the block is equal to the magnitude of the gravitational force or mg. We can now solve for the angle.

$$F_{pc,x} = 2F_{pc}\cos\theta = \mu_s n_{fc} = \mu_s mg$$

$$\cos\theta = \frac{\mu_s mg}{2F_{pc}}$$

$$\theta = \cos^{-1}\left(\frac{\mu_s mg}{2F_{pc}}\right) = \cos^{-1}\left(\frac{(0.45)(4.0\text{ kg})(9.8\text{ m/s}^2)}{2(12\text{ N})}\right) = 42.7°$$

6. [5 pts] A golf ball is struck at an angle of 40.0° with respect to the horizontal. Its initial speed is 35.0 m/s. The ball hits a house 80.0 m away and breaks a window. How high off the ground is the ball when it strikes the window?

   A. 5.2 m

   B. 13.8 m

   C. 23.5 m

   D. 33.6 m

   E. 54.5 m

   By treating the horizontal and vertical motions of the golf ball independently, we can solve for the height. The change in the ball's vertical position is given as:

$$\Delta y = v_{iy}\Delta t - \frac{1}{2}g(\Delta t)^2 = v_i\sin(40°)\,\Delta t - \frac{1}{2}g(\Delta t)^2$$

   And the time in the air can be determined by the x-velocity and the change in horizontal position.

$$\Delta t = \frac{\Delta x}{v_x} = \frac{\Delta x}{v_i\cos(40°)}$$

   We can now solve for the height:

$$\Delta y = v_i\sin(40°)\left(\frac{\Delta x}{v_i\cos(40°)}\right) - \frac{1}{2}g\left(\frac{\Delta x}{v_i\cos(40°)}\right)^2$$

$$\Delta y = \tan(40°)\,\Delta x - \frac{1}{2}g\left(\frac{\Delta x}{v_i\cos(40°)}\right)^2$$

$$\Delta\Delta y = \tan(40°)\,(80\text{ m}) - \frac{1}{2}\left(9.8\frac{\text{m}}{\text{s}^2}\right)\left(\frac{80\text{ m}}{\left(35\frac{\text{m}}{\text{s}}\right)\cos(40°)}\right)^2 = 23.5\text{ m}$$

7. [5 pts] A merry-go-round completes one revolution in 30 s. What is the speed of a rider located at a distance 3.0 m from the center of the merry go-round?

   A. 0.1 m/s

   B. 0.2π m/s

   C. 2π m/s

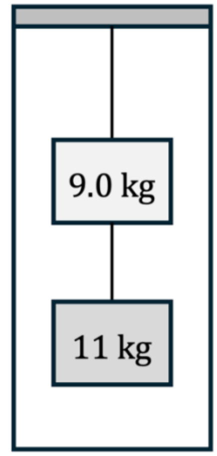
   D. 6π m/s

   E. 30 m/s

   We can solve for the speed as follows:

$$v = r\omega = (3.0 \text{ m})\left(\frac{2\pi}{30 \text{ s}}\right) = \frac{1}{5}\pi \text{ m/s} = 0.3 \text{ m/s}$$

8. [5 pts] A 9.00 kg and an 11.0 kg block are fastened to the ceiling of an elevator, as shown. The elevator accelerates upward at 2.20 m/s^2. Find the tension in the bottom rope.



   A. 24.2 N

   B. 44.0 N

   C. 106 N

   D. 132 N

   E. 196 N

   There are two forces on the 11-kg block, an upward tension force and a downward gravitational force. We can apply Newton's second law to the 11 kg block to solve for the tension in the bottom rope.

$$F_{net} = ma$$

$$T - F_G = ma$$

$$T = ma + F_G = ma + mg = m(a + g)$$

$$T = (11\text{ kg})(2.2\text{ m/s}^2 + 9.8\text{ m/s}^2) = 132\text{ N}$$

9. [5 pts] A medium-sized jet has a 3.80-m-diameter fuselage and a loaded mass of 85,000 kg. The drag on an airplane is primarily due to the cylindrical fuselage, and aerodynamic shaping gives it a drag coefficient of 0.0370. How much thrust must the jet's engines provide to cruise at 230 m/s at an altitude where the air density is 1.10 kg/m^3?

   A. 0.61 kN

   B. 9.06 kN

   C. 12.2 kN

   D. 15.5 kN

   E. 24.4 kN

   Since the airplane is moving at a constant speed, the thrust force must be equal in magnitude of the drag force.

$$F_{thrust} = F_{drag}$$

$$F_{thrust} = \frac{1}{2}C_D\rho Av^2 = \frac{1}{2}(0.037)(1.1\text{ kg/m}^3)(\pi(1.9\text{ m})^2)(230\text{ m/s})^2 = 12{,}209\text{ N} = 12.2\text{ kN}$$

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II. [15 points total] Lab multiple-choice questions

The situation below applies to the following two questions.

10. [5 pts] Two groups of students want to find the average speed of a cart moving in a straight line. They use a clock and a ruler as described below:

    Group 1: Records the position of the cart at equally-spaced time intervals.

    Group 2: Records the time at which the cart passes specific, equally-spaced positions.

    Which are the dependent and independent variables in each experiment? **(You can choose more than one answer.)**

    A. For Group 1, position is the dependent quantity, and time is the independent quantity.

    B. For Group 1, time is the dependent quantity, and position is the independent quantity.

    C. For Group 2, position is the dependent quantity, and time is the independent quantity.

    D. For Group 2, time is the dependent quantity, and position is the independent quantity.

    E. None of the above

11. [5 pts] Group 2 conducts 4 trials. For x = 10.0 cm they find the four times shown at right on their clock.

    Based on the ideas developed in labs A1 and A2, what are the corresponding *instrumental* and *random* uncertainties? (Use one significant digit.)

    A. Instrumental uncertainty is 0.005 s Random uncertainty is 0.3 s

    B. Instrumental uncertainty is 0.05 s Random uncertainty is 0.3 s

    C. Instrumental uncertainty is 0.005 s Random uncertainty is 0.05 s

    D. Instrumental uncertainty is 0.3 s Random uncertainty is 0.005 s

    E. Instrumental uncertainty is 0.3 s Random uncertainty is 0.05 s

    00: 02.08
    min sec

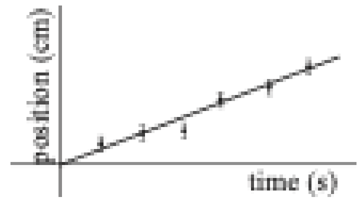
    00: 01.53
    min sec

    00: 02.12
    min sec

    00: 01.59
    min sec

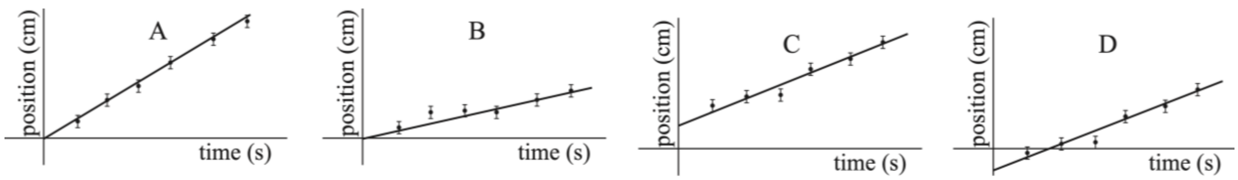
    Answer: Per lab, instrumental uncertainty for the clock is half the smallest division. The average time is 1.83 s. The largest deviation from average is 1.53 s, which is 0.3 s from the average.

12. [5 pts] In Lab A1, recall that students placed pennies on a piece of paper at 1s intervals to mark a cart's location. Group 1's graph is at right.



Group 2 used the same cart. In their case, the student who put down the pennies waited until they heard the metronome click, then took a penny from their hand, and finally reached across the table to the cart and placed the penny next to it. After graphing, Group 2 realized this procedure introduced a systematic error.

Which graph below **best** shows the data collected by Group 2? Assume the systematic error is the same for each instant. (Answer: C)



E. Graph same as intial group

When each penny was placed, the cart had moved past where it was at the metronome click. If the systematic error is the same for each click and the cart had constant speed, then the extra time for each location is the same. Thus, the graph is shifted upward.

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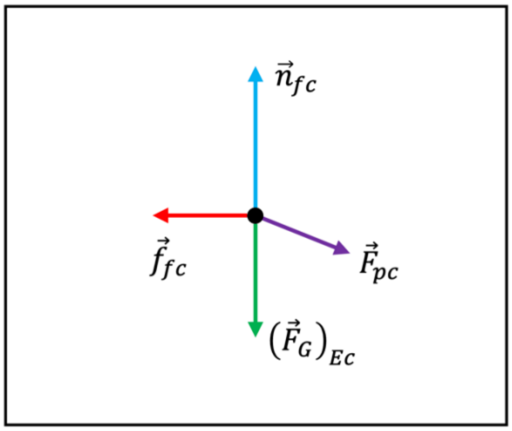
III. Lecture long-answer questions (25 points total)

A student pushes on a large crate with a force 300.0 N at an angle of 21.0° from the horizontal, as shown. The crate is on a rough floor and has a mass of 32.0 kg.

13. [4 pts] In the space below, draw a free-body diagram for the crate, *assuming it is at rest*. Label the forces to indicate the object exerting the force and the object on which the force is exerted.



14. [5 pts] What is the magnitude of the normal force exerted on the crate by the floor? Show your work.

We can apply Newton's second law to determine the magnitude of the normal force. The net force on the crate in the y-direction is zero, since the crate has no vertical acceleration.

$$F_{net,y} = 0$$

$$n_{fc} - (F_G)_{Ec} - F_{pc,y} = 0$$

$$n_{fc} = (F_G)_{Ec} + F_{pc,y}$$

$$n_{fc} = (32\text{ kg})(9.8\text{ m/s}^2) + (300\text{ N})\sin 21°) = 421\text{ N}$$

15. [5 pts] The coefficient of static friction between the crate and the floor is μ_s. What is the minimum value of μ_s such that the crate remains at rest? Show your work.

To find the minimum value of μ_s, we need to consider the horizontal forces on the crate. We are looking at the case where the crate is just about to slip, which corresponds to the external horizontal forces being equal to the maximum static friction force. The calculations are shown below.

$$F_{ext,x} = f_{s,max}$$

$$F_{pc,x} = \mu_s n_{fc}$$

$$\mu_s = \frac{F_{pc,x}}{n_{fc}} = \frac{(300\text{ N})\cos 21°}{421\text{ N}} = 0.67$$

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Since the student cannot move the crate, they try a different method. The student ties a rope to the crate and pulls directly to the right with a force of 310 N. This force is large enough to get the crate to move, and the coefficient of kinetic friction between the crate and the floor is $\mu_k = 0.63$.

16. [5 pts] Determine the magnitude of the acceleration of the crate. Show your work.

The crate will accelerate in the x-direction, and we can use Newton's second law to find the magnitude of the crate's acceleration.

$$F_{net,x} = ma_x$$

$$310\text{ N} - f_{k,fc} = ma_x$$

$$310\text{ N} - \mu_s n_{fc} = ma_x$$

$$310\text{ N} - \mu_s mg = ma_x$$

$$a_x = \frac{310\text{ N} - \mu_k mg}{m} = 3.51\text{ m/s}^2$$

17. [5 pts] If the crate starts from rest, what is the speed of the crate after it has traveled 2.0 m? Assume the student applies a constant 310-N force as shown in the diagram above. Show your wok.

We can use constant acceleration kinematics to solve for the speed of the crate after it has traveled 2.0 m.

$$v_f^2 = v_i^2 + 2a_x\Delta x$$

$$v_f = \sqrt{2a_x\Delta x} = \sqrt{2(3.51\text{ m/s}^2)(2.0\text{ m})} = 3.75\text{ m/s}$$

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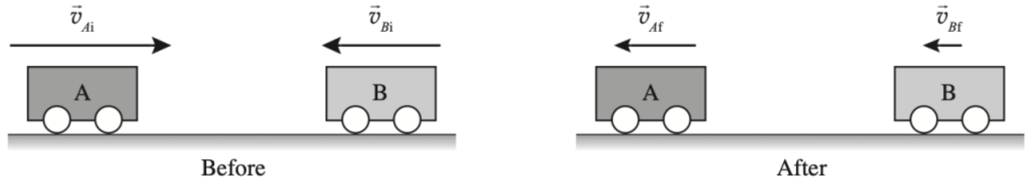
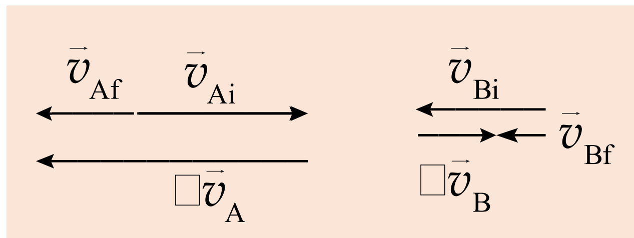
IV. Tutorial and lab long answer questions (15 points total)

18. [6 pts] Two carts, A and B, roll toward each other on a level table. The vectors represent the velocities of the cars just before and just after they collide.

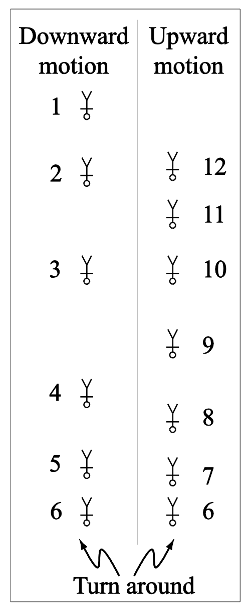


Draw and label a vector **for each cart** to represent the *change in velocity* ($\Delta\vec{v}$) of each cart. The magnitude and direction of your vectors should be consistent with those shown. Show your work.

Answer: Change in velocity is the vector added to the initial velocity to give the final velocity. Addition is done by placing the tail of $\Delta\vec{v}$ at the tip of $\vec{v_i}$. $\vec{v_f}$ is the arrow from the tail of $\vec{v_i}$ to the tip of $\Delta\vec{v}$.

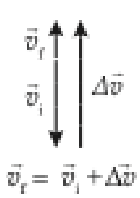


19. [4 pts] The diagram at right shows a bungee jumper's location at **equal time intervals**. At t_1 she steps off a bridge and falls straight down. At t_6, she is at the bottom with the cord fully stretched. She then begins moving upward.



For the interval between t_4 and t_8, draw arrows below to show (a) the *direction* of the change in velocity $\Delta\vec{v}_{4,8}$ and (b) the *direction* of the average velocity $\vec{v}_{\text{avg }4,8}$. Explain/show your work for each.

Direction of the *change in velocity* ($\Delta\vec{v}_{4,8}$)



Direction of the *average velocity* ($\vec{v}_{\text{avg }4,8}$)

At t_4, the bungee jumper is moving downward, and at t_8, the bungee jumper is moving upward. The direction of the jumper's velocity points in the same direction as their motion. Since the velocity of the jumper changes from a downward direction to an upward direction, the change in velocity points upward as shown in the left diagram.

The displacement of the bungee jumper from t_4 to t_8 is downward. Since $\vec{v}_{avg} = \frac{\Delta\vec{s}}{\Delta t}$, and $\Delta\vec{s}$ is downward, the direction of the average velocity is also downward.

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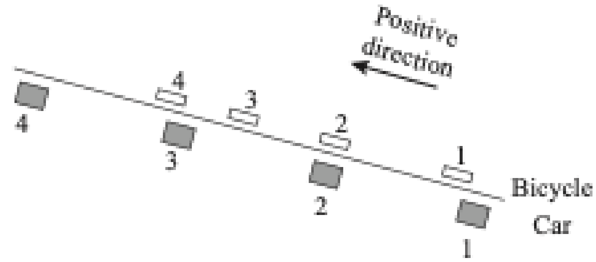
20. [5 pts] A bicycle slows down as it coasts up a hill while a car drives up the hill at constant speed. The diagram at right shows their positions in the ground reference frame at equally spaced time instants 1–4.



In the reference frame of the car, is the bicycle *speeding up, slowing down, or moving at constant speed* at instant 2? Explain.

In the car's frame, the bicycle has a greater displacement for each consecutive time interval. Thus, the bicycle is speeding up as it moves down along the hill relative to the car.