Problem 1 (21 points) Short Questions (3 points each)

1. The figure to the right shows two pucks on a frictionless table. Puck I is three times more massive than puck II. Starting from rest, both pucks are simultaneously and continuously pushed across the table by equal forces. Which puck will have the greater kinetic energy at the finish line?
   (a) puck I
   (b) puck II
   (c) They will both have the same energy.
   (d) Too little information to answer.

2. In the figure above, which will have the larger velocity
   (a) puck I
   (b) puck II
   (c) They will both have the same velocity
   (d) Too little information to answer.

3. Suppose you are pushing (directly horizontally) on a large box that moves across the floor at a constant speed. What do you know about the forces on the box?
   (a) The force you apply equals the frictional force on the box.
   (b) The force you apply is greater than the frictional force on the box.
   (c) The force you apply is greater than the weight of the box.
   (d) The force you apply is greater than the force that the box applies on you.
   (e) None of above

Questions 4 and 5 refer to a 16-lb bowling ball as it hits a 2-lb bowling pin.

4. Compare the relative sizes (magnitudes) of the forces on the ball and pin.
   (a) The ball exerts a greater force on the pin.
   (b) The pin exerts a greater force on the ball.
   (c) They exert equal size (magnitude) forces on each other.
   (d) Only the ball exerts a force on the pin.
   (e) Only the pin exerts a force on the ball.

5. During the impact of the bowling ball and pin, how does the acceleration of the ball and pin compare?
   (a) The ball accelerates less than the pin.
   (b) The ball and the pin have the same acceleration.
   (c) The ball and the pin have equal accelerations, but in opposite directions.
   (d) The ball accelerates more than the pin.
   (e) It is impossible to tell without knowing the velocity of the ball.
Problem 1 (21 points) Continued …

6. In order to start a car with a dead battery, you are pushing it along a road at a steadily increasing speed:

(a) the size of the force that you are exerting on the car is equal to that of the car pushing back against you.
(b) the size of the force that you are exerting on the car is less than that of the car pushing back against you.
(c) the size of the force that you are exerting on the car is greater than that of the car pushing back against you.
(d) whether the size of the force that you are exerting on the car is greater or less than that of the car pushing back against you depends on the weight of the car.
(e) whether the size of the force that you are exerting on the car is greater or less than that of the car pushing back against you depends on the frictional force.

7. Suppose you attach a ball to a string that you hold in your hand at point O (as shown in the figure to the right) and rotate it at a high constant speed in a vertical plane in front of you. The circle shows the path of the ball. Which of the free-body diagrams to the right represents the forces acting on the ball when it is at the bottom of the circular path and moving towards the right? Ignore air resistance and circle your answer.
Problem 2 (25 points) Learning Newton’s 2\textsuperscript{nd} Law during Spring break

You are leaving College Station on Spring break, but, unfortunately, your car breaks down in the middle of nowhere. You call a tow truck (weighing $W_{\text{truck}}$) on your cell phone. The driver attaches his cable to your car, weight ($W_{\text{car}}$) at an angle of ($\theta$) with the horizontal. He tells you that his cable strength is $F_T$ (in other words, the cable is broken if the tension force exceeds $F_T$) and that plans to take time ($T$) to tow your car (at a constant acceleration from rest) in a straight line along the flat road until he reaches a maximum speed limit of ($V_f$). Will the cable break? You assume that the coefficient of rolling friction between your car’s tires and the surface of the road is $\mu$.

Be sure to write down ALL of your assumptions, force diagrams and complete formula derivations. Box answers.

\[ a = \frac{V_f}{T} \]
\[ W_{\text{car}} = N + F_T \cos \theta \]
\[ f = \mu N = \mu (W_{\text{car}} - F_T \sin \theta) \]
\[ F_T \cos \theta - f = m a = \frac{W_{\text{car}}}{g} \]

\[ F_T = \frac{\mu + \frac{V_f}{gT}}{\sin \theta + \mu \cos \theta} W_{\text{car}} \]
Problem 3 (25 points) – Riding a loop-the-loop

You are employed at Texas Aggie Flag Co (TAFCo) that operates an amusement park in College Station. One of main attractions is a new loop-the-loop. The company president Teruki Kamon wants to know the minimum height of point A such that a car slides along the track without falling off at the top (point B). You, as Chief Engineer, have to submit a technical memo before 7 pm today. In the memo, you first state the assumptions: (i) the car slides without friction around the track; (ii) it starts from rest at point A at height $H$ above the bottom of the loop; (iii) the car is treated as a particle; and (iv) the air resistance is ignored.

a) (5 pts) Draw a free-body diagram for the car at point B when the car moves around the loop safely.

b) (5 pts) I have covered this topic in my lecture, where I showed two key concepts to solve this problem. What were they?

c) (10 pts) Express the minimum value of height $H$ (in terms of $R$) such that the car moves around the loop without falling off at the top (point B)?

d) (5 pts) If $H = 3.50 \, R$ and $R = 20.0 \, m$, compute the speed, radial acceleration, and tangential acceleration of the passengers when the car is at point C, which is the end of the horizontal diameter. Show these acceleration components in a diagram, approximately to scale.

\[ mg = \frac{1}{R} \]  

\[ m \frac{v^2}{R} \]  

\[ \text{Conservation of mechanical energy:} \]

\[ mgh = 2mgR + \frac{1}{2}mv^2 \]  

\[ H = \frac{5}{3} R \]

\[ mgh = mgh = mgh + \frac{1}{2}mv^2 \]

\[ v = 5g \]

\[ a = 5g \]

\[ \text{at top of the track, gravity provides the centripetal force.} \]

\[ \text{the critical situation is that the normal force from the track vanishes.} \]

\[ \text{obviously, when } N \rightarrow 0, \text{ the car is still safe.} \]

\[ \text{circular motion, } \]

\[ \text{conservation of mechanical energy.} \]

\[ \text{(b) } \]

\[ \text{1. circular motion, } \]

\[ \text{2. conservation of mechanical energy.} \]

\[ \text{(c) at top of the track, gravity provides the centripetal force.} \]

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\[ \text{circular motion, } \]

\[ \text{conservation of mechanical energy.} \]

\[ \text{(b) } \]

\[ \text{1. circular motion, } \]

\[ \text{2. conservation of mechanical energy.} \]
Problem 4: (30 points) – Piano delivery

You are employed at a delivery company, Texas Delivery Co (TDC). Since your boss Teruki Kamon knows you had passed PHYS218 from Texas A&M University, he asks you to report a delivery plan of a very expensive piano (mass \( M = 200 \) kg). You push the piano horizontally. It slides \( d = 5.00 \) m down a \( \theta = 30.0^\circ \) incline. The magnitude of the horizontal force is \( F_p = 500 \) N. Assume a coefficient of friction \( \mu_k = 0.280 \). The safety instruction requires the piano's speed at the bottom of the incline must be less than 1.00 m/s. Determine the speed of the piano (assuming it is zero initially) after this displacement and check if your plan meets the safety requirement. Note that the magnitude of the gravitational acceleration near the Earth's surface is \( g = 9.80 \) m/s\(^2\).

(a) (10 pts) Sketch a free-body diagram for the piano.

(b) (15 pts) Derive the expression (in terms of \( M, d, \theta, \mu_k, F_p, \) and/or \( g \)) needed to calculate numerical value of the piano's speed.

(c) (5 pts) Calculate the numerical value and state the conclusion of your report. This report must include how you can improve the safety problem if you find the piano’s speed exceeds 1.00 m/s.

\[ u = \left[ 2 \times \frac{mg \sin \theta - F \cos \theta - \mu_k mg \cos \theta - \mu F \sin \theta}{m} \right]^{1/2} \]

Approach 1:

Newton's 2nd Law:

(b) Decompose \( F \) and \( mg \) into the direction along and vertical to the incline.

in the vertical direction: \( N = mg \cos \theta + F \sin \theta \)

in the direction along the incline (x-direction): \( m \ddot{a}_x = mg \sin \theta - \mu N - F \cos \theta \)

\[ \ddot{a}_x = (mg \sin \theta - F \cos \theta - \mu mg \cos \theta - \mu F \sin \theta) / m \]

\[ u = \left[ 2 \times \frac{mg \sin \theta - F \cos \theta - \mu mg \cos \theta - \mu F \sin \theta}{m} \right]^{1/2} \]

(c) \( d = 5.00 \) m, \( M = 200 \) kg, \( F = 500 \) N, \( \mu = 0.28 \), \( \theta = 30^\circ \)

\[ u = \left[ 2 \times \frac{mg \sin \theta - F \cos \theta - \mu mg \cos \theta - \mu F \sin \theta}{m} \right]^{1/2} \]

Dr. Kamon will force you to use Matlab to solve this problem to solve this part (see next page)

Approach 2 (see next page)

Three ways to reduce the speed:

i) Increase \( F \)

ii) Manage to increase \( \mu \)

iii) Reduce the angle of the incline.
Problem 4: (30 points) – cont’d for your solutions

Approach 2: Work-energy theorem:

The difference is in part (b)

\[ W_{\text{external}} = E_f - E_i = (k_f - k_i) + (U_f - U_i) \quad (4) \]

\[ k_f - k_i = \frac{1}{2}mv^2 \quad (2) \]

\[ U_f - U_i = -mg \cdot d \cdot \sin \theta \quad (2) \quad (s = s_{\text{om}}) \]

\[ W_{\text{external}} = W_f + W_g + W_F \]

\[ W_f = -f \cdot d \cdot \cos \theta = -MN \cdot d \cdot \cos \theta \quad (3) \]

\[ W_g = mg \cdot d \cdot \sin \theta \quad (3) \]

\[ W_F = -F \cdot d \cdot \cos \theta \quad (3) \]

\[ -MN \cdot s + mgd \cdot \sin \theta - F \cdot d \cdot \cos \theta = \frac{1}{2}mv^2 + mgd \cdot \sin \theta \]

\[ v = \left[ 2d \left( mg \sin \theta - \mu N - F \cos \theta \right) \right]^{1/2} \]

\[ = \left[ 2d \left( mg \sin \theta - \mu mg \cos \theta - \mu F \sin \theta - F \cos \theta \right) \right]^{1/2} \quad (1) \]