Summer Physics Name: **KEY**

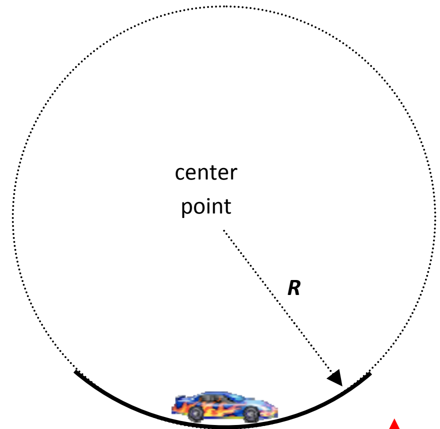
Midterm Exam Part B: Newton's Laws, Centripetal Motion, Statics, Conservation Laws, and SHM

Part 2: Centripetal Motion & Statics (Step 3)

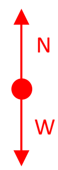
PLEASE use g = 10 m/s^2 instead of 9.8 m/s^2

1. An 800 kg car is driving through a rounded dip in the road with radius of curvature R = 115 m. Calculate the normal force acting on the car if the car is (a) moving very slowly (essentially at rest); (b) moving with a speed of 20 m/s; and (c) moving with a speed of 50 m/s.

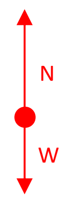
   In your solution, include (i) an explanation of your approach to the problem; (ii) a free body diagram; and (iii) an understandable numerical solution. Assume the car is going at constant speed throughout the dip.



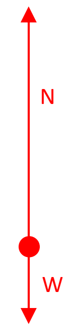
(a) mv^2/r = 0, so net force is equal to 0, so N = W = 8000 N.



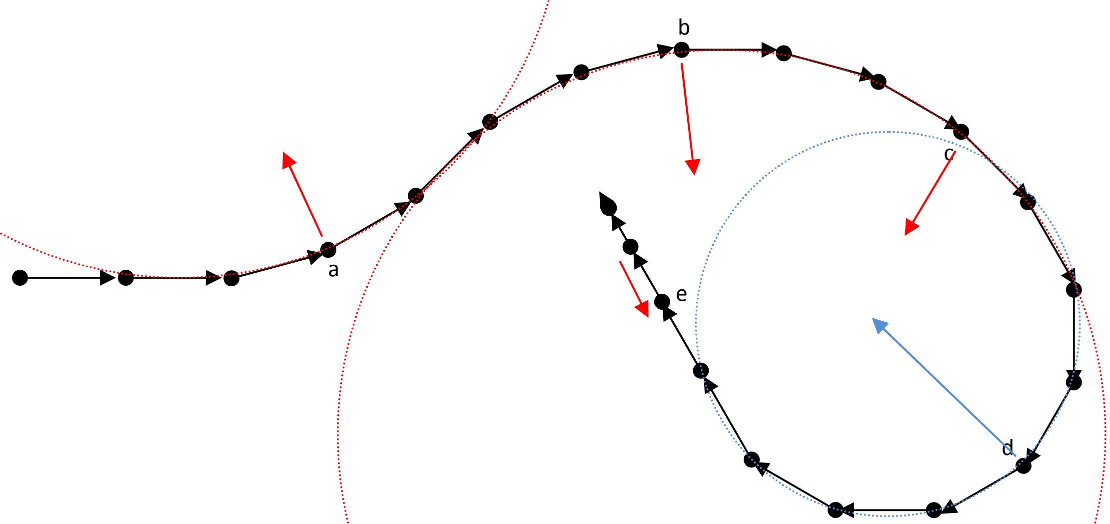
(b) mv^2/r = 2800 N, so net force is equal to 2800 N (upward), so N = 8000 N + 2783 N = 10,800 N



(c) mv^2/r = 17400 N, so net force is equal to 17400 N (upward), so N = 8000 N + 17400 N = 25,400 N



2. Below you'll find another of these 'motion diagrams' that shows a series of velocity vectors separated by 1 second time intervals.



   a. Sketch in vectors which show the direction of the acceleration at points (a) through (e).

   b. At which point ((a) through (d)) is the centripetal acceleration highest? How do you know?

At point D (in blue) – since v is the same otherwise, the acceleration is highest where r is *smallest*.

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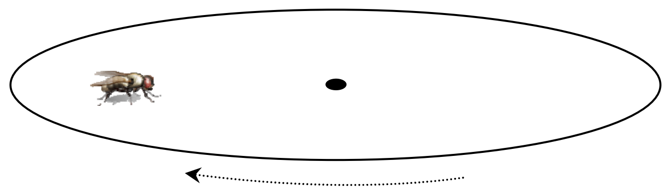
3. A fly is standing on a rotating turntable (a record player, say), as shown:

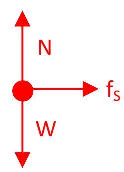


The distance from the center of the turn table to the spot where the fly is standing is 30 cm. The fly has a very small mass (12 mg) but is able to exert a relatively large static friction force (0.0001 N) due to the stickiness of the bottoms of his feet.

You turn on the turntable and the fly begins rotating faster and faster. Eventually, the fly reaches some speed where it can no longer hold on, and is "flung" off.

Calculate this critical speed. In your solution, include a free body diagram for the ant when it is still "holding on." Draw your FBD to match the drawing above.

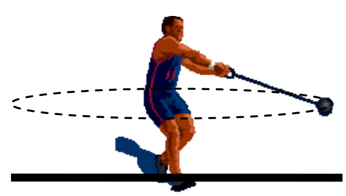
The static friction force is what keeps the fly moving in a circle – if this force is exceeded, the fly just moves in a straight line, and so appears to be "flung" off the turntable. The critical speed is when the maximum frictional force is equal to mv^2/r :



$0.0001\text{ N} = mv^2/r = (0.000012\text{ kg})v^2/(0.3\text{ m})$

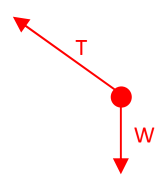
Solve for v = 1.6 m/s.

4. Paul is practicing his hammer throw, which requires swinging a heavy (2 kg) metal ball attached to a wire in a circle, as shown in the diagram. The radius of the dashed circle is 1.5 m.



a. Draw a schematic free-body diagram for the ball in the position shown.

b. The tension in the rope is 60 N. What is the speed of the ball?



Since the ball is accelerating horizontally, but not vertically, it must be that the vertical component of the tension equals the weight. So $T_y = W = 20$ N.

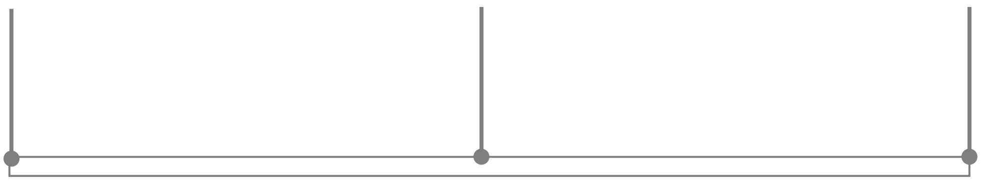
The total tension is 60 N, so we can figure out the horizontal component:

$T_x^2 + T_y^2 = T^2$ .... so $T_x^2 + (20\text{ N})^2 = (60\text{ N})^2$ .... you can solve this to get $T_x = 56.3$ N

Now we just set this equal to the centripetal force (since only the horizontal component of tension is acting on the hammer): $56.3\text{ N} = mv^2/r = (2\text{ kg})v^2/(1.5\text{ m})$ ... solve for v = 6.5 m/s.

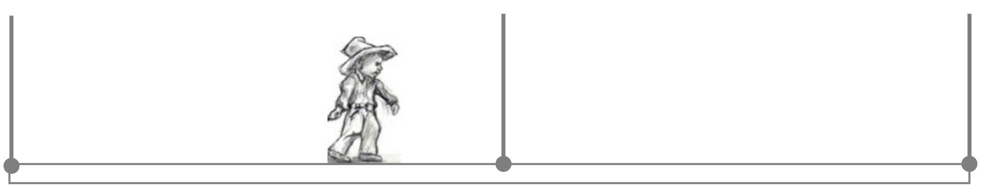
NOTE: the following problem was omitted from grading – the problem is under-constrained and so unsolvable as presented.

5. A wooden board 3.0 m in length with a weight of 300 N is supported on each end and at the middle by tensioned ropes.



   a. Begin by calculating the tension in each rope for the system at rest.

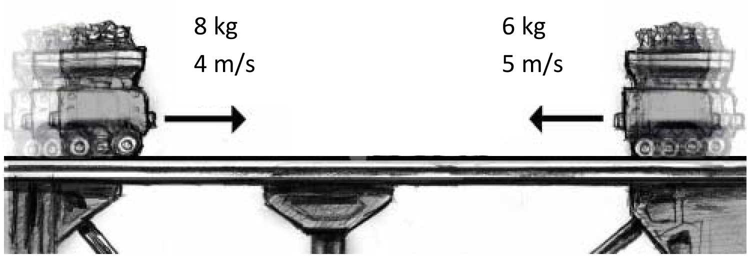
   b. The system is at rest, but now a 400 N window washer is standing a distance of 1.10 m from the left end. (Times are still tough, kid.) Calculate the tension in each of the ropes. Label each rope in the drawing with its tension once you're finished.



Summary Physics Name: **KEY**

Midterm Exam Part B: Newton's Laws, Centripetal Motion, Statics, Conservation Laws, and SHM

Part 2: Conservation Laws & SHM (Step 3)



1. Two carts are on a collision course as depicted in the picture above.

   a. What is the initial momentum of the more massive cart?

   p = mv = (8 kg)(4 m/s) = 32 kg·m/s (rightward)

   b. If the collision is inelastic (they stick together), then what is their final velocity? Include a direction in your answer.

   The total initial momentum is $p_1 + p_2$ = 32 kg·m/s (rightward) + (-30 kg·m/s (leftward)) = 2 kg·m/s (rightward). The final momentum must be the same – momentum is conserved in the collision. So the combined mass of 14 kg is moving rightward with a momentum of 2 kg·m/s, so the velocity must be v = p / m = 2 kg·m/s / 14 kg = 0.143 m/s.

   c. What impulse is delivered to the more massive cart?

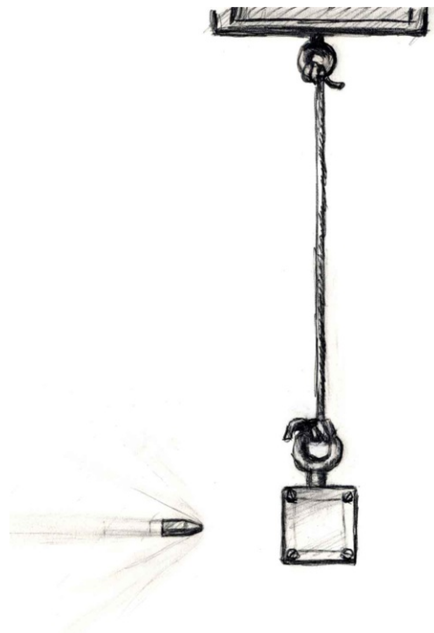
   The more massive cart goes from a speed of 4 m/s to a speed of 0.143 m/s, and so from a momentum of 32 kg·m/s to a momentum of (8 kg)(0.143 m/s) = 1.14 kg·m/s. This means its momentum has decreased by Δp = –30.86 kg·m/s.

   d. If the collision takes place over a time period of 0.3 s, what is the magnitude and the direction of the average force felt by the more massive cart during the collision?

   F = Δp/Δt = –30.86 kg·m/s / 0.3 s = –102.9 N (leftward)

   e. What is the magnitude and direction of the force felt by the less massive cart?

   Third law requires F = +102.9 N (rightward). You can also compute this using a momentum/impulse argument – it works out the same!



2. A bullet with mass 0.01 kg strikes a block with mass 0.10 kg hanging from a string of length 1.2 m. The bullet rips *through* the block and continues out the other side! Before impact, the bullet had a speed of 120 m/s. After the impact, the bullet has a speed of 100 m/s.

   We're going to do this in steps. For each step, **be sure** to write out the relevant equation before plugging in numbers. Otherwise, errors in earlier parts might propagate downwards.

   a. How much momentum did the block gain as a result of this collision?

   The bullet lost $p_i - p_f$ = (0.01 kg)(120 m/s – 100 m/s) = 0.2 kg·m/s, so the block must have gained this same amount due to conservation.

   b. What is the speed of the block as a result of the collision?

   v = p / m = (0.2 kg·m/s)/(0.10 kg) = 2 m/s.

   c. How much kinetic energy did the system lose during the collision? We can assume this energy went into breaking molecular bonds in the block, generating sound & heat, etc.

   Before the collision the bullet had all the KE ... so $KE_{before} = ½mv^2 = ½(0.01\text{ kg})(120\text{ m/s})^2 = 72$ J

   After the collision the bullet had KE = 50 J and the block had KE = 0.2 J, so a total of 50.2 J. So the system lost a total of 21.8 J of KE.

   d. The block now starts swinging back and forth like a pendulum. How long does it take to swing back and forth exactly once?

   $T = 2\pi(L/g)^{1/2} = 2\pi(1.2\text{ m} / 10\text{ m/s}^2)^{1/2} = 2.18$ seconds. Note that this does not at all depend on the details of the collision above.