Physics 200 Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Rotational Motion

Predicting Rubber Band Car Velocity and Acceleration Distance

**Warning:** Do not wind up and release a complete car and motor until after you have turned in this sheet! Once your sheet has been turned in, you may operate and fine tune your completed car in an attempt to make it perform as you predicted.

1. **Assemble your car.** 
   1. It is recommended that you insert your bearings before assembling the frame. They can be a tight fit, and you can bang them in with a hammer if you need to. It is best to have them protruding toward the outside of the car frame.
   2. Assemble the frame. Glue the front and sides of the frame first. Glue the top and bottom braces afterward.
   3. Assemble the wheel rims and wheels. When you glue the extra rims onto the wheels, take care to match the curved edges as closely as possible.
   4. Add rubber bands to wheels in order to increase traction.
2. **Mass your car**
   1. Total mass = \_\_\_\_\_\_\_\_\_ [Note that your car does not yet have a rubber band motor. That will add some mass. You can change this number later, when you know the motor mass.]
   2. Place your drive axle(s) on the balance. This will allow you to determine the normal force exerted on your drive wheels, and, therefore, the maximum force of static friction.
      1. Drive Axle reading = \_\_\_\_\_\_\_\_g
      2. Optional – 2nd axle reading = \_\_\_\_\_\_\_\_\_g [This would only be useful if you have a 4 wheel drive car.]
3. **Determine your car’s maximum rubber band force.** *(the maximum force that can be exerted by the rubber bands without your wheels slipping.)*
   1. If you haven’t already found the coefficient of friction for rubber bands on school floor tiles, do that now. µs = \_\_\_\_\_\_\_\_ *[note: you may want to use a digital force sensor instead of a spring scale.]*
   2. Use your drive axle reading from step 2bi, above, to calculate the normal force exerted on the drive wheels by the floor.
      1. Convert the reading to kg. Use w=mg to determine the weight with which those wheels push against the floor. On level ground, FN = mg. FN = \_\_\_\_\_\_\_\_\_\_
   3. Calculate the force of static friction between the floor tile and your drive wheels. Use FFr = µsFN Ffr = \_\_\_\_\_\_\_\_\_\_\_
   4. That force of static friction (from part C) is the maximum force that the edge of your wheel can use to push the car forward. Use that force to calculate your maximum drive wheel torque (without the wheels slipping). Use **T = Ffrr**, where r = the drive wheel radius. Tmax = \_\_\_\_\_\_\_\_\_
   5. This torque that is causing the wheels to push against the road is actually created by the string’s tension pulling tangentially on the drive axle. Use the torque formula and the axle radius to calculate the string’s tension. Axle radius = \_\_\_\_\_\_\_\_m. In this case Torquemax = (Tensionstring)r. String Tension = \_\_\_\_\_\_\_\_\_N.
   6. If all of your measurements and calculations are correct, this string tension is also the maximum rubber band force that your car can apply without making the wheels spin out. So, Maximum rubber band force = \_\_\_\_\_\_\_\_\_\_N.
4. **Create your optimal rubber band configuration.** The goal here is to transfer a maximum amount of energy to your car without exceeding the maximum rubber band force from number 3f, above. You will want to store as much energy as possible in the rubber bands. Here are some guidelines and tips…
   1. Remember this regulation -- Your rubber bands must stretch in a straight line, and they can’t touch the drive axle. Only string can touch the drive axle.
   2. When you wind up your car, you should not exceed the maximum rubber band force from step 3f.
   3. The more work you do when you wind the bands, the more energy they will store. W=Fd, so a longer stretch distance will give you more energy. Examine your car and find a way to make your rubber bands stretch as far as possible without exceeding the maximum rubber band force from #3f.
   4. Experiment with rubber band configurations and try to find one that will stretch a maximum distance with your desired maximum force.
   5. To precisely measure rubber band forces up to 50N, a digital force meter (and Logger Pro) may be the best option.
5. **Measure and record your rubber band motor’s force curve**.

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| Stretch Distance (m) | Force (N) |
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* 1. Hook your rubber bands to some fixed point and attach a digital force meter (connected to Logger Pro) to your string.
  2. Decide how many non-zero data points you are going to have. You must have at least 5, not counting Force = 0N. Number of Data Points = \_\_\_\_\_\_\_\_\_\_
  3. Calculate even increments over which you will increase force. Your maximum force will be the last data point, so divide the maximum force by your chosen number of data points. This will be the increment that you will use to increase force between each measurement. Force increment = \_\_\_\_\_\_\_\_\_\_\_\_
  4. Use the force meter to stretch your rubber bands. First measure and record the distance that you have to stretch the bands to reach the first force increment. Then stretch one force increment further and record that stretch distance. *[Example: if your max rubber band force is 18N, and you have 5 non-zero data points, your force increment will be 18/5 = 3.6. First you stretch the bands until you reach 3.6N. Then you stretch until you reach 7.2N. Then 10.8N… until you get to 18N]*
  5. Record your data in the table on the right.

1. **Find your wheel and axle moments of inertia and torques due to friction.**
   1. Obtain a thin thread and a weight. Attach the weight to one end of the thread.
   2. Wind the thread around the axle that you want to measure, starting at the end opposite the weight.
   3. Suspending the car steadily, release the wheels and axle, letting the weight fall and rotate the wheels and axle.
   4. Record the following:
      1. the distance that the weight falls while it is accelerating the wheel and axle. Fall Distance = \_\_\_\_\_\_\_m
      2. the time it takes the weight to fall ( you should use slow motion video for this). Fall time = \_\_\_\_\_\_\_s
      3. the mass of the falling weight. Mass of falling object = \_\_\_\_\_\_\_ kg
   5. Calculate the wheel and axle moment of inertia, and the torque from friction, by following the steps in our previous homework problem. Drive axle moment of inertia = \_\_\_\_\_\_\_\_kgm2 . Drive Axle Frictional Torque = \_\_\_\_\_\_\_\_Nm
   6. Repeat with the other axle.
      1. Fall distance = \_\_\_\_\_\_ m. Fall time = \_\_\_\_\_\_\_ s. Mass of falling object = \_\_\_\_\_\_\_\_ kg.
      2. Other axle moment of inertia = \_\_\_\_\_\_\_\_kgm2. Other Axle Frictional Torque = \_\_\_\_\_\_\_\_Nm
2. **Calculate the amount of work done in stretching your rubber bands.**
   1. Enter your stretch distance and force data into a spreadsheet.
   2. Dividing the stretching into separate intervals, calculate the stretch distance and average force for each interval.
   3. Find the work done during each interval by multiplying average force by average distance.
   4. Add up the work done during all of the intervals to get the total work done. Total Work done = \_\_\_\_\_\_\_\_ J
3. **Estimate your rubber bands’ efficiency**. There are a variety of ways to do this, and I don’t actually know which way is best. In class, I created a chain of rubber bands and dangled the chain from one end. I attached a mass to the end of the chain, released it, and let it fall and rebound. I calculated efficiency as rebound height/fall height [Since input energy = mghinitial and output energy = mghfinal , Efficiency = E Output/ E Input = mghfinal /mghinitial  = hfinal /hinitial  ]. Use whatever method you think is best. Rubber Band Efficiency = \_\_\_\_\_\_\_\_%
4. **Predict the energy lost to axle friction during your car’s acceleration period (and, in the process, find the acceleration distance).**  The calculation is Tfr∆Θ, where ∆Θ is the angular displacement of the axle, and Tfr is the frictional torque you calculated in
   1. First find the energy lost from your car’s drive axle rotation.
      1. Find your drive axle’s angular displacement (Θ), using ∆x = ∆Θr. In this case, ∆x is the length of string that unwinds from your drive axle, and r is the drive axle radius.
      2. Now find the energy lost to friction. Another way to describe this energy los is the “work done by friction.” In linear terms, w=Fd, so in angular terms, w = T∆Θ, or simply w = TΘ. In this case, the torque is the frictional torque you calculated in either step 6E or 6F. Energy lost from drive axle friction = \_\_\_\_\_\_\_\_\_ J
   2. Calculate your car’s acceleration distance. This is necessary for finding the frictional energy loss of your other axle. Again, use ∆x = ∆Θr. This time, ∆x represents the distance traveled by the edge of your drive wheels (i.e. the distance rolled by the car) and r represents the drive wheel radius. You found ∆Θ for the drive axle in step 9ai, above. Car acceleration distance = \_\_\_\_\_\_\_\_m
   3. Find the energy lost from your car’s other axle rotation.
      1. Use ∆x = ∆Θr to find your other axle’s angular displacement (∆Θ). ∆x is the distance that your car rolled, and r is the radius of your other axle wheels.
      2. Find energy lost to friction using w= TfrΘ. Energy lost from other axle friction = \_\_\_\_\_\_\_\_\_ J
5. **Calculate your car’s kinetic energy when it has traveled its acceleration distance**. Total KE = (work done in stretching rubber bands)\*(efficiency as a fraction)-(drive axle friction loss)-(other axle friction loss). Calculated Max KE = \_\_\_\_\_\_\_
6. **Optional -- Estimate any other energy loss that may not have been addressed up to this point**.
   1. **If** you have a hunch that we’ve left something out, and that your car won’t actually have the amount of energy we calculated in number 10, adjust the value here. Adjusted Max KE = \_\_\_\_\_\_\_\_\_\_.
   2. Explain your reasoning for your adjustment in part a.
7. Calculate your car’s speed at the end of its acceleration (aka Max speed).
   1. Your car should have only KE at this point. Car KE = Translational KE + Drive Axle Rotational KE + Other Axle Rotational KE.
   2. Write the above equation for Car KE.
   3. Convert angular terms to linear (ω = v/r).
   4. Solve for v. Car Max Speed = \_\_\_\_\_\_\_ m/s/