Last Name: ______________________ First Name: ______________________

Physics 101 Fall 2001: Test 2—Free Response and Instructions
7:45 AM, 8 November, 2001

- **Print your LAST and FIRST name on the front of your blue book, on this question sheet, the multiple-choice and matching question sheet and the multiple-choice and matching answer sheet.**
- **TIME ALLOWED 90 MINUTES**
- **The test consists of two free-response questions and nine multiple-choice and matching questions.**
- **The test is graded on a scale of 100 points; the first free-response question accounts for 29 points, the second for 40 points and the multiple-choice questions and matching questions account for 31 points.**
- **Answer the two free-response questions in your blue book. Answer the multiple-choice questions by marking a dark X or Roman numeral in the appropriate column and row in the table on the multiple-choice and matching answer sheet.**
- **Consult no books or notes of any kind. You may use a hand-held calculator in non-graphing, non-programmed mode.**
- **Do NOT take test materials outside of the class at any time. Return this question sheet along with your blue book and multiple-choice and matching question sheet.**
- **Write and sign the Pledge on the front of your blue book.**

Show your work for the free-response problems, including neat and clearly labelled figures, in your blue book. Answers without explanation (even correct answers) may not receive full credit.

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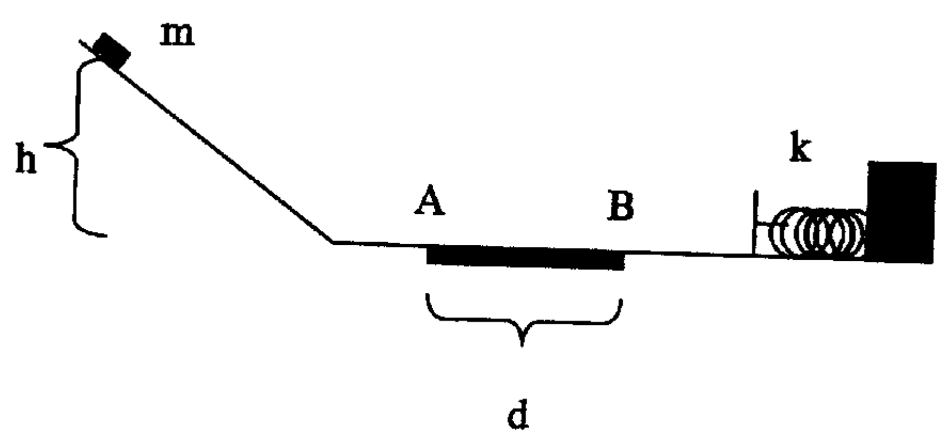
1. A small, $m = 0.5$ kg block is released from rest on a smooth, frictionless track $h = 3.5$ m above the floor (see Fig. 1 below). When this block reaches the bottom of the track, it makes a smooth transition into sliding on a level track which is also frictionless, except between point A and point B (separated by $d = 1.5$ m) where the coefficient of kinetic friction is $\mu_k = 0.4$. A little beyond point B the block hits a spring with $k = 80$ N/m.

   (a) Compute the distance x the spring is compressed upon collision with the block.

   (b) Compute the height to which the block rebounds.

   (c) Where does the block come to rest with respect to point A?

Fig. 1



2. Tarzan must rescue Chug-Chug, a young gorilla, from the crocodiles in a jungle stream (see Fig. 2 below). As he stands on a cliff of height H, he holds onto a light vine connected to a branch that is a distance L above Chug-Chug. His only hope to rescue Chug-Chug in time is to step off the cliff, grab Chug-Chug and then get off the vine onto the lower bank on the other side. Tarzan has mass M and Chug-Chug has mass m and the lower bank is at a height h above the stream.

   (a) Tarzan steps off the cliff and holds onto the rope. What is his speed just before he intercepts Chug-Chug in terms of some or all of M, H, L and g?

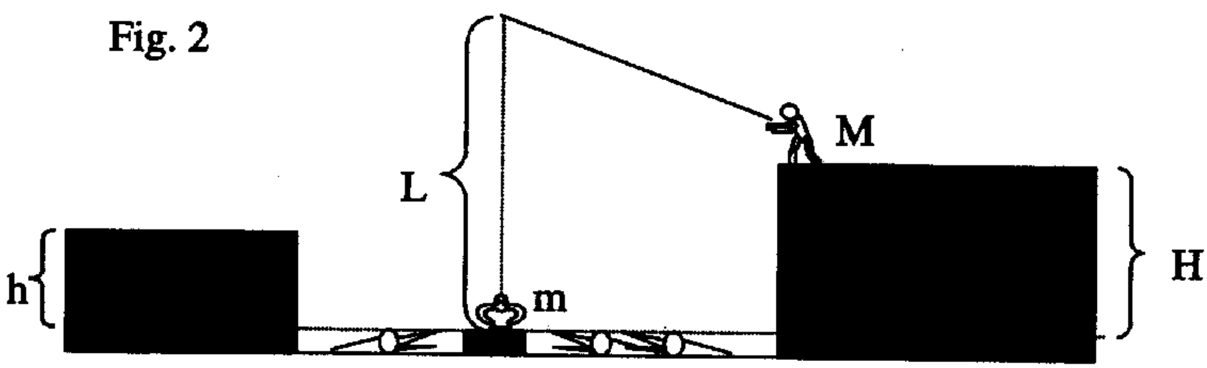
   (b) Tarzan grabs Chug-Chug and they hold on tight to each other. What is his speed just after he intercepts Chug-Chug in terms of some or all of M, m, H, L and g?

   (c) Find the tension in the vine *just before* and *just after* the collision in terms of some or all of M, m, H, L and g?

   (d) Using the values $M = 70$ kg, $m = 30$ kg, $H = 7$ m, and $L = 10$ m, find the maximum height h_{max} to which Tarzan and Chug-Chug will swing after the collision.

   (e) What is the maximum tension must the vine be able to withstand for Tarzan's plan to work?

Fig. 2

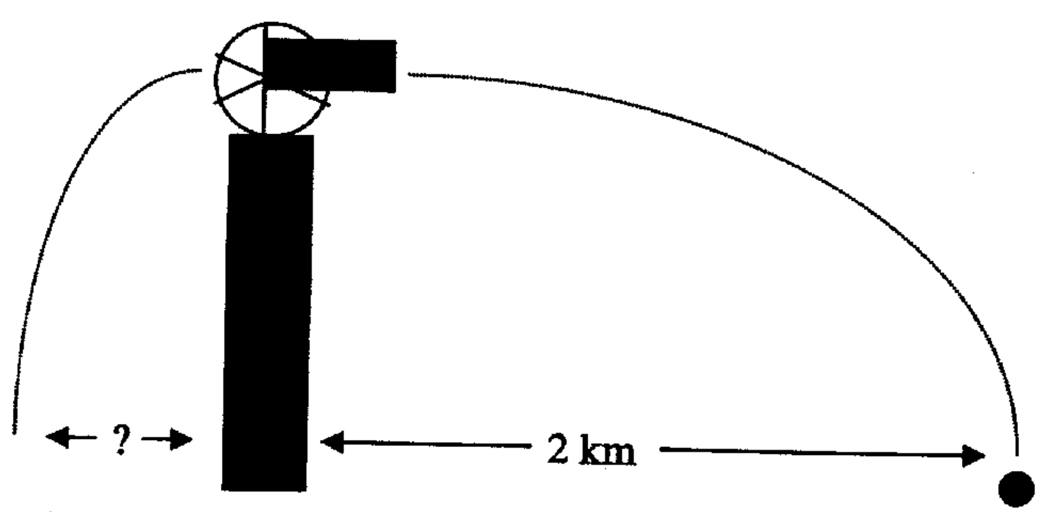


Multiple-Choice and Matching Questions

Multiple-Choice

1. A cannon with mass 400 kg sits atop a narrow wall (see figure) and horizontally launches an aid packet to hungry villagers a distance 2 km away. Someone forgot to lock the wheels of the cannon and the recoil causes it to roll backwards off the wall. If the aid packet has a mass of 10 kg and there is no friction in the wheel bearings of the cannon, how far does the cannon land behind the wall?

   (a) 40 m
   (b) 50 m
   (c) 160 m
   (d) 200 m
   (e) 2500 m



2. For a spacecraft launched from Earth to exit the solar system, it must escape not only the Earth's gravitational pull but also that of the sun. If the sun has a mass 33×10^5 times greater than the Earth and the average distance from the Earth to the sun is 24×10^4 times greater than the Earth's radius, how does the solar escape speed from Earth's orbital radius compare to the terrestrial escape speed from Earth's surface?

   (a) The solar escape speed is about 1/150th the terrestrial escape speed.
   (b) The solar escape speed is about 1/40th the terrestrial escape speed.
   (c) The solar escape speed is about 4 times the terrestrial escape speed.
   (d) The solar escape speed is about 14 times the terrestrial escape speed.
   (e) The solar escape speed is about 570 times the terrestrial escape speed.

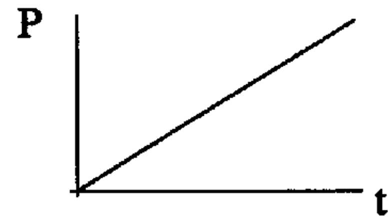
3. Alex throws a 0.15-kg rubber ball down onto the floor. The ball's velocity just before impact is 6.5 m/s and just after is 3.5 m/s. If the ball is in contact with the floor for 0.025 s, what is the magnitude of the average force applied by the floor on the ball/

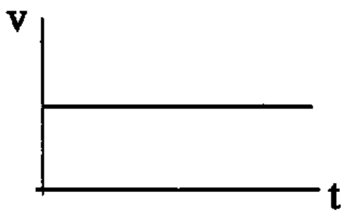
   (a) 133 N
   (b) 60 N
   (c) 30 N
   (d) 18 N
   (e) 3.0 N

4. A jack-in-the box consists of a 0.10-kg doll sitting on top of a spring with spring constant 200 N/m. The spring must be compressed 0.20 m from its natural length in order to force the doll into the box. The box is placed on its side and fixed in place so that the doll will pop out horizontally (i.e. parallel to the floor) and the box will not move. When the box is opened, the doll pops out. What is the approximate speed of the doll as it reaches the spring's relaxation point again? (Neglect the effects of friction and gravity and assume the spring is massless.)

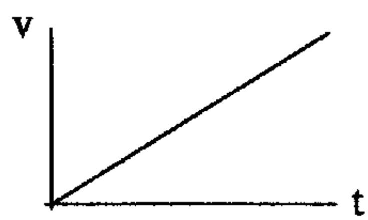
   (a) 4 m/s
   (b) 9 m/s
   (c) 12 m/s
   (d) 16 m/s
   (e) 20 m/s

5. When a prototype engine is turned on, the power provided increases linearly with time (see graph to the right). If all the work done by this engine is delivered into an object's kinetic energy, what will the speed of this object look like as a function of time? (Assume for simplicity that the object starts from rest.)

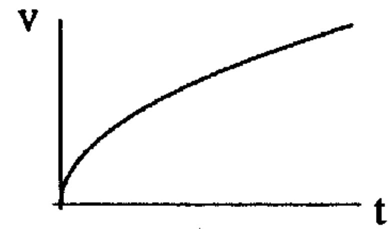




A

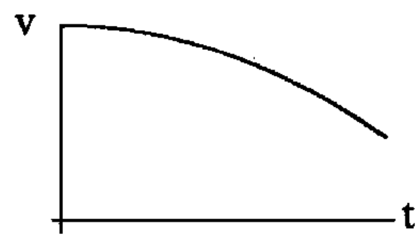


B



C

D



E

6. An object of mass m sits at a distance R from the axis of rotation on a record that is being played. The record makes a complete revolution in time T and friction holds the object in its place relative to the record. The coefficient of static friction between the object and the record is μ_s. How much work is done by friction in one revolution?

(a) none
(b) $4\pi^2 mR/T^2$
(c) $8\pi^3 mR^2/T^2$
(d) $2\pi\mu_s mgR$
(e) $4\pi^2\mu_s mgR/T^2$

7. Below are listed five potential energies as functions of the distance R. For which is the magnitude of the *force* at $R = 2$ the greatest?

(a) $U(R) = -6/R$
(b) $U(R) = R^2/2$
(c) $U(R) = 2e^{-3R}$
(d) $U(R) = -2R$
(e) $U(R) = 2R^{3/2}$

Matching

8. Match the physical situation on the left with the graph on the right. The graphs depict the variation of total energy (solid), potential energy (long dashes) and kinetic energy (short dashes) with time. Mark you answer by putting the correct Roman numeral in each lettered box on the answer sheet.

   (a) A mass on a spring released from compression until it reaches its furthest extension.

   (b) An object falling at terminal velocity.

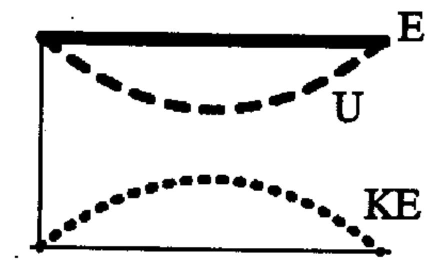
   (c) An object in circular orbit around the sun.

   (d) An object undergoing free fall.

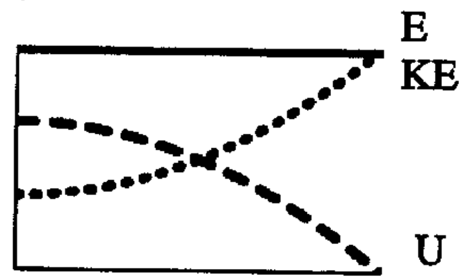
   (e) An object being pulled on a level, frictionless surface by a constant force in the horizontal direction.

I

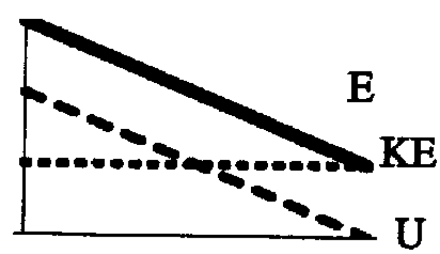
II



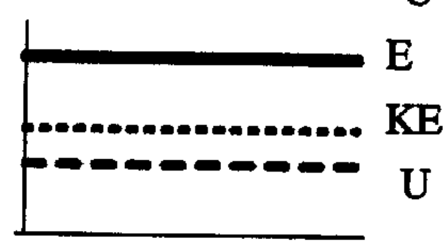
III



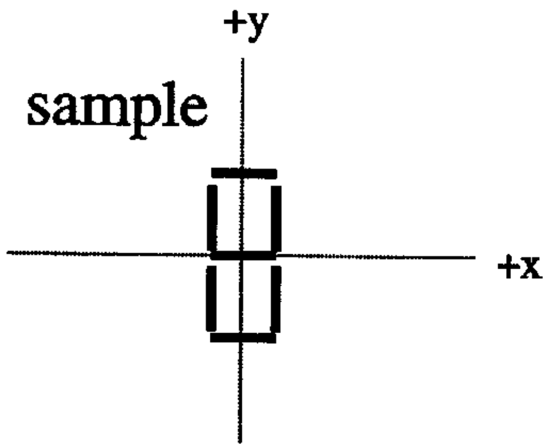
IV



V



9. On the left are statements about the location of the center of mass of the objects depicted on the right. The objects on the right are symbols constructed out of sticks of equal length and mass. The location of the center of mass is described using the coordinate system depicted in the sample. Mark you answer by putting the correct Roman numeral in the lettered box on the answer sheet.



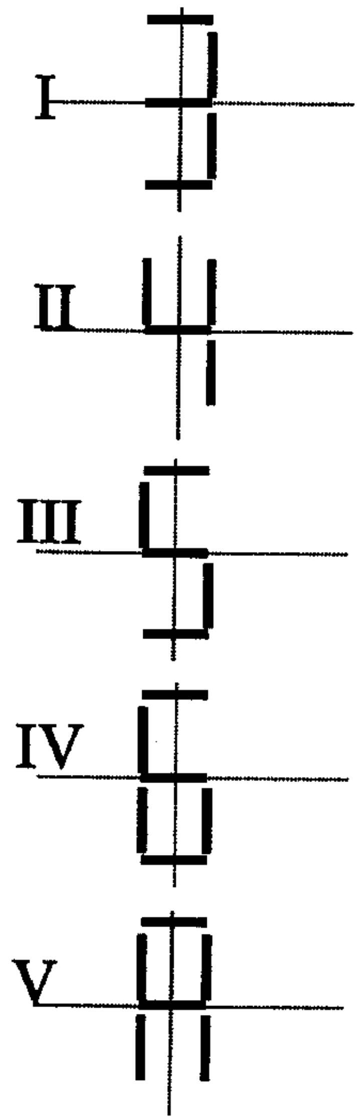
(a) The center of mass is at the origin.

(b) The center of mass is at $x > 0$ and $y = 0$.

(c) The center of mass is at $x = 0$ and $y > 0$.

(d) The center of mass is at $x > 0$ and $y > 0$.

(e) The center of mass is at $x < 0$ and $y < 0$.



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1. A small, $m = 0.5$ kg block is released from rest on a smooth, frictionless track $h = 3.5$ m above the floor (see Fig. 1 below). When this block reaches the bottom of the track, it makes a smooth transition into sliding on a level track which is also frictionless, except between point A and point B (separated by $d = 1.5$ m) where the coefficient of kinetic friction is $\mu_k = 0.4$. A little beyond point B the block hits a spring with $k = 80$ N/m.

   (a) Compute the distance x the spring is compressed upon collision with the block. **[10 pts]**
   To solve this problem we want to compare the total mechanical energy E_{tot} that the block has at point 1 (see figure 1.a) to the energy it has a point 2. We may need to consider the kinetic energy of the block KE, the gravitational and elastic potential energies U_g and U_e of the block and the work done by friction on the block W_f. I'll make a chart that summarizes the relevant information and then explain the chart:

	KE	U_g	U_e	E_{tot}	W_f
point 1	0	mgh	0	mgh	0
point 2	0	0	$kx^2/2$	$kx^2/2$	$-mg\mu_k d$

   At both points, the block is at rest so $KE = 0$. I have decided to set the gravitational potential energy of the level part equal to zero, so then the potential energy at point 1 is mgh. At first the spring is not compressed, but when the block is at point 2 the spring is compressed an unknown amount x (what we are looking for). Finally, we have calculated the work done by friction on the block:

$$\begin{aligned} W_f &= \vec{\mathbf{f}} \cdot \vec{\mathbf{d}} \\ &= fd\cos\theta \\ &= -\mu_k N d \\ &= -mg\mu_k d. \end{aligned}$$

   Now if friction had done no work, the total energy would be conserved. Instead we know

$$E_{tot} \text{ at point 1 } - W_f = E_{tot} \text{ at point 2.}$$

inserting the relevant information:

$$\begin{aligned}
mgh - mg\mu_k d &= \frac{kx^2}{2} \\
\Rightarrow kx^2 &= 2mg(h - \mu_k d) \\
\Rightarrow x &= \sqrt{\frac{2mg}{k}(h - \mu_k d)} \\
x &= \underbrace{60 \text{ cm}}.
\end{aligned}$$

- using difference in grav PE +2
- using elastic PE correctly +2
- finding work done by friction +2
- making correct relation between these +2
- getting answer +2

(b) Compute the height to which the block rebounds. **[9 pts]**

I'll again make a chart that summarizes the relevant information again and then explain the chart (see figure 1.b):

	KE	U_g	U_e	E_{tot}	W_f
point 1	0	mgh	0	mgh	0
point 3	0	mgh'	0	mgh'	$-2mg\mu_k d$

Now the block has traversed the sticky section twice, so twice us much energy has been lost to friction and $W_f = -2mg\mu_k d$. Using the same procedure as last time, we set up

$$\begin{aligned}
E_{tot} \text{ at point 1 } - W_f &= E_{tot} \text{ at point 3} \\
mgh - 2mg\mu_k d &= mgh' \\
\Rightarrow mgh' &= mg(h - 2\mu_k d) \\
\Rightarrow h' &= h - 2\mu_k d \\
h' &= \underbrace{2.3 \text{ m}}.
\end{aligned}$$

- using some sort of initial energy (either all the way at beginning like I did or at spring compression or other intermediate) +2
- using some sort of final energy +2
- finding work done by friction correctly +2
- making correct relation between these +2
- getting answer +1

(c) Where does the block come to rest with respect to point A? **[10 pts]**

The block will stop when the work done by friction has eaten up the all of the potential energy difference between the original height and the level track. Since the block only loses energy when it crosses the sticky patch, we can start out by calculating how much total distance D the block could travel on the sticky patch before coming to rest:

$$\begin{aligned}
U_g - W_f &= 0 \\
mgh - mg\mu_k D &= 0 \\
\Rightarrow \mu_k D &= h \\
\Rightarrow D &= \frac{h}{\mu_k} \\
&= 8.75 \text{ m}
\end{aligned}$$

So that means the block will cross the sticky patch $8.75/1.5 = 5.83$ times. That is, it will cross 5 times and then make it 0.83×150 cm $= 125$ cm of the way back from point B to point A. In other words, the block end up 25 cm to the right of point A in the sticky section.

- using some sort of initial energy (either all the way at beginning like I did or at spring compression or other intermediate) +2

- using final energy equals zero +1
- finding work done by friction as a function of distance travelled +2
- making correct relation between these +2
- getting the correct final answer +3

2. Tarzan must rescue Chug-Chug, a young gorilla, from the crocodiles in a jungle stream (see Fig. 2 below). As he stands on a cliff of height H, he holds onto a light vine connected to a branch that is a distance L above Chug-Chug. His only hope to rescue Chug-Chug in time is to step off the cliff, grab Chug-Chug and then get off the vine onto the lower bank on the other side. Tarzan has mass M and Chug-Chug has mass m and the lower bank is at a height h above the stream.

   (a) Tarzan steps off the cliff and holds onto the rope. What is his speed just before he intercepts Chug-Chug in terms of some or all of M, H, L and g? **[8 pts]**

   We can use conservation of energy to find this. If Tarzan lowers a distance H by the time he gets Chug-Chug, then we can set

$$\begin{aligned} -\Delta U &= \Delta KE \\ -(0 - mgH) &= \frac{Mv^2}{2} \\ \Rightarrow v &= \underbrace{\sqrt{2gH}} \end{aligned}$$

   - using PE +2
   - using KE +2
   - using cons of energy +2
   - getting the correct final answer +2

   (b) Tarzan grabs Chug-Chug and they hold on tight to each other. What is his speed just after he intercepts Chug-Chug in terms of some or all of M, m, H, L and g? **[10 pts]**

   Now we will use momentum conservation. In what's below, I use primes to denote the quantity after collision, e.g. v'_T is the speed of Tarzan after the collision and p_C is the momentum of Chug-Chug before the collision:

$$\begin{aligned} p_T + p_C &= p'_T + p'_C \\ Mv + 0 &= Mv'_T + mv'_c. \end{aligned}$$

   We know (since they stick together) $v'_T = v'_C = v'$, so

$$\begin{aligned} Mv &= (M+m)v' \\ \Rightarrow v' &= \frac{M}{M+m}v \\ &= \underbrace{\frac{M}{M+m}\sqrt{2gH}}. \end{aligned}$$

   - using cons of momentum +1
   - finding expression for momentum of both before collision (or expression for impulse on Tarzan) +2
   - finding expression for momentum of both after coll (or expression for impulse on Tarzan) +2
   - recognizing $v'_T = v'_C = v'$ + 1
   - getting the v' in terms of v +2
   - getting v' in terms of only M, m, H +2

   (c) Find the tension in the vine *just before* and *just after* the collision in terms of some or all of M, m, H, L and g? **[16 pts]**

   First, since this is a question about a force, we need to draw free body diagrams of Tarzan just before the collision and of Tarzan and Chug-Chug (together) just after. See Fig. 2.b.

Applying Newton's laws to the situation just before the collision, we get nothing interesting in the tangential direction (there is no tangential acceleration at the bottom). In the radial direction, we get

$$T - Mg = Ma_{rad}.$$

Since this is circular motion, we know that the instantaneous radial acceleration must be v^2/L. Solving for the tension just before the collision, we get

$$\begin{aligned} T &= M\left(g + \frac{v^2}{L}\right) \\ &= M\left(g + \frac{2gH}{L}\right) \\ &= \underbrace{Mg\left(1 + \frac{2H}{L}\right)}. \end{aligned}$$

For the tension after the collision, similar analysis and plugging in for v' yields:

$$\begin{aligned} T' &= (M+m)\left(g + \frac{(v')^2}{L}\right) \\ &= (M+m)\left[g + \frac{1}{L}\left(\frac{M}{M+m}v\right)^2\right] \\ &= (M+m)\left[g + \left(\frac{M}{M+m}\right)^2 \frac{2gH}{L}\right] \\ &= \underbrace{(M+m)g\left[1 + \left(\frac{M}{M+m}\right)^2 \frac{2H}{L}\right]}, \end{aligned}$$

or an equivalent form.

For EACH tension

- drawing FBD +1
- using N's 2nd law to get equation for T +1
- using centripetal acc for a_{rad} +2
- getting expression for tension in terms of M, m, g, v, L + 2
- getting expression for tension in terms of M, m, g, H, L + 2

(d) Using the values $M = 70$ kg, $m = 30$ kg, $H = 7$ m, and $L = 10$ m, find the maximum height h_{max} to which Tarzan and Chug-Chug will swing after the collision. **[10 pts]**

Using the same logic as in part 2.a., we know that an conservation of energy will give us the height an object with speed v' will swing to:

$$\begin{aligned} \frac{(M+m)(v')^2}{2} &= (M+m)gh \\ \Rightarrow gh &= \frac{(v')^2}{2} \\ \Rightarrow h &= \frac{1}{2g}\left(\frac{M}{M+m}v\right)^2 \\ &= \frac{1}{2g}\left(\frac{M}{M+m}\right)^2 (2gH) \\ &= \left(\frac{M}{M+m}\right)^2 H \\ &= \underbrace{3.43 \text{ m}}. \end{aligned}$$

- using cons of energy +2
- finding KE +2
- finding PE +2
- solving for h +2
- getting expression for tension in terms of M, m, H + 2

(e) What is the maximum tension must the vine be able to withstand for Tarzan's plan to work? **[6 pts]**

Maximum tension will occur at the bottom of the swing. Plug in the values and $T = 1646$ N and $T' = 1652$ N. So...the vine should be able to withstand tension greater than T' at the very least or it could break either before or after the collision.

- noting maximum tension at the bottom (must do this) +1
- finding T +2
- finding T' +2
- choosing bigger of two and saying must be greater (must do this) +1