Assignment 6; Phys 185 Name ________________

**1. (30 points)** You have a glass with mass $m$ bouncing off the floor. Its duration of contact with the floor—the time difference between first touching the floor and last touching the floor—is $\tau$. Its velocity when it first touches the floor is $v_{iy}$, and its velocity as it launches off the floor is $v_{fy}$. If, at any time during its contact with the floor, the force on the glass ever exceeds $F_{\text{max}}$, even for the tiniest fraction of a second, the glass will break. Note that the force on the glass during its collision with the floor will *not* be constant, and you have no idea what the exact force graph looks like.

(a) Write down an inequality describing the condition under which it is certain that the glass *will* break. *Hint:* Sketching an $F$ vs. $t$ graph might help you think about this.

(b) Let's say the inequality you wrote down does not hold. Does this mean that the glass is certain to remain unbroken? Explain.

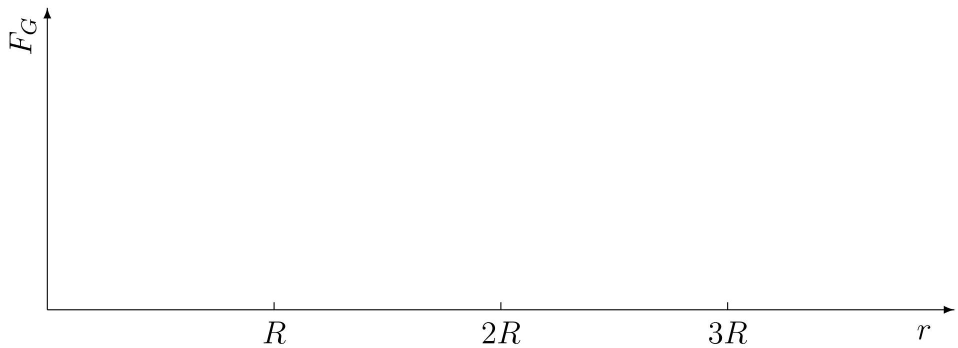
**2. (30 points)** You do a collision experiment with carts in the lab, but this time you work with expensive equipment that reduces friction with the track to a negligible level. You also work with carts that incorporate a spring that can be compressed and released during a collision, imparting the energy stored in the spring to the carts rebounding from the collision.

You set up the collision with a cart with mass $2m$ with initial velocity $v_{2i} = v$ heading toward a cart with mass $m$ that starts at rest. You measure the final velocity of the cart with mass $m$ in three different experiments, obtaining $v_{1f} = v$, $v_{1f} = \frac{4}{3}v$, and $v_{1f} = 2v$. Analyze these three experiments and determine which experiments must have had a compressed spring released during the collision.

**3. (40 points)** Remember how we got the gravitational potential energy $mgh$: the applied force acting against gravity had a magnitude of $mg$, and we found the area under the force-versus-distance curve, a rectangle of height $mg$ and base $h$.

Now we want to generalize this to beyond locations close to the Earth's surface. Take the gravitational force magnitude $F_G$ between two point masses $m_1$ and $m_2$ separated by a distance $r$. We will again look at the area under the force-distance curve.

(a) Sketch a graph of $F_G$ versus $r$.




Now, according to your sketch, do you do more work in changing $r$ from $R$ to $1.1R$, from $2R$ to $2.1R$, or from $3R$ to $3.1R$?

(b) The convention for gravitational potential energy is to say that it is zero when the masses are infinitely far from each other. So the expression for $U_G$ must become very small as $r$ becomes large. Given this, and the behavior you found in part (a), which of the following is the correct general equation for $U_G$? (Only one of the options given is consistent with what you found about $U_G$.)

(i) $U_G = \frac{1}{2}Gr^2$

(ii) $U_G = m_1 m_2 r$

(iii) $U_G = \frac{m_1}{m_2}e^{-Gr}$

(iv) $U_G = -\ln Gr$

(v) $U_G = -Gm_1m_2/r$

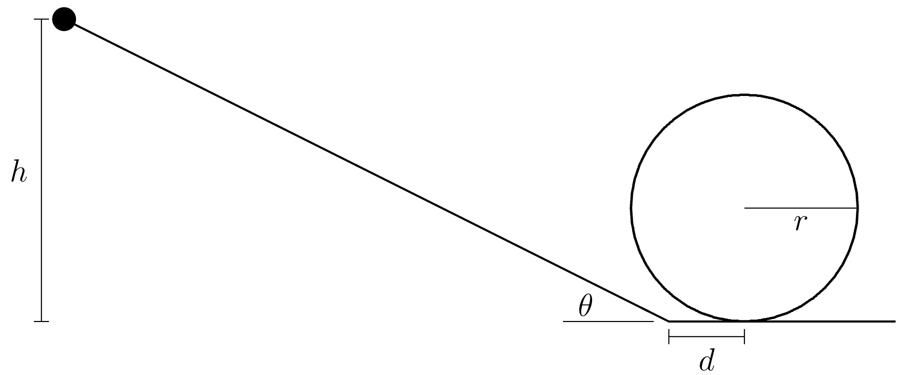
Show your work checking consistency:

(c) Given your $U_G$, find the escape speed of an object launched away from Earth. This is the minimum speed necessary to never fall back to Earth under the influence of gravity: You start from $r$ equal to the radius of Earth and speed equal to your escape speed, and end up at $r$ equal to infinity and the object at rest. You can look up data about the Earth to find a numerical result.

(d) Find an equation for the radius $r_s$ for the event horizon of a black hole with mass $m$. The event horizon marks the point beyond which nothing can return, since it would have to travel faster than light. You find $r_s$ by setting the escape speed equal to the speed of light $c$.

# Extra Problems (not graded)

**4. (0 points)** A roller coaster cart starts from an initial height $h$, goes downhill at an angle $\theta$ with the horizontal, travels a horizontal distance $d$, and goes through a loop with radius $r$.

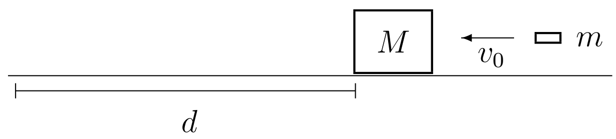



(a) Assuming dissipative forces such as friction and drag are negligible, what is the minimum height $h_{\text{min}}$ for the cart to be able to complete the loop?

(b) Assume that the cart loses energy to dissipative forces at a rate of $\varepsilon$ per length of track traveled: if, for example, it travels a distance $l$, then $E_{\text{loss}} = \varepsilon l$. In that case, what would $h_{\text{min}}$ now be?

(c) Describe the ways in which the assumption of losing $\varepsilon$ per length traveled, regardless of the orientation of the track, is not completely accurate.

**5. (30 points)** You decide to design a variation on the idea of a ballistic pendulum. You keep the part with a bullet with mass $m$ and initial velocity $v_0$ embedding in a block of mass $M$. But after that totally inelastic collision, instead of having the bullet-block combination swing upwards on a pendulum, you let it slide on a rough and flat surface, with a coefficient of kinetic friction $\mu_k$. You wait for the bullet-and-block to come to a stop, and measure the distance $d$ it traveled from the point where the bullet first struck the block.




(a) Find an equation for $v_0$. *Hint:* Think about how to account for the work done by friction, which will give you the energy loss.

(b) Assume you will use your setup to measure bullet speeds of around $v_0 = 500\,\mathrm{m/s}$, with bullet masses around $m = 0.01\,\mathrm{kg}$. Other reasonable values would be $\mu_k = 0.5$ and $d = 1.0\,\mathrm{m}$, which is practical to measure in the lab. What, then, would the block mass $M$ have to be in your setup?