First Name_____ Last Name_____ NetID_____

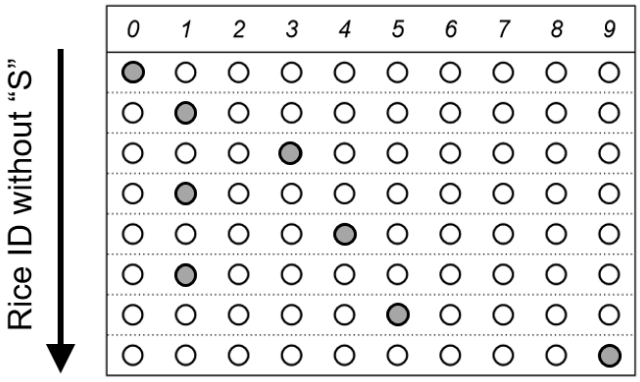
Physics 101 Fall 2021 Final Exam

Time allowed: 180 minutes, closed book

Instructions:
Please print your name and NetID in **three** places: on the top of this cover sheet and on the multiple-choice answer sheet. **(No name, No credit!)**

- There are 20 multiple choice questions and 4 free response questions in total.
- The maximum possible points are 100 points.
- Mark your answers to the multiple-choice questions on the answer sheet provided. Make sure to fill the appropriate bubble completely using a #2 pencil, or a black pen. Any multiple-choice responses written on pages other than the answer sheet will NOT be graded.
- Write all your solutions to the free response questions in the space provided in the exam packet, or on the extra space provided at the end of the exam packet. Make sure that it is very clear which problem your work corresponds to. If needed, extra paper will be provided at the front of the exam room. Remember to print your name on any extra sheets and staple them to the exam packet.
- When you finish, please place the exam packets and the multiple-choice answer sheet in two separate piles at the front of the exam room. If you used additional sheets of paper, make sure to staple them to the exam packet. Hand in all your work at the end of the 90-minute exam period.
- You are not allowed to take anything written away from the exam room.
- You may not use phones, computers, tablets, or any other web connected device during the exam.
- You may not use the symbolic manipulation or graphing capabilities of your calculator. (You can look up trig functions, *i.e*. sin(45) is not a symbolic manipulation.)
- You may not store, or use pre-stored formulae, saved in your calculator's memory, or anything written down in advance of entering the exam.

On your multiple-choice answer sheet, you will need to fill in your Rice ID. Beginning with the numbers "01, enter your Rice ID by bubbling in one number per row. In the example below, the Rice ID entered is "S01314159".



The acceleration due to gravity at (or near) the surface of the Earth is 9.8 m/s²

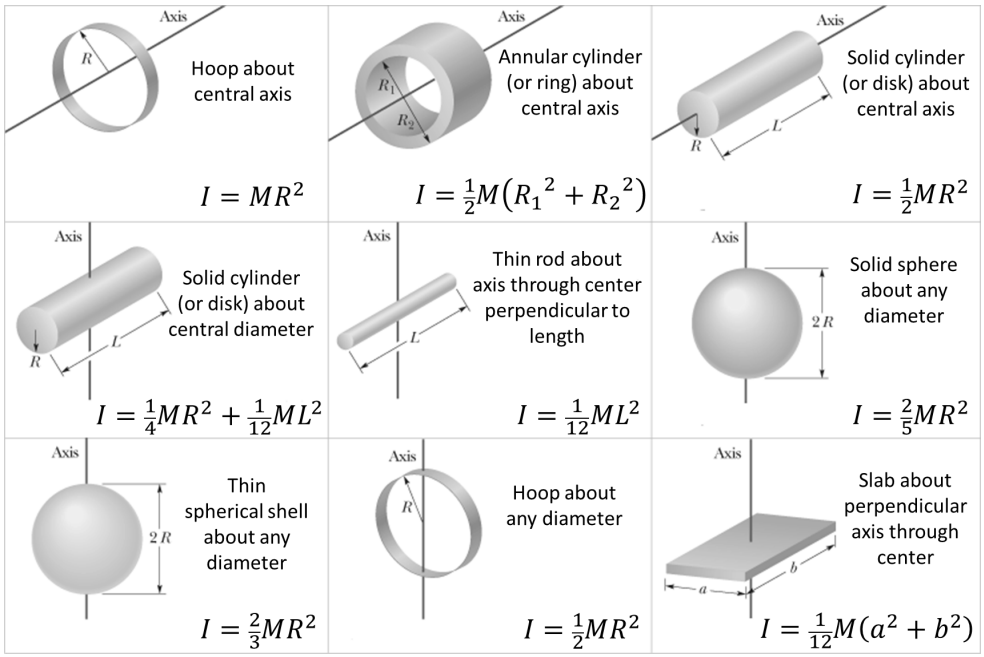
Other Constants: $G = 6.674 \times 10^{-11} \ \frac{\text{N} \cdot \text{m}^2}{\text{kg}^2}$, $R_{Earth} = 6.37 \times 10^6 \ \text{m}$, $M_{Earth} = 5.97 \times 10^{24} \ \text{kg}$

Potentially Useful Integrals and Derivatives:

$$\int x^n \, dx = \frac{x^{n+1}}{n+1} \quad (\text{for } n \neq -1)$$
$$\int \frac{dx}{x} = \ln x$$
$$\int \sin ax \, dx = -\frac{1}{a} \cos ax$$
$$\int \cos ax \, dx = \frac{1}{a} \sin ax$$
$$\int e^{ax} dx = \frac{1}{a} e^{ax}$$

$$\frac{d}{dx}(ax^n) = nax^{n-1}$$
$$\frac{d}{dx}(\ln ax) = \frac{1}{x}$$
$$\frac{d}{dx}(\sin ax) = a \cos ax$$
$$\frac{d}{dx}(\cos ax) = -a \sin ax$$
$$\frac{d}{dx}(e^{ax}) = a \, e^{ax}$$

Moments of Inertia:



Rice Honor Code:

On my honor, I have neither given nor received any unauthorized aid on this exam.

Signature: _____

Multiple Choice Questions (2 points each):

1) Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the roof of a single-story building at the same instant in time. The time it takes the balls to reach the ground below will be _____.

   A. about half as long for the heavier ball as for the lighter one.
   B. about half as long for the lighter ball as for the heavier one.
   C. about the same for both balls.
   D. considerably less for the heavier ball, but not necessarily half as long.
   E. considerably less for the lighter ball, but not necessarily half as long.

2) The figure below shows a person swinging on a rope, starting at a point higher than point A. Consider the following distinct forces:

   I. A downward force of gravity.
   II. A force exerted by the rope pointing from A to $\mathcal{O}$.
   III. A force in the direction of the person's motion.
   IV. A force that points from $\mathcal{O}$ to A.

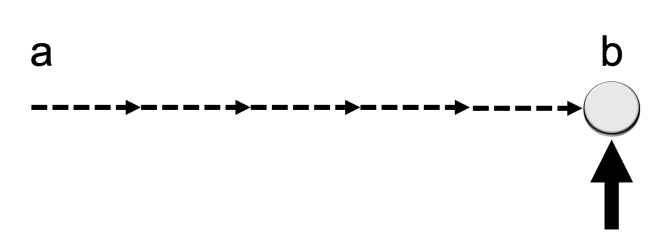
   Which of the above forces is (are) acting on the person when the person is at position A?

   A. I only.
   B. I and II.
   C. I and III.
   D. I, II, and III.
   E. I, III, and IV.

3) A person exerts a constant horizontal force on a large cardboard box. As a result, the box moves across a horizontal concrete floor at a constant speed, v_0. The constant horizontal force applied by the person_____.

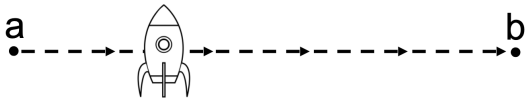
A. has the same magnitude as the weight of the box.
B. is greater than the weight of the box.
C. Is less than the weight of the box.
D. is greater than the friction force, which resists the motion of the box.
E. is greater than either the weight of the box or the friction force, which resists its motion.

4) The figure below depicts a hockey puck sliding with constant speed v_0 in a straight line from point a to point b on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down at the puck. When the puck reaches point b, it receives a swift horizontal kick in the direction of the large solid arrow. Had the puck been at rest at point b, then the kick would have set the puck in horizontal motion with a speed v_k in the direction of the kick. The speed of the puck immediately after it received the kick is_____.

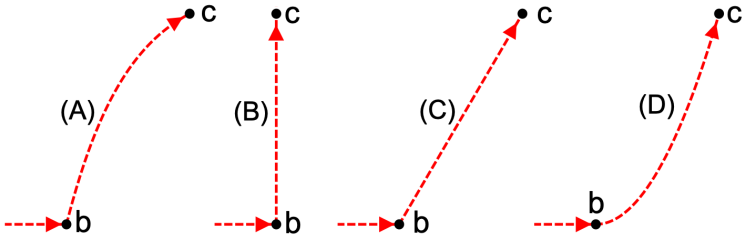


A. equal to speed v_0, the speed it had before it received the kick.
B. equal to the speed v_k.
C. equal to $v_0 + v_k$, the sum of v_0 and v_k.
D. smaller than either of the speeds v_0 or v_k.
E. greater than either the speeds v_0 or v_k, but less than $v_0 + v_k$.

5) A rocket drifts sideways in outer space from point a to point b as shown in the figure below. The rocket is subject to no external forces. Starting at position b, the rocket's engine is turned on and produces a constant force on the rocket at right angles to the line ab. The constant force is maintained until the rocket reaches a point c in space.

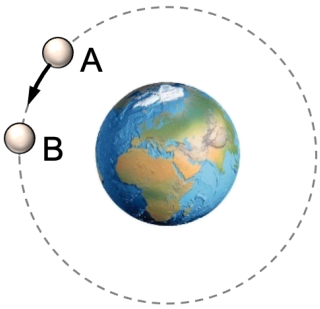


Which path below best represents the path of the rocket between point b and point c?



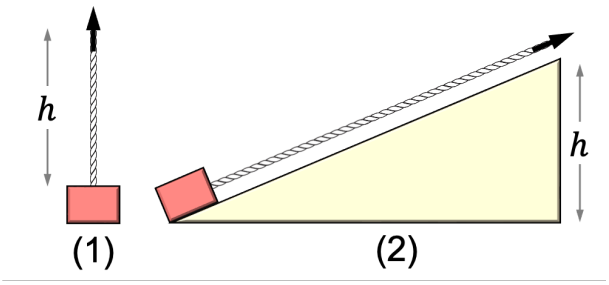
(E) None of these are qualitatively correct.

6) A satellite is moving around Earth in a circular orbit at a constant speed as shown in the figure below. The only force that acts on the satellite is Earth's gravitational force which points directly toward Earth's center. Which of the following statements is true as the satellite moves from point A to point Bin the orbit?



A. The gravitational potential energy of the satellite decreases as it moves from A to B.
B. The work done on the satellite by the gravitational force is negative from the motion from A to B.
C. The work done on the satellite by the gravitational force is zero for the motion from A to B.
D. The velocity of the satellite remains unchanged as it moves from A to B.
E. None of the statements are true.

7) You want to lift a heavy block through a height h by attaching a string of negligible mass to it and pulling so that the block moves at a constant velocity. You have the choice of lifting the block either by pulling the string vertically upward or along a frictionless inclined plane as shown in the figure below. Which one of the following statements is true?



A. The magnitude of the tension force in the string is smaller in case (1) than in case (2).
B. The magnitude of the tension force in the string is the same in both cases.
C. The work done on the block by the tension force is the same in both cases.
D. The work done on the block by the tension force is smaller in case (2) than in case (1).
E. The work done on the block by the gravitational force is smaller in case (2) than in case (1).

8) You drop a ball from a tower, and it falls freely under the influence of the gravitational force. Which of the following statements is true?

A. The kinetic energy of the ball increases by equal amounts in equal times.
B. The kinetic energy of the ball increases by equal amounts in equal distance.
C. There is zero work done on the ball by the gravitational force as it falls
D. The work done on the ball by the gravitational force is negative as it falls.
E. The total mechanical energy of the ball-earth system decreases as the ball falls.

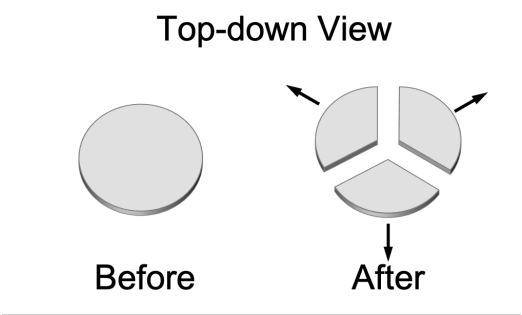
9) The brakes of your bicycle have failed, and you must choose between slamming into either a haystack or a concrete wall. Which one of the following statements best justifies why hitting a haystack is a better choice than hitting a concrete wall?

A. The haystack gives you a smaller impulse than the concrete wall.
B. The haystack changes your momentum over a longer time.
C. Your change in kinetic energy is smaller if you hit the haystack than if you hit the concrete wall.
D. Your change in momentum is smaller if you hit the haystack than if you hit the concrete wall.
E. More potential energy is stored in the wall which is released upon the impact and results in a greater force on you.

10) A bomb at rest on a horizontal frictionless surface explodes and breaks into three pieces that fly apart horizontally as shown in the figure below. Select all the following statements that must be true after the bomb has exploded:

I. The total kinetic energy of the bomb fragments is the same as that of the bomb before the explosion.
II. The total momentum of the bomb fragments is the same as that of the bomb before the explosion.
III. The total momentum of the bomb fragments is zero.

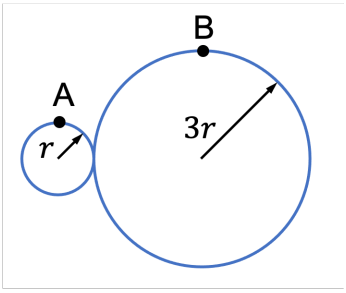
A. I only
B. II only
C. III only
D. II and III only
E. I, II, and III



11) A ball is thrown straight up from the surface of a small spherical asteroid with no atmosphere. It rises to a height equal to the radius of the asteroid, then falls back towards the surface of the asteroid. The acceleration of the ball at the top of its path is _____.

A. at its maximum for the ball's flight.
B. equal to the acceleration at the surface of the asteroid.
C. equal to one half of the acceleration at the surface of the asteroid.
D. equal to one quarter of the acceleration at the surface of the asteroid.
E. zero.

12) Two wheels of radius r and $3r$ are placed in contact as shown. If no slipping occurs at the point of contact and both wheels are rotating with constant angular speeds, which of the following expressions relates the accelerations, a_A and a_B, respectively of the points A and B shown in the figure?

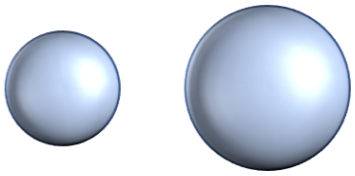


A. $a_A = a_B/9$
B. $a_A = a_B/3$
C. $a_A = a_B$
D. $a_A = 3a_B$
E. $a_A = 9a_B$

13) Assume the aerodynamic force on a car is proportional to the square of its speed (*i.e.*, the force magnitude is $F = \beta v^2$ where β is an unknown constant). What is the ratio of the output powers that the car's engine must provide when traveling at 60 mph and 30 mph?

A. 1
B. $\sqrt{2}$
C. 2
D. 4
E. 8

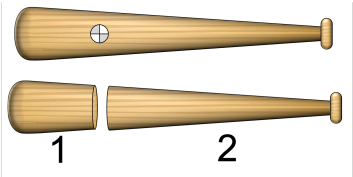
14) The two spheres shown are made of the same material, are uniformly dense, and are subject only to their mutual gravitational attraction. They are released from rest. At all times up to the point where the two spheres collide, which quantity has the same magnitude when measured for one sphere as for the other?



A. acceleration
B. velocity
C. kinetic energy
D. displacement
E. momentum

15) A baseball bat is cut through its center of mass to create two pieces, labeled 1 and 2 as shown. After the bat is cut, the piece with the largest mass is _____.

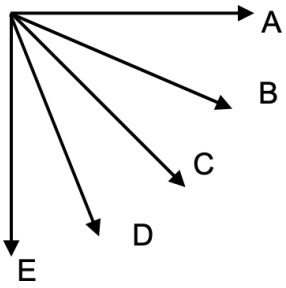
You can assume that the bat has uniform density.

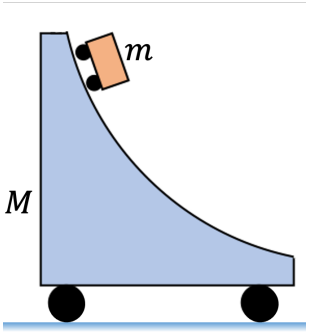


A. Piece number 1.
B. Piece number 2.
C. Both pieces have the same mass.
D. It depends on whether it is a wooden or aluminum bat.
E. It cannot be determined from the information given.

16) Consider two carts shaped as shown that run on friction- free wheels. The small mass m is free to roll along the curved surface of the larger mass $M = 4m$, which is free to roll along the floor. If the system is initially positioned as in the figure and is released from rest, which vector best represents the motion of the center of mass of the system while the cart is moving down the curved surface?

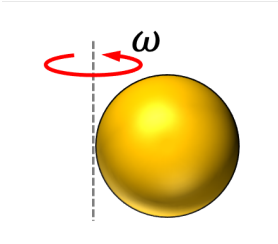
A. A
B. B
C. C
D. D
E. E



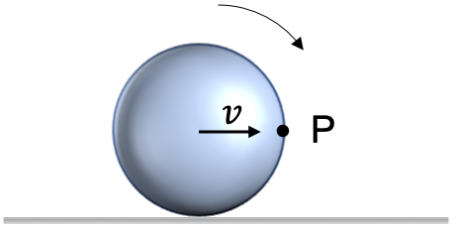


17) The moment of inertia of a solid sphere of mass M and radius R about a diameter through its center is $\frac{2}{5}MR^2$. If the spere is rotated about an axis that is tangent to the surface, as shown, the sphere's moment of inertia about the rotation axis is _____.

A. $\frac{4}{5}MR^2$
B. MR^2
C. $\frac{6}{5}MR^2$
D. $\frac{7}{5}MR^2$
E. $\frac{9}{5}MR^2$

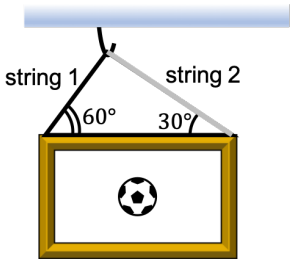


18) A solid ball of radius R rolls without slipping along a flat level surface as shown in the figure. If the center of mass of the ball has a speed v with respect to a fixed laboratory frame, what is the instantaneous speed of the foremost point P on the ball in this frame?



A. v
B. $\sqrt{2}\,v$
C. $2v$
D. $2\sqrt{2}\,v$
E. $4v$

19) A picture of mass m is suspended by a single hook by two separate light-weight strings (of unequal fixed length) and held at rest in the position shown. If the picture is released from rest, which of the following statements is true?



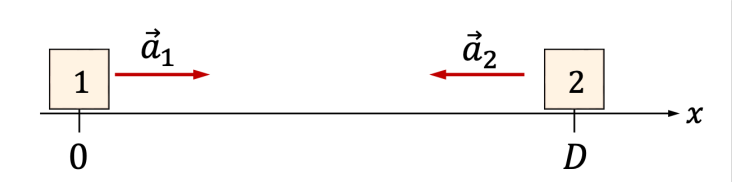
A. The picture will remain level and stationary.
B. The picture's CM will move leftward only.
C. The picture's CM will move downward only.
D. The picture's CM will move down and to the left.
E. None of these statements are true.

20) To mix a can of paint a machine shakes the can vertically with simple harmonic motion. The can is shaken with an oscillation frequency $f = 10$ Hz and an amplitude of 3 cm. What is the maximum speed with which the can moves?

A. 1.88 m/s
B. 2.55 m/s
C. 3.66 m/s
D. 5.77 m/s
E. 7.22 m/s

Free Response Questions (15 points each):

1) Object 1 of mass $M_1 = 0.1$ kg and object 2 of mass $M_2 = 0.2$ kg initially sit at rest a distance $D = 1000$ m apart. At time $t = 0$, the two objects begin to move towards one another. Object 1 moves with a constant acceleration of magnitude a_1. The distance traveled by object 2 is given by $d_2 = \left(0.01 \frac{\text{m}}{\text{s}^3}\right) t^3$. The two objects collide at $t = 35$ s.



A. What is the value of a_1?

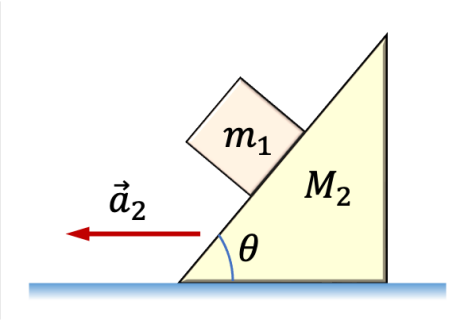
B. What is the speed of object 2 immediately before the collision at time $t = 35$ s?

1) Cont.

C. What is the center of mass speed of the two objects immediately before the collision at time $t = 35$ s?

D. The two objects stick together during the collision. Assuming that the collision occurs over a very small time interval Δt, what impulse acts on object 2 during the collision?

2) A block of mass $m_1 = 0.4\ \text{kg}$ lies on an inclined plane of mass $M_2 = 3.2\ \text{kg}$ with angle $\theta = 50°$ as shown in the figure below. The coefficient of static friction between the block and the inclined plane is $\mu_s = 0.3$. The inclined plane is accelerating to the left with a constant magnitude of a_2. The block is stationary relative to the accelerating inclined plane, but it is on the verge of slipping down the ramp (This means that if a_1 was any smaller, the block would slide down ramp.)



A. Draw a free body diagram for the block of mass m_1, clearly labeling all forces acting on the block.

B. What is the magnitude of the normal force applied to the block by the inclined plane?

2) Cont.

C. What is magnitude of the acceleration of the block?

D. What is the total work done on the block as it travels through a horizonal distance of $d = 5\ \mathrm{m}$?

3) A space traveler is exploring a spherical planet of radius $R = 0.5R_E$, where R_E is the radius of the Earth. While on the surface of the planet, the space explorer measures a period of $T = 3.3\ \mathrm{s}$ for a simple pendulum of length $L = 1.0\ \mathrm{m}$ that is moving in simple harmonic motion.
You can assume the effects of the planet's atmosphere to be negligible.

A. What is the magnitude of the acceleration due to gravity near the surface of the planet?

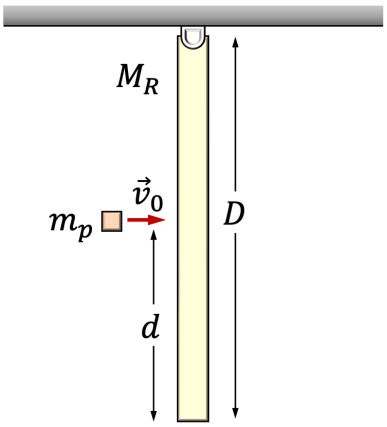
B. When the space explorer hits a golf ball at a launch angle of $30°$ above a horizontal surface, the golf ball reaches a maximum vertical distance of $h = 8.0\ \mathrm{m}$ relative to its launch position. What was the initial speed of the golf ball?
Hint: Note that $h \ll R_E$.

3) Cont.

C. Assuming that the planet is uniformly dense, estimate the ratio of the planet's mass to the Earth's mass.

D. What minimum initial speed must a golf ball have in order for it to leave the planet and fully escape the planet's gravitational influence? (Note: if the golf ball were launched from the surface of the Earth, the minimum initial speed would be $v = 11.2 \frac{\text{km}}{\text{s}}$.)

4) A thin uniform rod of mass $M_R = 3.0\ \text{kg}$ and length $D = 2.0\ \text{m}$ is suspended from a frictionless axle, and hangs vertically at rest, as shown. A particle of mass $m_P = 1.5\ \text{kg}$ then hits the rod at a distance $d = 1.0\ \text{m}$ from the lower end of the rod, as shown, and sticks to the rod at the point of contact.



At the moment of impact, the velocity of the particle is directed perpendicular to the rod and has a magnitude of $v_0 = 1.2\ \text{m/s}$. After the collision, the "rod + particle" system will rotate about the frictionless axle.

A. What is the moment of inertia of the "rod + particle" system about the suspension point after the collision?

B. What is the angular speed of the "rod + particle" system about the suspension point immediately after the collision?

4) Cont.

C. What is the kinetic energy of the “rod + particle” system immediately after the collision?

D. To what maximum angle θ, measured from the vertical, will the “rod-particle” system swing after the collision?

Extra Work Space (Clearly indicate which problem your work corresponds to):