Name: ANSWER KEY NetID: _____ Exam version **A**

Lab Section: **L** _____ Discussion Section: **D** _____

Instructions – ***Turn off your cell phone and put it away. Please keep your calculator on your own desk. Calculators may not be shared.***

This is a closed book exam. You have (1.5) hours to complete it.

Exam Grading Policy—

The exam is composed of multiple-choice and free-response questions.

The multiple choice questions have only one correct response but you may select multiple answers for partial credit.

Please completely fill the oval next to any answer you would like to select.

MC5: M*ultiple-choice-five-answer questions are each worth up to 6 points.*

MC3: *Multiple-choice-three-answer questions are each worth up to 3 points.*

MC2: *Multiple-choice-two-answer questions are each worth up to 2 points.*

Partial credit will be granted as follows.

(a) If you mark only one answer and it is the correct answer, you earn full points.
(b) If you mark N answers, one of which is the correct answer, you earn **full points / N**

For example, if you mark 3 choices on an MC5 question and one of them is correct you will receive 6/3 = 2 points

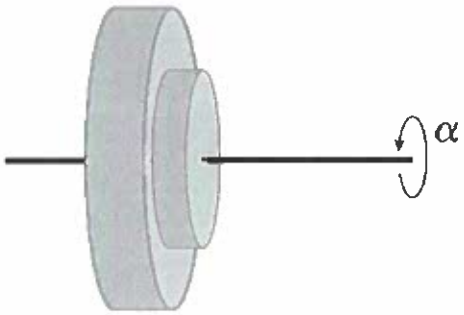
Free-response

The maximum point value for each question is given in parentheses at the end of each question. Solutions should start with equations provided on the equation sheet. Partial credit will be given as appropriate.

Academic Integrity—Giving assistance to or receiving assistance from another student or using unauthorized materials during a University Examination can be grounds for disciplinary action, up to and including dismissal from the university.

The next four questions pertain to the situation described below.

Two coaxial solid disks are glued together and placed on a common axle passing through the center of mass of the disks normal to their circular cross sections. A constant 100 N force F is applied at the rim of the larger disk by a string wound around its rim (the string is not shown in the figure). The string does not slip. The radii of the smaller and larger disks, R_S and R_L are 0.8 m and 1 meter, respectively, but the disks have identical masses M. The disks are initially at rest. At $t = 0$ the disks are allowed to rotate.



1) The disks complete the first full rotation at $t = 2.1$ seconds. What is the angular acceleration $a_{\text{two disks}}$ of the disks?

a. ○ 0.67 rad/s^2
b. ○ 1.42 rad/s^2
c. ● 2.85 rad/s^2

2) How much work is done by the force applied to the rim of the larger disk between $t = 0$ and the time when the disks have completed one full revolution?

a. ○ 100 J
b. ● 628.3 J
c. ○ 210 J
d. ○ not enough information to tell
e. ○ 9 J

3) At the end of the first rotation, a force F_s of constant magnitude is applied to the rim of the smaller disk, tangentially to the rim, to counteract the force F applied to the larger disk. What should the magnitude of the second force be for the system of disks to maintain a constant angular velocity?

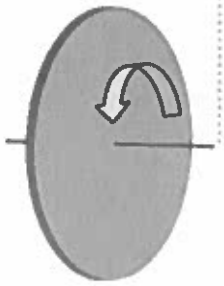
a. ○ 80 N
b. ○ 100 N
c. ● 125 N

4) Now the system of disks is brought back to rest and the smaller disk is removed. (Recall that both disks have mass M and their radii are R_L and R_S.) The same force F is applied to the rim of the remaining disk as before. How does the angular acceleration of the larger disk alone, $\alpha_{\text{single disk}}$, relate to the angular acceleration of the system of two disks, $\alpha_{\text{two disks}}$, measured previously?

a. ○ $\alpha_{\text{single disk}} / \alpha_{\text{two disks}} = (R_L + R_S)/R_L$
b. ● $\alpha_{\text{single disk}} / \alpha_{\text{two disks}} = (R_L^2 + R_S^2)/R_L^2$
c. ○ $\alpha_{\text{single disk}} / \alpha_{\text{two disks}} = R_S^2/R_L^2$
d. ○ $\alpha_{\text{single disk}} / \alpha_{\text{two disks}} = (R_L^2 + R_S^2)/R_S^2$
e. ○ $\alpha_{\text{single disk}} / \alpha_{\text{two disks}} = R_L/(R_L + R_S)$

The next two questions pertain to the situation described below.

A gyroscope made from a solid disk of mass M = 6.3 kg and radius R = 0.46 m hangs from a rope attached to the ceiling. The disk spins around a horizontal axle through its center in the direction shown by the arrow, and the rope is attached to one end of this axle at a distance D = 1.56 m from the disk. The angular momentum of the disk is L = 50.2 kg-m^2/s.



5) What is the magnitude of the angular velocity of the spinning disk?

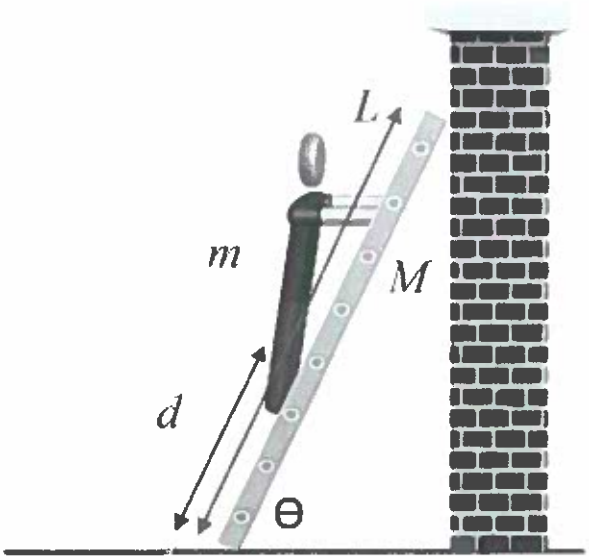
a. ○ ω = 90 rad/s
b. ● ω = 75 rad/s
c. ○ ω = 113 rad/s

6) What direction will the Gyroscope precess from its current position?

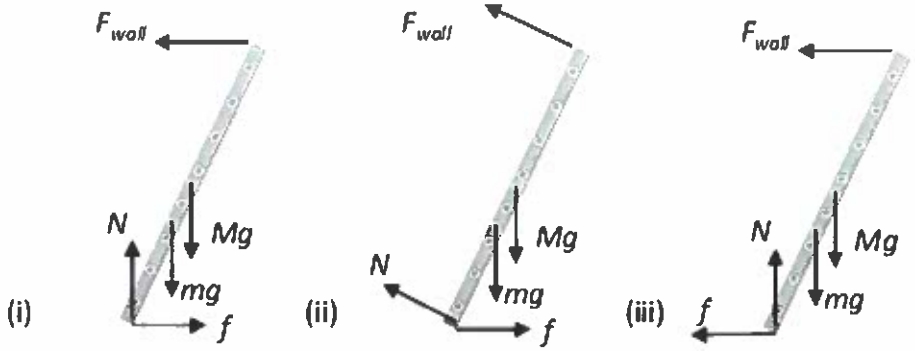
a. ● into the page (with the pivot on the string fixed, the gyroscope will move further from you.)
b. ○ out of the page (with the pivot on the string fixed, the gyroscope will come closer to you.)

The next two questions pertain to the situation described below.

A ladder of length $L = 8$ meters and mass $M = 15$ kg leans on a wall at an angle of $\theta = 47$ degrees. The coefficient of static friction between the floor and the ladder is μ_s. There is no friction between the ladder and the wall. A man of mass $m = 75$ kg climbs a distance d up the ladder.



7) Which diagram best represents the free body diagram of the ladder?



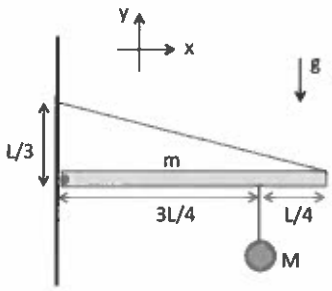
a. ● Diagram (i)
b. ○ Diagram (ii)
c. ○ Diagram (iii)

8) What is the minimum value of the coefficient of static friction that would allow the man to climb to the top of the ladder?

a. ○ 0.78
b. ● 0.85
c. ○ 0.39
d. ○ 0.63
e. ○ 0.34

The next four questions pertain to the situation described below.

A beam of mass m and length L is hinged and extends outward perpendicular to a wall, as shown. A string is attached to the end of the beam with its other end attached to the wall a distance L/3 above the hinge; the tension in that string is T = 60 N. A mass M = 1.5 kg hangs a distance L/4 from the end of the beam.



9) What is the mass, m, of the beam?

a. ○ 3.2 kg
b. ● 1.6 kg
c. ○ Cannot be determined unless a value for L is provided
d. ○ 9.4 kg
e. ○ 0.3 kg

10) What is the x-component of the force exerted by the hinge on the beam?

a. ○ 19 N
b. ○ 30 N
c. ○ 40 N
d. ○ Cannot be determined unless a value for L is provided
e. ● 56.9 N

11) Suppose that the string is now attached higher at a distance of L/2 above the hinge and the tension adjusts (it is no longer 60 N) so that the set-up remains in equilibrium. How would the x-component of the force exerted by the hinge on the beam change from previously?

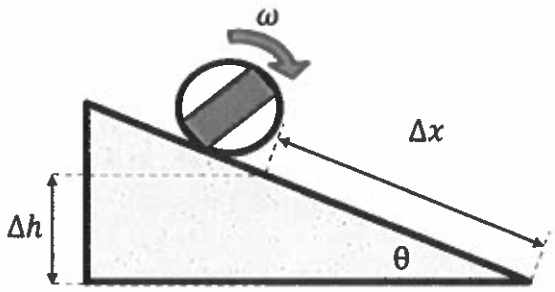
a. ● It would decrease
b. ○ It would increase
c. ○ It would remain the same

12) Now suppose that the string is cut from the original situation at the top of the page. In terms of m, M, g and L, which expression below is gives the magnitude of the angular acceleration of the beam about the hinge immediately after the string is cut?

a. ○ $6g(m+M)/L$
b. ○ $6g(1+M/m\,)/L$
c. ● $3g(1+3M/(2m)\,)/(2L)$

The next two questions pertain to the situation described below.

In Lab 9 of the Physics 211 course, you were asked to experimentally determine the moment of inertial of the IOlab about its y axis by rolling it down an incline plane. The IOLab was released from rest a vertical distance $h = 15$ cm from the bottom of a ramp. A gyroscope measurement found the IOlab's angular velocity to be 18 rad/s when it reached the bottom ramp. The mass of the IOlab, including the two tape rolls, was 220 g and the outer radius of each roll was 5 cm.



13) What was the moment of inertial of the IOlab, including the two tape rolls?

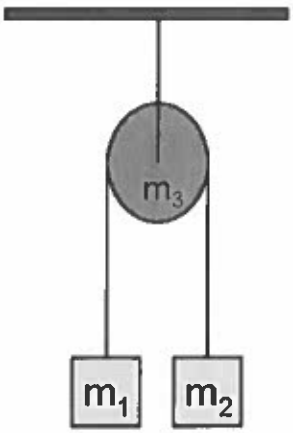
a. ○ 5.5×10^{-4} kg m^2
b. ○ 0.002 kg m^2
c. ● 0.00145 kg m^2

14) Which of the following would **not** affect accuracy of the measurement?

a. ○ The IOlab not being placed at the highest point of the ramp
b. ● The IOlab not having a uniform distribution of its mass.
c. ○ The IOlab gyroscope sensor not being properly calibrated

The next five questions pertain to the situation described below.

Two boxes hang from a solid disk pulley that is free to rotate as the blocks rise/fall. The left box has a mass $m_1 = 3.8$ kg and the right box has a mass $m_2 = 1.5$ kg. The pulley has mass $m_3 = 2.6$ kg and radius $R = 1.5$ m. The boxes are initially held at rest at the same height as shown in the image. They are then released.



15) What is the speed of box 1, after it has falled a distance of $h = 1.3$ m? (6)

Using energy:

$$(m_1 - m_2)gh = \frac{1}{2}(m_1 + m_2)v^2 + \frac{1}{2}I\omega^2$$

$$I = \frac{1}{2}MR^2 \qquad \omega = \frac{v}{R}$$

$$\Rightarrow (m_1 - m_2)gh = \frac{1}{2}(m_1 + m_2)v^2 + \frac{1}{4}Mv^2$$

$$\Rightarrow v = \sqrt{\frac{2(m_1 - m_2)gh}{(m_1 + m_2 + \frac{1}{2}M)}} = \boxed{2.98\ m/s}$$

Using forces: (see next page for a)

$$v^2 = v_0^2 + 2ah$$

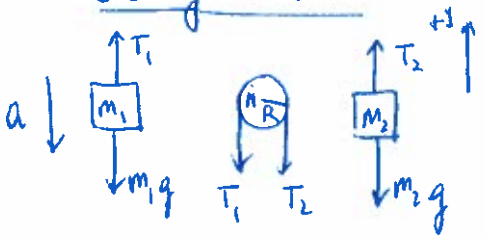
$$v = \sqrt{2ah} = \boxed{2.98\ m/s}$$

16) Compare the magnitude of the tension in the string attached to box 1, to the magnitude of the tension of the string attached to box 2.

a. ○ $|T_1| = |T_2|$
b. ● $|T_1| > |T_2|$
c. ○ $|T_1| < |T_2|$

17) What is the acceleration of box 2? (8)

Using forces:



$T_1 - m_1 g = -m_1 a$

$T_2 - m_2 g = m_2 a$

$(T_1 - T_2)R = \frac{1}{2} M R^2 \alpha$

$a = R\alpha$

$\Rightarrow T_1 - T_2 = \frac{1}{2} M a$

$\Rightarrow (m_1 g - m_1 a) - (m_2 a + m_2 g) = \frac{1}{2} M a$

$\Rightarrow a = \frac{(m_1 - m_2) g}{(m_1 + m_2 + \frac{1}{2} M)} = \boxed{3.4\ m/s^2}$

Using energy:

$v = \sqrt{2ah} \Rightarrow a = \frac{v^2}{2h} = \boxed{3.4\ m/s^2}$

18) Compare the magnitude of the tension in the string attached to the ceiling, to the to the weight of the boxes and pulley.

a. ○ $|T_3| = |(m_1 + m_2 + m_3)g|$
b. ○ $|T_3| > |(m_1 + m_2 + m_3)g|$
c. ● $|T_3| < |(m_1 + m_2 + m_3)g|$

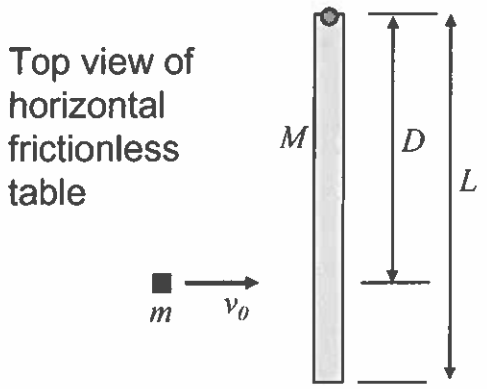
19) Briefly explain your answer to the previous question (3)

$T_3 = T_1 + T_2 + m_3 g = (m_1 + m_2 + m_3)g + (m_2 - m_1)a$

Since $m_2 - m_1 < 0$, then $|T_3| < |(m_1 + m_2 + m_3)g|$

The next five questions pertain to the situation described below.

A block (which you should treat like a point particle) has mass m = 0.38 kg and slides with initial speed v_0. It hits and sticks a distance D = 1.8 from the end of a horizontal rod of length L = 2.2 m and mass M = 0.57 kg, which is initially at rest and oriented perpendicular to the path of the block. Everything is on top of a horizontal frictionless table, and the rod has a fixed frictionless pivot through its end that allows it to rotate freely but keeps its end from moving.



20) After the block hits the rod they rotate together with a constant angular velocity of ω = 5.5 rad/sec. What was the initial speed of the block? (6)

21) As the block rides on the rod, it eventually slides further to the edge of the rod ultimately sticking at the very edge, a distance L from the pivot. What is the speed of the block as it rotates around with the rod at this new location? (6)

20) $L_i = mv_0 D \qquad L_f = \left(\frac{1}{3}ML^2 + mD^2\right)\omega \qquad L_i = L_f$

$$v = \frac{\left(\frac{1}{3}ML^2 + mD^2\right)\omega}{mD} = \boxed{17.3\ m/s}$$

21) $D \to L \qquad I_f \to I_f' = \frac{1}{3}ML^2 + mL^2 = \left(\frac{1}{3}M + m\right)L^2$

$$L_f = L_f' \Rightarrow I_f\omega = I_f'\omega'$$

$$\omega' = \frac{I_f}{I_f'}\omega = \frac{\left(\frac{1}{3}ML^2 + mD^2\right)}{\left(\frac{1}{3}M + m\right)L^2}\omega = 4.29\ rad/s$$

$$v = \omega' L = \boxed{9.4\ m/s}$$

22) Compare the kinetic energy of system (block+rod) when the mass is a distance D from the end, to the kinetic energy of the system when it is at a distance L from the end.

a. ● $KE_D > KE_L$
b. ○ $KE_D = KE_L$
c. ○ $KE_D < KE_L$

23) If friction is not sufficient to hold the block, and it slides off the end of the rod, the angular velocity of the rod will

a. ○ increase
b. ● remain the same
c. ○ decrease

24) Explain your answer to the prior question (3)

At the moment when the block leaves, it has $v = L\omega$ and angular momentum $L_{block} = mL^2\omega$ and the rod has $L_{rod} = I\omega = \frac{1}{3}ML^2\omega$, so $L_{tot} = \frac{1}{3}ML^2\omega + mL^2\omega$, hence the angular momentum of the rod does not change.