Physics 1110
Summer 2019
Exam 3

NAME

Student ID #

TA's Name (Circle one): PETER (110) BRYCE (111) IAN (112)

Please do not open the exam until you are asked to.

In a meantime, please fill out your bubble sheet according to the following instructions and check boxes when you are done.

☐ Circle the name of your TA above.
☐ Print and bubble in your name on the bubble sheet.
☐ Print and bubble in your student Identification Number.

When we ask you to open the exam, please check if your exam has 12 pages, numbered 1 thru 12 with problems on them. This exam consists of 25 questions, worth 4 points each for a total of 100 points. As you take the exam, show all your work on the exam and circle the correct answers on your exam. SHOW CALCULATIONS LEADING TO A NUMERICAL ANSWER CHOSEN. Page 11 and 12 are left blank for you to show these calculations that do not fit next to the problem. Don't forget to label your calculations on pages 11 and 12 with the number of the corresponding question.

Your circled exam answers and bubbled answers must agree. Fill in the bubble sheet with a #2 pencil, erase mistakes thoroughly, and make no extraneous marks.

YOUR EXAM WILL BE CHECKED FOR COMPLETENESS OF CALCULATIONS LEADING TO A NUMERICAL ANSWER CHOSEN. IF YOU PICKED A CORRECT ANSWER BUT THERE ARE NO CALCULATIONS JUSTIFYING IT, YOU'LL GET NO CREDIT.

When you are finished, please turn in your bubble sheet and your booklet.
By handing in this exam, you affirm the following statement:

"I have read and followed the instructions above. On my honor, as a University of Colorado student, I have neither given nor received unauthorized assistance on this exam."

Signature
Possibly useful information:
Gravitational force: \( F = \frac{Gm_1m_2}{r^2} \), where \( G = 6.67 \times 10^{-11} \text{Nm}^2/\text{kg}^2 \)
Speed of a satellite in a circular orbit of a radius \( r \) about a central mass \( M \): \( v_o^2 = \frac{GM}{r} \)
Escape speed from a location at a distance \( r \) from a central mass \( M \): \( v_e = \sqrt{2}v_o \)

Moments of inertia of circular or spherical objects with mass \( M \) and radius \( R \) about an axis along the axis of symmetry:

Parallel Axis Theorem:
\( I_{axis} = I_{CM} + Md^2 \)

1. A small satellite of mass \( m \) is in circular orbit around a large planet of mass \( M \). The force of gravity on the satellite from the planet has magnitude \( F_{on \ satellite} \). The force of gravity on the planet from the satellite has magnitude \( F_{on \ planet} \). What is the ratio of the sizes of the forces \( \frac{F_{on \ planet}}{F_{on \ satellite}} \)?

A) \( m/M \)  B) \( M/m \)  C) \( (m/M) \)  D) zero  E) 1

Newton's 3rd Law
2. At a particular instant in time, a small object of mass $m$ is directly in between two large stars with masses $3M$ and $M$, as shown. The small object is a distance $r$ from the star with mass $M$ and a distance $3r$ from the star with mass $3M$. There are no other objects around. What is the magnitude of the net force on the small object $m$?

![Diagram](image)

A) $\frac{2GMm}{3r^2}$  
B) $\frac{4GMm}{3r^2}$  
C) zero  
D) $\frac{8GMm}{9r^2}$

The next four questions refer to this situation: Kepler's third law states that the ratio $\frac{T^2}{r^3}$ has the same value for all objects orbiting the Sun. The orbital period $T$ of the Earth is 1 year, and the mean distance from the Earth to the Sun is defined as 1 A.U. (Astronomical Unit). Consider an asteroid in circular orbit of radius $r = 9$ A.U. around the Sun.

3. The period of the asteroid is...

A) 9 years  
B) 18 years  
C) 21 years  
D) 27 years  
E) none of these

4. The orbital speed of the asteroid, compared to the orbital speed $v_E$ of Earth, is

A) $v_E$  
B) $\frac{1}{3}v_E$  
C) $\frac{1}{3}v_E$  
D) $\frac{1}{4}v_E$  
E) none of these

5. Now consider an asteroid in elliptical orbit around the Sun of eccentricity $e = 0.8$ and the perihelion (closest approach) distance of 0.8 A.U. What is the period of the asteroid?

A) 4 years  
B) 8 years  
C) 16 years  
D) 32 years  
E) none of these

6. If the speed of the asteroid at perihelion is $v_p$, what is $v_a$, the speed of the asteroid at aphelion?

A) $\frac{2}{3}v_p$  
B) $0.4v_p$  
C) $\frac{1}{9}v_p$  
D) $\frac{1}{10}v_p$  
E) None of these
7. Planet X has the same mass as the Earth, but 1/2 the radius. (Planet X is more dense than the Earth). Assume both planets have no atmosphere.

\[ U_c = \frac{G M_e}{R_e} \rightarrow U_0 = \frac{G M_e}{R_e} \]

\[ U_x = \sqrt{\frac{G M_e}{\frac{1}{2} R_e}} = \sqrt{\frac{G M_e}{\frac{1}{2} R_e}} \]

Orbital speed of a satellite in a “grazing” orbit just above Earth’s surface is \( v_0 = 7.9 \frac{km}{s} \).

What is the value of the orbital speed \( v_x \) of a satellite in a “grazing” orbit just above the planet X surface?

A) \( v_0 \) (same)  B) \( \sqrt{2} v_0 \)  C) \( 2v_0 \)  D) \( 2\sqrt{2} v_0 \)  E) \( 4v_0 \)

8. A clay block of mass \( 2m \) moving to the right with speed \( v_0 \) strikes a second block of mass \( m \) moving to the left with the same speed \( v_0 \). The two clay blocks stick together after the collision. There are no outside forces acting on the blocks.

What is the total kinetic energy of the system after the collision?

A) \( m v_0^2 \)  B) \( \frac{2}{3} m v_0^2 \)  C) \( \frac{1}{6} m v_0^2 \)  D) \( \frac{1}{3} m v_0^2 \)  E) 0

\[ P_x = 2m v_0 + m(-v_0) = m v_0 \]

\[ m v_0 = \frac{1}{3} m v_0 \]

\[ K_E = \frac{1}{2} \left( \frac{1}{3} m v_0 \right)^2 \]

9. Two flat square tiles, with edge lengths \( L \) and \( 2L \), are arranged on a floor as shown. Each tile is uniform, has the same thickness, and is made of the same material. The origin is at the left edge of the left tile, as shown.

What is the x-coordinate of the center-of-mass of this 2-tile system?

A) \( 1.00 L \)  B) \( 0.75 L \)  C) \( 2.25 L \)  D) \( 1.70 L \)  E) \( 2.00 L \)

\[ x_{cm} = \frac{m \left( \frac{1}{2} L \right) + \frac{1}{2} m \left( 2L \right)}{m + \frac{1}{2} m} = \frac{8.5}{5} L = 1.7 L \]
The next two questions refer to this situation: Two blocks with masses \( m_1 = m \) and \( m_2 = 2m \) are held together by a latch with a compressed massless spring between them, as shown. The whole structure is initially at rest. Suddenly the latch releases, and the spring pushes the masses apart. There are no other forces on the masses, besides the force from the spring. After the masses \( m \) and \( 2m \) fly apart, their momenta are \( \vec{p}_1 \) and \( \vec{p}_2 \), respectively.

**BEFORE**

**AFTER**

\[
\text{Before:} \quad p_{\text{initial}} = 0 = \vec{p}_{\text{final}} = \vec{p}_1 + \vec{p}_2
\]

10. How do the magnitudes of the momenta compare?

A) \( |p_1| = |p_2| \)  
B) \( |p_1| = \frac{1}{2} |p_2| \)  
C) \( |p_1| = 2 |p_2| \)  
D) \( |p_1| = \sqrt{2} |p_2| \)  
E) None of these

11. How do the kinetic energies compare?

A) \( KE_1 = \frac{1}{2} KE_2 \)  
B) \( KE_1 = KE_2 \)  
C) \( KE_1 = \sqrt{2} KE_2 \)  
D) \( KE_1 = 2 KE_2 \)  
E) \( KE_1 = 4 KE_2 \)

12. Two gliders, labeled A and B, are on a frictionless air track, initially heading toward each other. The mass of A is greater than the mass of B. After they collide, glider A is moving left and glider B is moving right, with equal speeds, as shown. (The arrows in the diagram only show direction of motion; their lengths do not indicate speed or magnitude of momentum.)

Before the collision, how does the magnitude of the momentum of A compare to the magnitude of the momentum of B?

A) \( |p_A| > |p_B| \)  
B) \( |p_A| < |p_B| \)  
C) \( |p_A| = |p_B| \)  
D) Not enough information is given to answer the question.
13. A ball bounces off the wall of a space station (where there is no gravity). The collision with the wall is elastic, and the path of the ball is shown. What is the direction of the impulse vector imparted to the ball during the collision?

![Diagram of a ball bouncing off a wall](image)

E) No direction, since the impulse is zero

14. A large wooden sphere of mass $M$ is initially at rest hanging from a string, as shown. A bullet of mass $m$, with initial speed $v$, strikes the sphere and buries itself in the sphere, causing the bullet + block to swing up to a maximum height $h$ above the initial height. How does the initial KE of the bullet compare to the final gravitational PE of the bullet + block?

![Diagram showing a sphere before and after a bullet strike](image)

A) $\frac{1}{2} m v^2 = (M + m) g h$
B) $\frac{1}{2} m v^2 > (M + m) g h$
C) $\frac{1}{2} m v^2 < (M + m) g h$
D) Impossible to say from the information given.

Mechanical energy is lost in inelastic collision (heat generated).
15. Ball 1 collides with Ball 2. The figure shows the momentum of both Ball 1 and Ball 2 before the collision, and the momentum of Ball 1 after the collision. There are no forces on the balls except the collision forces. In units of the figure, what is $p_{2Fx}$, the x-component of the momentum of ball 2 after the collision?

A) 2 B) $-\sqrt{3}$ C) $-3$ D) $\sqrt{5}$ E) None of these.

$$p_x = +3 - 3 = 0 = -2 + p_{2Fx}$$

16. A simplest model of Atwood’s Machine consists of two blocks suspended with a massless string over a massless pulley that rotates with no friction (essentially a frictionless peg). The blocks have masses $m$ and $2m$, as shown. Find the magnitude of the acceleration of the center of mass of the system.

A) $a_{CM} = g$ B) $a_{CM} = (1/3) g$ C) $a_{CM} = (1/9) g$ D) $a_{CM} = 0$ E) None of these

$$a = \frac{2m_g - m_g}{3m} = \frac{1}{3} g$$
$$a_{CM_y} = \frac{1}{3m} \left[ m(-a) + 2m(a) \right] = \frac{1}{3} a = \frac{1}{3} g$$

17. A bike wheel mounted on the front desk of the lecture hall is spinning clockwise, with $\omega = 12.0$ rad/s. Assume the bike wheel has moment of inertia $I = 20$ kg m$^2$ about its center. Friction slows it down, and after 2.0 minutes it comes to rest. What was the magnitude of the average net torque on the wheel about the center while it is slowing?

A) 2.0 Nm B) 120 Nm C) 6.0 Nm D) 0.1 Nm E) There is not enough information to decide.

$$\frac{I\omega}{(20kgm^3) \cdot \frac{12rad}{5s}} = \frac{2 \cdot \frac{3m}{s^2}}{s^2}$$

18. Two masses of size $m$ and $3m$ are connected by a massless thread and are strung over a frictionless pulley of radius $R$ and moment of inertia $I_0$. The two masses are held motionless at the same height (h=0 in the diagram) and then released from rest. After the mass 3m has fallen a distance $L$ and the mass $m$ has risen the same distance $L$, what is the total kinetic energy of the entire system?

A) $2mgL$ B) $3mgL$ C) $4mgL$ D) $2mgL + \frac{1}{2} I_0 gL/R^2$ E) $3mgL + \frac{1}{2} I_0 gL/R^2$

$$E_i = E_f$$

$$0 + 0 = mgL + 3mg(-L) + KE_{total} \rightarrow KE_{total} = \frac{1}{2} mgL$$

$$I = \frac{1}{2} m\omega^2 + \frac{1}{2} (2m) \omega^2 + \frac{1}{2} I_0 (\frac{\omega}{R})^2$$

if you need to find $\omega$
19. A structure consists of a uniform rod of mass $m_0$ and length $L$ with an axis of rotation at its center (perpendicular to the drawing), and two masses $m_1$ and $m_2$ attached at its ends (where $m_2 > m_1$), so the total mass of the structure is $(m_0 + m_1 + m_2)$. The rod is initially held horizontally and then released from rest. Consider the following two statements:

I. The net torque on the structure, immediately after release, depends on the mass $m_0$ of the rod.  (No)

II. The angular acceleration of the structure depends on the mass $m_0$ of the rod.  (Yes)

Which statements are true?

A) Both are true.  B) Neither are true.  C) Only I is true.  D) Only II is true.

20. An object consists of 5 point masses, each of mass $m$, connected by massless rods as shown. The three short rods have length $L$ and the long rod has length $2L$. Although the diagram shows the masses as small spheres, assume they are points. What is the moment of inertia about an axis perpendicular to the diagram (out of the page) and through the middle mass labeled $x$.

A) $5mL^2$  B) $7mL^2$  C) $8mL^2$  D) $12mL^2$  E) $13mL^2$

$$I = mL^2 \times 3 + m(2L)^2 = \frac{13}{3}mL^2$$

21. Three identical blocks, labeled I, II, and III, are on a horizontal table, initially at rest with identical orientations, as shown. Blocks I and II have no friction between them and the table, but there is friction between Block III and the table. All three blocks are pulled with forces of equal magnitudes and direction, parallel to the table, as shown (this is a top view of the table, i.e. what you see looking down on the table.) The forces on blocks I and III are exerted at the centers of the blocks; the force on block II is exerted at a point on the far right of the block as shown. The centers-of-mass of the blocks are marked with an $\times$. What is the correct ranking of the accelerations of the center-of-masses of the three blocks?
Looking down on the table:

I
II
III

NO friction
NO friction
Friction

A) \( a_1 = a_{II} > a_{III} \)  B) \( a_1 = a_{II} = a_{III} \)  C) \( a_1 > a_{II} = a_{III} \)  D) \( a_1 > a_{II} > a_{III} \)

E) Impossible to answer without more information

22. A rope is wrapped around a pulley that can be modelled as a solid disk of mass \( M = 4.0 \) kg and radius \( R = 0.40 \) m.
The pulley is initially at rest. Your hand applies a force \( F = 15 \) N on the free end of the rope, pulling it down.
What is the rotational speed of the disk when you pulled the free end of the rope the distance of 1.2 m?
(You still keep pulling.)

\[
\Delta (KE) = W_F = \frac{1}{2}(0.32 \text{ kg} \cdot \text{m}^2)(\omega^2) = 0.16 \text{ J}
\]
\[
\omega = \sqrt{\frac{2 \cdot 0.16 \text{ J}}{0.32 \text{ kg} \cdot \text{m}^2}} = 1.2 \text{ rad/s}
\]

\(\omega = 12.5 \text{ rad/s}\)

A) 10.6 rad/s  B) 12.8 rad/s  C) 13.7 rad/s  D) 16.2 rad/s  E) None of the above

23. Two objects labeled A and B are attached to a merry-go-round which is spinning at a constant rate of 6 rpm
(revolutions per minute). There is a motor on the merry-go-round which keeps the rotation rate constant. Object A is
near the center and object B is near the rim. Consider the following 4 quantities of each object:

1) the speed \( v \),
2) the magnitude of the angular velocity \( \omega \),
3) the magnitude of the angular acceleration \( \alpha \),
4) the magnitude \( a \) of the overall acceleration vector \( \vec{a} \).

\[ a_c = \frac{v^2}{r} = r \omega^2 \leq 0 \quad \alpha_c, A_r \leq \alpha_c, B \]

How many of these 4 quantities are larger for object B than for object A?

A) None of them is larger for B
B) Only one of them is larger for B.
C) Only two are larger for B
D) Three of them are larger for B
E) All four (object B has larger \( v \), \( \omega \), \( \alpha \), and \( a \))
24. Initially, a person is sitting stationary on a stool that can rotate on a frictionless pivot, and the person is holding a spinning wheel with its axis vertical as shown. The moment of inertia of the person + stool about the stool's axis is $I_p = 20 \text{ kg m}^2$. The wheel has moment of inertia $I_w = 5 \text{ kg m}^2$ about its axis and it is initially spinning with $\omega_w = 4 \text{ rad/s}$, oriented so its angular momentum vector $L_w$ is pointing down.

The person then carefully flips the axle of the wheel so that it is still rotating with $\omega_w = 4 \text{ rad/s}$ (relative to the room), but it is now oriented so its angular momentum vector $L_w$ is pointing up. What is the rotation rate of the person?

\[ \omega_w = 4 \text{ rad/s} \]

\[ L_{w,\text{fin}} = +20 \text{ kg m}^2 \text{ rad/s} + L_{p+s} = -20 \text{ kg m}^2 \text{ rad/s} \]

\[ L_{p+s} = -40 \frac{b_y m^2}{s} \]

\[ -40 \frac{b_w m^2}{s} = \left(20 \frac{b_w m^2}{s}\right) \left(c_w \right) \]

\[ c_w = -2 \frac{\text{rad}}{s} \]

So the rotation rate is $\omega = 2 \frac{\text{rad}}{s}$

A) zero   B) $1 \text{ rad/s}$   C) $\frac{3}{2} \text{ rad/s}$

D) $\frac{4}{5} \text{ rad/s}$   E) $2 \text{ rad/s}$

25. An ice cube, a hoop, and a steel ball move at the same speed $v_i$ at the bottom of an incline, as shown. The ice cube slides without friction, while the hoop and disk roll without slipping. Each object reaches the plateau and continue to move there with a speed $v_f$. All objects have different masses, and the hoop and the steel ball have different radii.

Rank the objects from greatest to lowest speed $v_f$

A) Cube, ball, hoop

B) Hoop, ball, cube

C) Ball, hoop, cube

D) Ball and hoop with the same speed, cube

E) All have same speed.

\[ c = \frac{1}{2} m v_i^2 \]

\[ h_{\text{hoop}} = \frac{1}{2} m_h v_i^2 + \frac{1}{2} I_h \omega_i^2 \]

\[ h_{\text{ball}} = \frac{1}{2} m_b v_i^2 + \frac{1}{2} I_b \omega_i^2 \]

\[ KE_i = \frac{1}{2} m c v_i^2 \]

\[ KE_f = \frac{1}{2} m c v_f^2 = \frac{1}{2} m c v_i^2 - m g h \]

\[ m_h u_i^2 + \frac{1}{2} h_{i} \omega_i^2 = m_b u_i^2 + \frac{1}{2} b_{i} \omega_i^2 \]

\[ \frac{1}{h} m_b u_{b,\text{top}} + \frac{1}{b} m_h u_{h,\text{top}} = \frac{1}{h} m_b u_{b,\text{top}} - \frac{1}{b} m_h u_{h,\text{top}} \]

Page 10