Instructions-
This is a closed book exam. No memory aids of any kind, electronic or otherwise, may be used.
You have fifty (50) minutes to complete it.

1. Before starting work, check to make sure that your test is complete. You should have 8 numbered pages
   plus a formula sheet.
2. When you are done, you MUST hand in all 8 pages of the exam.

Exam Grading Policy-
This exam consists of 13 questions; true-false questions are worth 2 points each, three-choice multiple choice
questions are worth 3 points each, five-choice multiple choice questions are worth 5 points each. The
maximum possible score is 53. Basic questions are marked by a single star *. More difficult questions are
marked by two stars **. The most challenging questions are marked by three stars ***. Circle only ONE
answer. If you decide to change an answer, erase vigorously. If you circle no answer, or circle more than
one answer, you earn zero (0) points for that problem.

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Total
This and the next two questions are about the following situation:

1. (*) A block of mass $M$ is on a stationary inclined plane inclined at an angle $\theta = 30^\circ$. A horizontal rope is attached to the block and is pulled to the right with tension $T$. The tension remains horizontal even in the event that the block moves down the plane. The coefficient of static friction between the block and the inclined plane is $\mu_s$.

Which of the following is the correct free-body diagram for the block if it is stationary?

(a)  
(b)  
(c)  

2. (***) What is $T_{\text{max}}$, the maximum value of $T$ for which the block can be held in place with static friction? Be careful with the force components.

   (a) The block cannot be held in place with static friction for any value of $T$.  
   (b) $T_{\text{max}} = mg\left[\left(\mu_s \cos \theta + \sin \theta\right) / \left(\cos \theta - \mu_s \sin \theta\right)\right]$  
   (c) $T_{\text{max}} = mg\left[\left(\mu_s \cos \theta - \sin \theta\right) / \left(\cos \theta + \mu_s \sin \theta\right)\right]$  
   (d) $T_{\text{max}} = mg\mu_s \cos \theta$  
   (e) $T_{\text{max}} = mg\mu_s \sin \theta$

3. (*) If $\theta$ were increased, the value of $T_{\text{max}}$ found in the previous problem would decrease.

   (a) True  
   (b) False
4. (**) When a certain airplane travels through the air, the viscous drag force on the airplane has magnitude $bv^2$. The airplane engines have a maximum total power $P = F_{\text{engines}} \cdot v$. What is the maximum speed $v_{\text{max}}$ of the airplane with respect to the air? *Hint: this is like a terminal velocity problem – draw the free body diagram and consider only the horizontal motion.*

(a) $v_{\text{max}} = P/b$
(b) $v_{\text{max}} = P/b^2$
(c) $v_{\text{max}} = (P/b)^{1/2}$
(d) $v_{\text{max}} = (P/b)^{1/3}$
(e) $v_{\text{max}} = (P/b)^{3/2}$

5. (**) An amusement park ride consists of a large vertical cylinder that spins about its axis fast enough such that any person inside is held up against the wall when the floor is made to drop away (see figure below). The coefficient of static friction between the person and wall is $\mu_s$, and the radius of the cylinder is $R$. What is the magnitude of the frictional force, $f$, in terms of the angular velocity, $\omega$, of the cylinder?

(a) $f = \mu_s m \omega^2 R + mg$
(b) $f = \mu_s m \omega^2 R - mg$
(c) $f = \mu_s m \omega^2 R/4$
(d) $f = \mu_s m \omega^2 R/2$
(e) $f = \mu_s m \omega^2 R$
This and the next question are about the following situation:

6. (***) A block of mass \( m_1 \) is attached to a cord that is fixed at one end. The block moves in a circle of radius \( L_1 \). A second block of mass \( m_2 \) is attached to the first by a cord so that the blocks are \textbf{SEPARATED} by length \( L_2 \). Block \( m_2 \) also moves in a circle as shown in the figure. Both blocks are aligned radially and move on a horizontal, frictionless table. Both cords \( L_1 \) and \( L_2 \) are ideal and massless. The blocks are moving with angular velocity \( \omega \).

What is the tension in cord \( L_1 \)?

(a) \( \omega^2 \left[ (m_1 - m_2)(L_1 + L_2) \right] \)
(b) \( \omega^2 m_1 L_1 \)
(c) \( \omega^2 m_2 (L_1 + L_2) \)
(d) \( \omega^2 \left[ m_1 L_1 + m_2 (L_1 + L_2) \right] \)
(e) \( \omega^2 \left[ m_1 (L_2 - L_1) + m_2 (L_1 + L_2) \right] \)

7. (*) If cord \( L_2 \) snaps (\( L_1 \) and does not break), which of the following most correctly describes what will happened to the two masses?

(a) \( m_1 \) will continue to travel in a circle while \( m_2 \) will travel in a straight line.
(b) \( m_1 \) will continue to travel in a circle while \( m_2 \) will travel in a circle of larger radius.
(c) both \( m_1 \) and \( m_2 \) will no longer travel in a circular path.
This and the next two questions are about the following situation:

8. (*) A 6 kg box is pulled across a horizontal floor by a rope. The tension in the rope is $T = 5$ N. Consider a time interval during which the velocity of the box increases from 0.8 m/s to 1.5 m/s. If the floor is frictionless, how far has the box moved?

(a) 0.47 m  
(b) 0.97 m  
(c) 1.21 m  
(d) 1.50 m  
(e) 1.77 m

9. (*) Suppose now that there is friction between the box and the floor. The box now has to be pulled for 2 m to increase its speed from 0.8 m/s to 1.5 m/s (still with tension $T = 5$ N). What is the magnitude of the frictional force?

(a) 2.59 N  
(b) 5.00 N  
(c) 5.17 N  
(d) 7.42 N  
(e) 14.83 N

10. (*) Suppose now that the tension reverses direction and the box returns to its initial position. In this case, the total work done on the box by friction is zero.

(T) True  
(F) False
11. (***) The ball launcher in a pinball machine has a spring that has a force constant, \( k = 10 \text{ N/m} \) (see figure below). The surface on which the ball moves is inclined 10° with respect to the horizontal. How much must the spring be compressed so that when the plunger is released a 0.1 kg ball will travel 1.0 m up the incline with respect to the relaxed position of the spring? Friction and the mass of the plunger are negligible.

(a) 3.4 cm  
(b) 4.8 cm  
(c) 12 cm  
(d) 18 cm  
(e) 44 cm
12. (***) In Jules Verne’s “From the Earth to the Moon” the intrepid space travelers of mass \( m \) are fired from a giant cannon constructed by the Baltimore Gun Club. In an early test firing of the cannon, which is pointed straight up, the constructors want to shoot a projectile to an altitude of \( 1.5 \, R_E \), where \( R_E \) is the radius of the earth. Ignore the effects of air resistance and the rotation of the earth. (Note: 
\[ g = \frac{GM_E}{R_E^2}, \]
where \( G \) is Newton’s gravitational constant, \( M_E \) is the mass of the earth, and \( R_E \) is the radius of the earth.)

What must the muzzle speed of the projectile be for it to get this high?

(a) \( v = \left( \frac{gR_E}{3} \right)^{\frac{1}{2}} \)
(b) \( v = \left( 2gR_E/3 \right)^{\frac{1}{2}} \)
(c) \( v = \left( 4gR_E/3 \right)^{\frac{1}{2}} \)
(d) \( v = \left( 6gR_E/5 \right)^{\frac{1}{2}} \)
(e) \( v = \left( 8gR_E/5 \right)^{\frac{1}{2}} \)

13. (*) What is the speed of the projectile when it returns to the surface of the earth (just before hitting the ground)?

(a) less than the muzzle speed
(b) same as the muzzle speed
(c) more than the muzzle speed
**Kinematics**

\[ \mathbf{v} = \mathbf{v}_0 + \mathbf{a}t \]
\[ \mathbf{r} = \mathbf{r}_0 + \mathbf{v}_0 t + \frac{1}{2} \mathbf{a} t^2 \]
\[ v^2 = v_{0x}^2 + 2a(x - x_0) \]
\[ x - x_0 = \frac{(v_x + v_t) t}{2} \]
\[ g = 9.81 \text{ m/s}^2 = \frac{GM_E}{R_E^2} \]

**2D Motion**

\[ h_{\text{max}} = \frac{v_y^2 \sin^2 \theta}{2g} \]
\[ \text{Range} = \frac{v_y^2 \sin 2\theta}{g} \]

**Uniform Circular Motion**

\[ a = \frac{v^2}{r} = \omega^2 r \]
\[ v = \omega r \]
\[ \omega = \frac{2\pi}{T} = \frac{2\pi}{ \text{rev} / \text{sec} \text{.} } \]

**Galilean Transformations**

\[ \mathbf{r}' = \mathbf{r} - \mathbf{v}_0 t \]
\[ \mathbf{v}' = \mathbf{v} - \mathbf{v}_0 \]

**Dynamics**

\[ \mathbf{F}_{\text{net}} = m \mathbf{a} \]
\[ \mathbf{F}_{\text{A,B}} = -\mathbf{F}_{\text{B,A}} \]
\[ F = mg \] (gravity near earth's surface)
\[ F_{12} = -\frac{GM_1M_2}{r^2} \; ; \; G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2 \]
\[ F_{\text{spring}} = -k(\Delta x) \]

**Friction & Drag**

\[ f = \mu_L N \] (kinetic)
\[ f \leq \mu_s N \] (static)
\[ \vec{f}_{\text{drag}} = -bv \] (low speed)
\[ |f_{\text{drag}}| = \frac{1}{2} D \rho A v^2 \] (high speed)

**Work & Kinetic Energy**

\[ W = \int \mathbf{F} \cdot d\mathbf{r} \]
\[ W = \mathbf{F} \cdot \mathbf{r} = Fr \cos \theta \] (constant force)
\[ W_{\text{grav}} = -mg\Delta y \] (near earth surface)
\[ W_{\text{grav}} = GmM \left( \frac{1}{r_2} - \frac{1}{r_1} \right) \] (in general)
\[ W_{\text{spring}} = -k \left( x_2^2 - x_1^2 \right) / 2 \]
\[ KE = \frac{1}{2} m v^2 \]
\[ W_{\text{NET}} = \Delta KE \]

**Power**

\[ P \equiv dW/dt = \mathbf{F} \cdot \mathbf{v} \] (for constant force)