You can only us the TI-36X Pro for this exam.

You may use your calculator, writing utensils and supplied scratch paper. No other aids are allowed.

Throughout the exam, use \( g = 9.8 \, \text{m/s}^2 \). Most problems use 2 significant figures.

There is no penalty for guessing.

Your instructor cannot answer questions about the exam or aid in interpretation.

Write directly in the exam booklet showing your work and clearly circling your answers.

A SCANTRON form is to be filled out after you have completed the entire exam.

When done, turn in your SCANTRON, exam, equation sheet, and any scratch paper you used.

NOTE: The key to this exam appears on the last page.
1. You go for a 10 km “walk + run”. You walk the first 5 km at 6 km/hr and then you run the next 5 km at 12 km/hr. Your average speed over the 10 km was
   A. 9 km/hr
   B. 11 km/hr
   C. 10 km/hr
   D. 8 km/hr
   E. 7 km/hr

2. A particle’s position as a function of time is given by $x = 7.0te^{-t}$ where $x$ is in meters and $t$ is in seconds. The particle’s speed at $t = 3$ s is
   A. 0.35 m/s
   B. 0.23 m/s
   C. 0.81 m/s
   D. 0.58 m/s
   E. 0.70 m/s

3. A particle has a velocity at $t = 0$ of $v_{0x} = +16$ m/s. It experiences an acceleration $a_x = -4t$ where $a_x$ is in m/s$^2$ and $t$ is in s. At what positive time $t$ is the particle instantaneously at rest?
   A. 8.0 s
   B. 2.8 s
   C. 2.0 s
   D. 5.6 s
   E. 4.0 s
4. From ground level, a rock is thrown straight up with a speed of 12 m/s. The maximum height reached by the rock is
A. 7.3 m  
B. 15 m  
C. 8.9 m  
D. 11 m  
E. 13 m

5. A particle is traveling counterclockwise in a circle in the $xy$ plane around the origin. At some instant, its velocity is $\vec{v} = (1 \text{ m/s})\hat{i} + (-3 \text{ m/s})\hat{j}$. At this instant, the particle's position is in which quadrant?
A. quadrant 1  
B. quadrant 2  
C. quadrant 3  
D. quadrant 4  
E. The quadrant can't be determined from the given information.

6. The dashed line shows a car’s path. At time $t_1$, the car’s velocity is $\vec{v}_1$. At a later time $t_2$, it is $\vec{v}_2$. The direction of the car’s average acceleration from $t_1 \rightarrow t_2$ is closest to
A. south  
B. southeast  
C. west  
D. southwest  
E. northwest
7. A projectile is released from a diving airplane. At release, this projectile shares the same velocity as the airplane itself. Neglecting air drag, where does the projectile land?

A. \( x = 1300 \text{ m} \)

B. \( x = 190 \text{ m} \)

C. \( x = 400 \text{ m} \)

D. \( x = 940 \text{ m} \)

E. \( x = 540 \text{ m} \)

8. A ball on the end of a cord is being whirled at constant speed in a horizontal circle. Which choice describes the directions of the ball’s velocity \( \vec{v} \) and acceleration \( \vec{a} \)?

A. \( \vec{v} \) and \( \vec{a} \) are tangential to the ball’s circular arc.

B. \( \vec{v} \) and \( \vec{a} \) are radially outward.

C. \( \vec{v} \) is tangential, \( \vec{a} \) is radially outward.

D. \( \vec{v} \) and \( \vec{a} \) are radially inward.

E. \( \vec{v} \) is tangential, \( \vec{a} \) is radially inward.

9. The Ames Research Center has a centrifuge that is human-rated up to 12.5 \( g \). Suppose an occupant is rotating in this centrifuge at a radius of 8.8 m and at constant speed. If this occupant is experiencing a centripetal acceleration of 100 m/s\(^2\), the period of rotation is

A. 1.1 s

B. 0.55 s

C. 1.9 s

D. 1.3 s

E. 1.7 s
10. The velocity of ship A relative to the ground is \( \vec{v}_{AG} = (-5\hat{i} + 3\hat{j}) \) m/s. The velocity of ship B relative to the ground is \( \vec{v}_{BG} = (2\hat{i} + 7\hat{j}) \) m/s. The velocity of ship B relative to ship A is

A. \( \vec{v}_{BA} = (-7\hat{i} - 4\hat{j}) \) m/s
B. \( \vec{v}_{BA} = (3\hat{i} - 10\hat{j}) \) m/s
C. \( \vec{v}_{BA} = (7\hat{i} + 4\hat{j}) \) m/s
D. \( \vec{v}_{BA} = (-3\hat{i} + 10\hat{j}) \) m/s
E. \( \vec{v}_{BA} = (2\hat{i} + 7\hat{j}) \) m/s

11. You are in a train that is moving along a straight section of track on level ground at a very high constant speed. Facing forward, you are repeatedly tossing and catching a coin. Relative to you (in a reference frame that moves with you and the train), you must be throwing the coin

A. at a large angle forward from the vertical.
B. at a large angle backward from the vertical.
C. only slightly forward from the vertical.
D. only slightly backward from the vertical.
E. straight up along the vertical.

12. A 7.0 kg object moves in the horizontal \( xy \) plane. The two forces shown are the only forces that affect motion in the \( xy \) plane. The magnitude of the object’s acceleration is

A. 1.7 \( \text{m/s}^2 \)
B. 6.0 \( \text{m/s}^2 \)
C. 8.0 \( \text{m/s}^2 \)
D. 3.1 \( \text{m/s}^2 \)
E. 9.5 \( \text{m/s}^2 \)
13. A cement block is placed on a scale at rest. The scale reads 26 pounds. You place this block and scale on the floor of an elevator and you ride the elevator up to the 50th floor. As you are nearing the 50th floor and the elevator is \textit{gradually slowing down}, the scale might read

A. 22 pounds
B. 30 pounds
C. 0 pounds
D. 26 pounds
E. The scale will read a negative number.

14. A horizontal force is applied to keep this 2.4 kg block stationary on this frictionless inclined plane. The normal force exerted on the block by the plane is

A. 57 N
B. 40 N
C. 26 N
D. 24 N
E. 21 N

15. A 120 kg linebacker tackles a 93 kg quarterback. How do the force the linebacker exerts on the quarterback and the force the quarterback exerts on the linebacker compare?

A. The force the quarterback exerts is less in magnitude than the force the linebacker exerts.
B. Caught off guard, the force the quarterback exerts can be less in magnitude than the force the linebacker exerts.
C. With a proper stance, the force the quarterback exerts can be greater in magnitude than the force the linebacker exerts.
D. The force the quarterback exerts is equal in magnitude to the force the linebacker exerts.
E. More than one of the above are possible.
16. Due to a steady push on the 3.0 kg block, these blocks accelerate together across a frictionless floor. As they accelerate, the 4.0 kg block exerts a leftward 6.0 N contact force on the 5.0 kg block. The magnitude of the acceleration of the three blocks is

A. 1.5 m/s^2
B. 1.2 m/s^2
C. 0.50 m/s^2
D. 0.75 m/s^2
E. 1.3 m/s^2

17. A 4.5 kg block is pulled along the floor by a 29 N tension force at 35° above horizontal. The coefficient of kinetic friction between the block and floor is 0.42. The magnitude of the block’s acceleration is

A. 1.2 m/s^2
B. 2.3 m/s^2
C. 1.9 m/s^2
D. 3.4 m/s^2
E. 2.7 m/s^2

18. A horizontal force is applied to the bottom block. The stacked blocks accelerate as one due to static friction \( f_s \) between the blocks. The floor is frictionless. \( F_{\text{net},x} \) on the TOP block is

A. 0
B. \( +f_s \)
C. \( -f_s \)
D. \( F_{\text{app}} + f_s \)
E. \( F_{\text{app}} - f_s \)
19. Spheres A and B move through air. Each experiences a drag force \( F_{\text{drag}} = \frac{1}{2} C \rho A v^2 \). The value of the drag coefficient \( C \) is the same for both spheres. Compared to A, B has twice the radius and instantaneously twice the speed. The ratio of the drag force on B to that on A is

A. 4  
B. 2  
C. 8  
D. 1  
E. 16

20. A 7.5 kg particle experiences a force that varies with position as shown. At \( x = 0 \), the particle’s velocity is \( v_0 = 4 \text{ m/s} \). The particle’s speed at \( x = 8 \text{ m} \) is

A. 7.7 m/s  
B. 5.7 m/s  
C. 3.1 m/s  
D. 4.0 m/s  
E. 6.9 m/s

21. A 5000 kg elevator starts from rest on the ground. Over a period of 2.0 s, the elevator rises 3.0 m and speeds up to 2.5 m/s. The average power of the elevator’s motor during this time is

A. 65 kW  
B. 7.8 kW  
C. 120 kW  
D. 81 kW  
E. 74 kW
22. A 1.0 kg ball on the end of a string of length 1.2 m is released at 35° from vertical. From release to the bottom of the ball’s arc, the magnitude of the work done on the ball by the string’s tension force is
A. 0 J  
B. 9.6 J  
C. 6.7 J  
D. 12 J  
E. 2.1 J

23. Holding a 0.20 kg block in the palm of your hand, you attach the block to an ideal spring being careful to keep the spring relaxed. You then release the block and observe that the spring reaches a maximum stretch of 0.70 m (at the turning point). The spring’s spring constant is
A. 2.8 N/m  
B. 12 N/m  
C. 1.6 N/m  
D. 3.0 N/m  
E. 5.6 N/m

24. A block of mass \( m \) is released on a frictionless track from height 5\( R \). If the bottom of the track has curvature of radius \( R \), the \textit{normal force} on the block as it passes through the bottom is
A. 11 mg  
B. 3 mg  
C. 5 mg  
D. 7 mg  
E. 9 mg
25. A 10 kg box moving at 8.0 m/s slides onto a stretch of floor where the coefficient of kinetic friction between the box and floor is 0.24. How far along this stretch does the block slide as it comes to rest?

A. 18 m  
B. 14 m  
C. 7.1 m  
D. 11 m  
E. 3.5 m

26. Standing on a frictionless frozen pond, Emma and Zak hold opposite ends of a long massless pole of length $L$. Zak weighs twice as much as Emma. While Zak holds onto his end, Emma pulls herself along the pole until the two meet. During this process, approximately how far did Emma move?

A. $L/3$  
B. $2L/3$  
C. 0  
D. $L/2$  
E. $L$

27. This graph approximates a time-dependent net force experienced by a 2.2 kg object. Just before the force begins, the object’s velocity is $v_{ix} = -14$ m/s. Just after the force terminates, its velocity is

A. $v_{fx} = +14$ m/s  
B. $v_{fx} = +50$ m/s  
C. $v_{fx} = +22$ m/s  
D. $v_{fx} = +28$ m/s  
E. $v_{fx} = +36$ m/s
28. On a plane of ice, a heavy puck collides with a light puck. Which choice describes the center-of-mass (COM) trajectory of this 2-puck system?

A. How the collision alters the COM trajectory depends on the relative masses of the pucks.
B. How the COM trajectory is altered depends on the extent to which the collision is inelastic.
C. The COM moves with constant velocity showing no sign of the collision.
D. The degree the collision is glancing versus head-on affects how the COM trajectory is altered.
E. The COM trajectory can be altered by multiple factors including at least two of the above.

29. These two incoming clay blobs have different masses, speeds, and directions. They collide at the origin sticking together. What is the speed of the outgoing clay blob?

A. 12 m/s  
B. 17 m/s  
C. 20 m/s  
D. 24 m/s  
E. 14 m/s

![Diagram](image)

30. A centrifuge spinning at 16 rad/s is brought to rest at a constant angular acceleration of magnitude 8.0 rad/s². Through how many radians does the centrifuge spin as it winds down?

A. 32 rad  
B. 2.0 rad  
C. 16 rad  
D. 4.0 rad  
E. 8.0 rad
31. These three small spheres (they can be approximated as point particles) are fastened to a massless rod that spins around the pivot. The speed of the sphere furthest out is 4.2 m/s. The kinetic energy of rotation of this system is

A. 24 J
B. 8.0 J
C. 4.0 J
D. 6.2 J
E. 12 J

32. A rectangular plate of width $a$ and length $b$ and mass $M$ is mounted to an axle at one corner. The integral that calculates this plate’s rotational inertia about this axle is

A. $\int_{0}^{\sqrt{a^2+b^2}} r^2 M \, dr$
B. $\int_{0}^{a} x^2 M \, dx + \int_{0}^{b} y^2 M \, dy$
C. $\int_{0}^{\sqrt{a^2+b^2}} r^2 M \, \frac{dr}{\sqrt{a^2+b^2}}$
D. $\int_{y=0}^{b} \int_{x=0}^{a} (x^2 + y^2)M \frac{dx \, dy}{ab}$
E. $\int_{y=0}^{b} \int_{x=0}^{a} (x^2 + y^2)M \, dx \, dy$

33. This 0.65 kg uniform aluminum meter stick is mounted to a pivot at the 30 cm mark. At 70° away from vertical, what is the torque exerted by gravity on this meter stick about the pivot?

A. 1.2 N·m
B. 4.5 N·m
C. 3.7 N·m
D. 3.5 N·m
E. 4.2 N·m
34. The pulley has rotational inertia $I = 0.0030 \text{ kg m}^2$ and radius $r = 0.050 \text{ m}$. The 0.60 kg block descends as the cord unwinds without slipping. The magnitude of the block’s acceleration is

A. 8.9 m/s$^2$
B. 3.3 m/s$^2$
C. 4.5 m/s$^2$
D. 9.8 m/s$^2$
E. 6.5 m/s$^2$

35. Four cylinders roll without slipping down a ramp starting from rest. Which cylinder completes the run down the ramp in the least time?

A. A large solid cylinder of low density.
B. Like cylinder A but with a hole drilled out.
C. Like cylinder B but with a matching high density core glued into the hole.
D. Just the high density core on its own.
E. They all finish with the same time.

36. Two identical cylinders A and B roll without slipping along the horizontal at ground level and at the same speed. A rolls onto an incline that has sufficient grip for A to continue to roll without slipping. B rolls onto a frictionless incline. The inclines have different slopes.

Which cylinder reaches the greatest vertical height, $h_{\text{max}}$?

A. cylinder B
B. The disks reach the same maximum height.
C. cylinder A
D. The disk that rolls onto the incline of greater slope.
E. The disk that rolls onto the incline of lesser slope.
37. This 10 kg particle is 1.8 m from the origin \(O\), moving at 1.2 m/s in the direction shown. Relative to \(O\), the magnitude of the particle’s angular momentum is

A. 11 kg·m\(^2\)/s  
B. 41 kg·m\(^2\)/s  
C. 24 kg·m\(^2\)/s  
D. 22 kg·m\(^2\)/s  
E. 32 kg·m\(^2\)/s

38. Two disks spin freely at different rates around a frictionless axle. With no external torque delivered, the disks are slid along the axle and brought into contact. After a short period of sliding against one another, the disks spin together as one. During this process, which of the following is/are conserved for this two-disk system?

A. Kinetic Energy  
B. Mechanical Energy  
C. Angular Momentum  
D. None of the above are conserved.  
E. More than one of the above are conserved.

39. An object weighs 100 N on Earth. This object on a planet that has twice the radius and twice the mass of Earth would weigh

A. 100 N  
B. 50 N  
C. 400 N  
D. 200 N  
E. 25 N
40. A satellite in a circular orbit is a distance \( r = 7.2 \times 10^6 \) m from the center of the Earth. The satellite’s speed is

A. 7400 m/s  
B. 11000 m/s  
C. 7900 m/s  
D. 1900 m/s  
E. 1200 m/s

41. A projectile is launched vertically from Earth’s surface. It falls back to Earth after reaching a maximum radius from Earth’s center of \( r = 3R_{\text{Earth}} \). The projectile’s launch speed was

A. \( \sqrt{\frac{2GM}{3R_{\text{Earth}}}} \)  
B. \( \sqrt{\frac{4GM}{9R_{\text{Earth}}}} \)  
C. \( \sqrt{\frac{GM}{3R_{\text{Earth}}}} \)  
D. \( \sqrt{\frac{4GM}{3R_{\text{Earth}}}} \)  
E. \( \sqrt{\frac{2GM}{9R_{\text{Earth}}}} \)

42. An inground pool is filled to depth \( h_{\text{max}} \) with water of density \( \rho \). One sidewall is of width \( w \). With \( p_0 \) denoting atmospheric pressure at the surface, which integral calculates the magnitude of the force on this sidewall exerted by just the water that is in direct contact with this sidewall?

A. \( \int_0^{h_{\text{max}}} (p_0 + \rho gh)h_{\text{max}} \, dh \)  
B. \( \int_0^{h_{\text{max}}} (p_0 + \rho gh) \frac{w \, dh}{h_{\text{max}}} \)  
C. \( \int_0^{h_{\text{max}}} (p_0 + \rho gh) \frac{h_{\text{max}} \, dh}{w} \)  
D. \( \int_0^{h_{\text{max}}} (p_0 + \rho gh) \, dh \)  
E. \( \int_0^{h_{\text{max}}} (p_0 + \rho gh) w \, dh \)
43. A hollow sphere made of aluminum ($\rho_{\text{aluminum}} = 2700 \text{ kg/m}^3$) is neutrally buoyant when fully submerged in fresh water ($\rho_{\text{water}} = 1000 \text{ kg/m}^3$). If the outer radius of this sphere $R$ is 1.0 m, what is the sphere’s inner radius $r$?

A. 79 cm  
B. 81 cm  
C. 58 cm  
D. 86 cm  
E. 63 cm

44. A block that hangs from a spring is pulled down slightly and released. Over the span of the block’s oscillations, where do $v_{\text{max}}$ and $a_{\text{max}}$ occur?

A. $v_{\text{max}}$ at the middle, $a_{\text{max}}$ at the top and bottom.  
B. $v_{\text{max}}$ at the top and bottom, $a_{\text{max}}$ at the middle.  
C. $v_{\text{max}}$ and $a_{\text{max}}$ both in the middle.  
D. $v_{\text{max}}$ and $a_{\text{max}}$ both at the top and bottom.  
E. $v_{\text{max}}$ at the middle, $a_{\text{max}}$ just at the bottom.

45. A 0.20 kg mass oscillates on the end of a spring according to $x = (0.060 \text{ m}) \cos[(3.4 \text{ rad/s}) t]$. The mechanical energy of this oscillator is

A. 0.020 J  
B. 0.24 J  
C. 0.12 J  
D. 0.0042 J  
E. 0.0061 J
46. A simple pendulum is released $4^\circ$ from vertical and its period is measured to be 1.6 s. Now instead, the bob is released $8^\circ$ from vertical. We will now measure a period of

- A. 2.8 s
- B. 2.3 s
- C. 2.0 s
- D. 1.6 s
- E. 3.2 s

47. A 0.70 kg block oscillates on the end of a spring. This system experiences damping with a damping constant $b = 0.15$ kg/s. How long does it take for the amplitude of the block’s oscillations to decay to half of its starting value?

- A. 4.7 s
- B. 6.5 s
- C. 7.3 s
- D. 8.4 s
- E. 9.2 s

48. The equation of a traveling wave on a string is $y = (6.0 \text{ cm}) \sin[(14 \text{ rad/m}) x + (87 \text{ rad/s}) t]$. If the string’s tension is 22 N, what is the string’s linear mass density?

- A. 0.81 kg/m
- B. 0.57 kg/m
- C. 0.25 kg/m
- D. 0.64 kg/m
- E. 0.45 kg/m
49. When this string under tension is driven at 172 Hz, you see the depicted standing wave. If you continuously increase the driving frequency, the next frequency for which the string responds resonantly is

A. 280 Hz
B. 258 Hz
C. 344 Hz
D. 243 Hz
E. 215 Hz

50. Deep underwater, an attack sub moves at a speed of 12.0 m/s through still water. As it approaches an underwater mountain it sends a 900 Hz sonar wave that travels through the water at 1482 m/s. The wave reflects off the mountain and the sub detects this reflected wave.

The sub detects a reflected frequency of

A. 893 Hz
B. 907 Hz
C. 886 Hz
D. 915 Hz
E. 900 Hz

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1 D 13 A 25 B 37 A 49 E
2 E 14 C 26 B 38 C 50 D
3 B 15 D 27 C 39 B
4 A 16 A 28 C 40 A
5 C 17 E 29 A 41 D
6 B 18 B 30 C 42 E
7 E 19 E 31 D 43 D
8 E 20 E 32 D 44 A
9 C 21 D 33 A 45 D
10 C 22 A 34 B 46 D
11 E 23 E 35 C 47 B
12 B 24 A 36 C 48 B