

The Thirty-second Annual SLAPT Physics Contest
Washington University in Saint Louis
April 22nd, 2017

Mechanics Exam

$$g = 9.8 \text{ m} \cdot \text{s}^{-2}$$

$$G = 6.67 \times 10^{-11} \text{ m}^3 \cdot \text{kg}^{-1} \cdot \text{s}^{-2}$$

$$c = 3 \times 10^8 \text{ m} \cdot \text{s}^{-1}$$

Please answer the following questions on the supplied answer sheet. You may write on this test booklet and keep it for your records. Only the answer sheets will be scored.

Your sheets must have your name, your school, and MECHANICS on them.

1. If a particle moves with constant velocity, the path that it follows:

- a) must be a straight line
- b) must be a circle
- c) must be a parabola
- d) may be straight or circular
- e) may be straight or curved, and not necessarily circular

2. Suppose a car moves along a straight line (x-axis) with constant acceleration. Initially its velocity was +8.0 m / s. At $t = 5.0$ s, its velocity is +32.0 m / s. The displacement of the car during the 0.0 to 5.0 second interval is:

- a) 100 m
- b) 120 m
- c) 160 m
- d) 200 m
- e) 500 m

3. A 0.50 kg block attached to an ideal spring with a spring constant of 80 N / m oscillates on a horizontal frictionless surface. The total mechanical energy is 0.12 J. The greatest speed of the block is:

- a) 0.15 m / s
- b) 0.24 m / s
- c) 0.49 m / s
- d) 0.69 m / s
- e) 1.46 m / s

4. What happens when an object of mass **m**, strikes a stationary object of equal mass?

- a) the two objects (cannot) stick together
- b) the collision must be elastic
- c) the first object must stop
- d) momentum is not necessarily conserved
- e) none of the above

5. At a location where $g = 9.8 \text{ m} / \text{s}^2$, an object is thrown vertically down with an initial speed of 1.0 m / s. After 5 seconds the object will have traveled:

- a) 125 m
- b) 127.5 m
- c) 245 m
- d) 250 m
- e) 255 m

6. A 90.0 kg man stands in an elevator that has a downward acceleration of $1.4 \text{ m} / \text{s}^2$. The force exerted by him on the floor is about:

- a) 0 N
- b) 90 N
- c) 760 N
- d) 880 N
- e) 1010 N

7. How long would it take a car moving at a speed of 42.0 m/s to come to a complete stop if it undergoes a constant deceleration of magnitude 5.1 m/s^2 ?

- a) 2.94 s
- b) 5.38 s
- c) 5.83 s
- d) 9.83 s
- e) 11.25 s

8. A cat leaps to catch a bird. If the cat's jump was at 55.0° off the ground, and its initial speed was 8.5 m/s , what is the highest point of its trajectory?

- a) 0.796 m
- b) 2.39 m
- c) 2.47 m
- d) 4.78 m
- e) 31.6 m

9. A skydiver reaches a terminal velocity of 90 km/hr . If the skydiver has a mass of 125.0 kg , what is the magnitude of the upward force on the skydiver due to wind resistance, when terminal velocity is reached?

- a) 0 N
- b) 686 N
- c) 755 N
- d) 1225 N
- e) 8400 N

10. A child swings a ball tied to a string, in a horizontal circle of radius 1.4 m . If the mass of the ball is 0.60 kg and it makes 1.5 rev/s , what is the magnitude of the ball's angular momentum?

- a) $0.9 \text{ kg} \cdot \text{m}^2/\text{s}$
- b) $4.5 \text{ kg} \cdot \text{m}^2/\text{s}$
- c) $5.7 \text{ kg} \cdot \text{m}^2/\text{s}$
- d) $6.3 \text{ kg} \cdot \text{m}^2/\text{s}$
- e) $11.1 \text{ kg} \cdot \text{m}^2/\text{s}$

11. An ice skater with a moment of inertia of $65.0 \text{ kg} \cdot \text{m}^2$ is spinning at 85 rpm. If the skater pulls in her arms, her moment of inertia decreases to $55.2 \text{ kg} \cdot \text{m}^2$. As such, what is her resulting angular speed?
- a) 21 rpm
 - b) 29 rpm
 - c) 49 rpm
 - d) 57 rpm
 - e) 100 rpm
12. Given two wheels of identical mass, A and B, the mass of wheel A is spread uniformly over the disk of the wheel, while the mass of wheel B is concentrated at the rim. Which wheel has the larger moment of inertia?
- a) Wheel A.
 - b) Wheel B.
 - c) Both wheels have the same moment of inertia.
13. A person sits on a swing. When the person sits still, the swing oscillates back and forth at its natural frequency. If two people, each with the same mass as the first person, both sit on the swing at the same time, and oscillate, the new natural frequency of the swing will be:
- a) Greater.
 - b) The same.
 - c) Smaller.
14. A 1500 kg cannon fires a 128.0 kg cannonball horizontally, at a speed of 55 m / s relative to the ground. Assuming that frictional forces are negligible, what is the recoil velocity of the cannon?
- a) 3.9 m / s
 - b) 4.3 m / s
 - c) 4.7 m / s
 - d) 5.2 m / s
 - e) 11.5 m / s

15. A tennis ball falls from a shelf and bounces on the floor three times. If each time it bounces, it loses 27.0 % of its energy due to heat, how high does it bounce after the third time if the shelf is 3.0 m from the floor?

- a) 11 cm
- b) 11.5 cm
- c) 16 cm
- d) 24 cm
- e) 73 mm

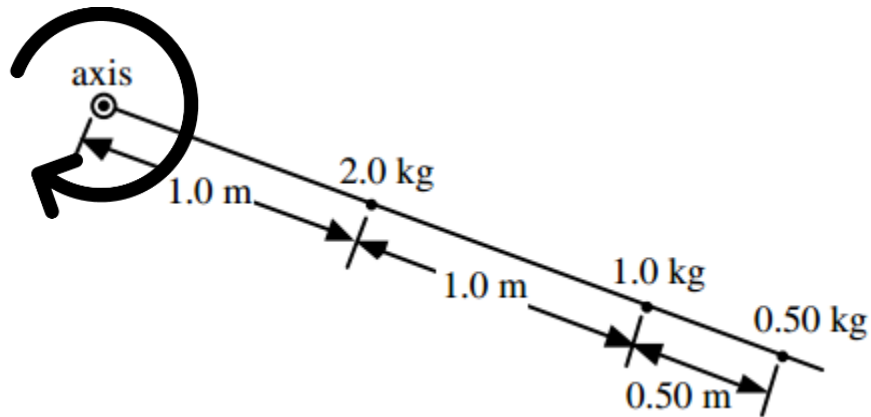
16. A 37.0 g bullet pierces a sandbag that is 41 cm thick. If the initial bullet speed is 75 m / s, and emerges from the sandbag with 20 m / s, what is the magnitude of the average frictional force that the bullet experiences as it travels through the bag?

- a) 2.4 N
- b) 24 N
- c) 97 N
- d) 240 N
- e) 136 N

17. Which of the following statements is true about planets in elliptical orbits?

- a) The tangential speed of each planet is constant.
- b) The tangential speed of each planet is constantly changing, with the highest speed coming when the planet is farthest from the sun.
- c) The tangential speed of each planet is constantly changing, with the highest speed coming when the planet is closest to the sun.
- d) None of the above.

18. Three objects are attached to a massless rigid rod that has an axis of rotation as shown. If each mass is located at the point shown for each, calculate the moment of inertia of this system.



- a) $1.3 \text{ kg} \cdot \text{m}^2$
- b) $3.1 \text{ kg} \cdot \text{m}^2$
- c) $5.3 \text{ kg} \cdot \text{m}^2$
- d) $7.2 \text{ kg} \cdot \text{m}^2$
- e) $9.1 \text{ kg} \cdot \text{m}^2$

19. It is known that human reaction times are worsened under the influence of alcohol. If a drunk driver is driving alongside a sober driver at 49 miles / hr, and both press their brakes upon seeing a stoplight – how much farther does the drunk driver’s car travel? Assume that after seeing the stoplight, the sober driver hits her brakes 0.33 seconds later, but the drunk driver takes 1.0 second to do the same.

- a) 34 ft
- b) 40 ft
- c) 45 ft
- d) 48 ft
- e) 53 ft

20. A box weighing 100.0 N slides down an incline plane at a constant acceleration of 1.5 m / s^2 . If the plane is raised 20 degrees above the surface, what is the tangential force of friction?
- a) 10.2 N
 - b) 18.9 N
 - c) 26.3 N
 - d) 34.8 N
 - e) 94.0 N
21. Complete the following statement: an inertial reference frame is one in which:
- a) Newton's first law of motion is valid.
 - b) The inertia of each of the objects within the frame, are zero.
 - c) The frame is accelerating.
 - d) The acceleration due to gravity is greater than zero m / s^2 .
 - e) Newton's third law of motion is not valid.
22. A bullet of mass 45.0 g is fired horizontally from a height of 2.0 m; and, at the same instant a 5.0 kg bowling ball is dropped from rest at the same height. Ignoring air-resistance, which is the correct outcome?
- a) the bullet hits the ground first, much sooner than the bowling ball
 - b) the bullet hits the ground first, then quickly followed by the bowling ball
 - c) the bowling ball hits the ground first, much sooner than the bullet
 - d) the bowling ball hits the ground first, then quickly followed by the bullet
 - e) both hit at the same time
23. Consider a mass connected to a spring that is hanging vertically from a post. At $t = 0$ the mass is passing through the equilibrium position and moving in the $-x$ direction. If the equation of motion for the oscillating mass can be described by $x(t) = A \cos(\omega t + \theta)$, determine the phase angle θ .
- a) $+\pi$
 - b) $+\pi/2$
 - c) $-\pi/2$
 - d) $-\pi/2$
 - e) 0

24. A tension of 9000 N in an elevator cable gives the elevator an upward acceleration of 0.5 m / s^2 .

What tension would be required to produce an upward acceleration of 1.0 m / s^2 ?

- a) 4,500 N
- b) 9,440 N
- c) 12,620 N
- d) 14,800 N
- e) 18,000 N

25. A 4.0 kg particle moving at 5.0 m / s follows a circular path whose radius is 2.0 m. The magnitude of the net force acting on this particle is:

- a) 10.0 N
- b) 20.0 N
- c) 30.0 N
- d) 40.0 N
- e) 50.0 N

26. For a particle undergoing circular motion, the rate at which the magnitude of its velocity is changing is given by the:

- a) magnitude of the acceleration vector
- b) tangential component of the acceleration vector
- c) centripetal (or radial) component of the acceleration vector
- d) partly by the tangential and centripetal component of the acceleration vector
- e) none of the above

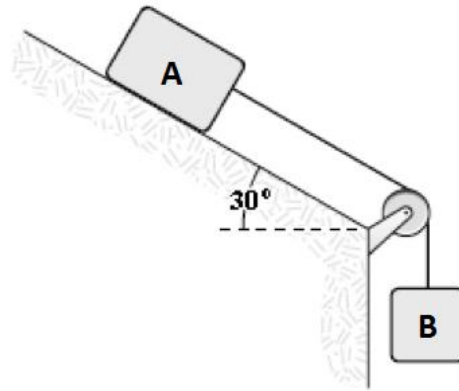
27. An arrow is aimed horizontally, directed at the center of a target 20.0 m away. Upon release and traveling through the air, the arrow hits 0.050 m below the center of the bulls-eye. Neglecting air-resistance, what was the initial speed of the arrow?

- a) 20 m / s
- b) 40 m / s
- c) 100 m / s
- d) 200 m / s
- e) 400 m / s

28. A simple pendulum of mass m , and length L has a period of oscillation T , at angular amplitude $\theta = 5$ degrees from its equilibrium position. If the amplitude is changed to 10° , and everything else remains constant, the new period of the pendulum would be approximately:

- a) $2 T$
- b) $\sqrt{2} T$
- c) T
- d) $T / \sqrt{2}$
- e) $T / 2$

29. Two masses are connected by a string which passes over a frictionless, massless pulley.



Mass B hangs vertically and mass A slides on a 30 degrees incline. The vertically hanging mass is 4.0 kg, and the mass on the frictionless incline is 6.0 kg. The acceleration of the 4.0 kg mass is:

- a) $0.98 \text{ m} / \text{s}^2$
- b) $3.92 \text{ m} / \text{s}^2$
- c) $5.75 \text{ m} / \text{s}^2$
- d) $6.86 \text{ m} / \text{s}^2$
- e) $7.84 \text{ m} / \text{s}^2$

30. A hobby rocket reaches a maximum height of 72.3 m and lands 111.0 m away from the launch site.

What was the angle at launch?

- a) 45°
- b) 69°
- c) 75°
- d) 82°
- e) 15°

31. Future space stations will create an artificial gravity by rotating. Consider a cylindrical space station of 390 m in diameter rotating about its axis. Astronauts walk on the inside of the space station. What rotation period will provide a “normal” gravity?

- a) 4.4 s
- b) 6.3 s
- c) 14 s
- d) 28 s
- e) 56 s

32. A block starts from rest at the top of a 31.0° inclined plane, and encounters a spring of constant 3.4 kN / m, rigidly attached to the plane. If the block’s mass is 33.0 kg, and it compresses the spring by 37.0 cm, find the distance the block traveled before it encountered the spring

- a) 1.0 m
- b) 1.37 m
- c) 1.74 m
- d) 1.82 m
- e) 1.96 m

33. A prankster drops a water balloon from the top of a building onto an unsuspecting person on the sidewalk below. If the balloon is traveling at 30.3 m / s when it strikes the person’s head (1.5 m above the ground), how tall is the building?

- a) 48 m
- b) 49 m
- c) 50 m
- d) 51 m
- e) 63 m

34. A force of 55.0 N stretches a spring 0.73 m from its equilibrium position. What is the value of the spring constant?

- a) 75 N / m
- b) 40 N / m
- c) 62 N / m
- d) 84 N / m
- e) 105 N / m

35. A tightrope walker walks across a 30.0 m long wire tied between two poles. The center of the wire is displaced vertically downwards by 1.0 m when she is halfway across. If the tension in both halves of the wire at this point is 6262 N, what is the mass of the tightrope walker? Neglect the mass of the wire.

- a) 43 kg
- b) 74 kg
- c) 85 kg
- d) 91 kg
- e) 81 kg

36. A box of mass 11.0 kg must be slid across a level floor. If the coefficient of static friction between the box and the floor is 0.37, what is the minimum force needed to start moving the box from rest?

- a) 28 N
- b) 40 N
- c) 56 N
- d) 70 N
- e) 108 N

37. In the absence of friction, how much work would a child do while pulling a 12.0 kg wagon a distance of 4.3 m, with a 22 N force?

- a) 52 J
- b) 67 J
- c) 80 J
- d) 95 J
- e) 102 J

38. A spring has a spring constant of 1734 N / m and it moves horizontally in simple harmonic motion, on a frictionless tabletop. If a mass of 756.7 g is attached to it, what is the mass's speed as it passes through the equilibrium point? The spring's maximum extension is 31.02 cm .

- a) 0 m / s
- b) 0.5 m / s
- c) 14.85 m / s
- d) 46.4 m / s
- e) 63.7 m / s

The following two questions, #39 and #40, refer to the following information:

Two vehicles, A and B, approach a right angle intersection from different streets, and then collide. After the collision, they become entangled. If the mass of car B is 3 times that of car A, and car A had a speed of 14 m / s while car B had a speed of 13 m / s .

39. What is the final velocity of the wreck?

- a) 9.1 m / s
- b) 10.4 m / s
- c) 12.1 m / s
- d) 13.8 m / s
- e) 15.2 m / s

40. At what angle does the wreck move off from the initial direction of B?

- a) 19°
- b) 43°
- c) 45°
- d) 70°
- e) 85°

41. A car accelerates from 8.0 m/s to 21.0 m/s at a rate of 3.0 m/s^2 . How far does it travel while accelerating?

- a) 38 m
- b) 63 m
- c) 107 m
- d) 189 m
- e) 206 m

42. An object moving with a velocity of $\vec{v} = 4 \frac{\text{m}}{\text{s}} \hat{x} - 1 \frac{\text{m}}{\text{s}} \hat{y} + 3 \frac{\text{m}}{\text{s}} \hat{z}$ is acted on by a force whose components are $\vec{F} = -5\text{N}\hat{x} + 5\text{N}\hat{z}$. What is the power of the energy transferred to the object that is involved in this interaction?

- a) -35 W
- b) -5 W
- c) 0 W
- d) $+5 \text{ W}$
- e) $+35 \text{ W}$

43. Two people slide on a frictionless, flat, horizontal plane of ice. Person A, whose mass is 54 kg , is sliding due east at a speed of 2.5 m/s . Person B, whose mass is 68 kg , is sliding due south at a speed of 1.8 m/s . These people collide and hold on to each other. What is the magnitude of their joint velocity after the collision?

- a) 1.5 m/s
- b) 2.0 m/s
- c) 2.5 m/s
- d) 3.0 m/s
- e) 3.5 m/s

44. A rock is released at rest from the top of a tall cliff. What is its speed when it is 70.0 m from its starting point?

- a) 9.8 m / s
- b) 13.1 m / s
- c) 18.5 m / s
- d) 26.2 m / s
- e) 37.0 m / s

45. The center of gravity coincides with the center of mass:

- a) always
- b) never
- c) if the center of mass is at the geometrical center of the body
- d) if the gravitational field strength is uniform over the body
- e) if the body has a uniform distribution of mass

46. Two identical carts travel at 1.0 m / s in opposite directions on a common horizontal surface. They collide head-on, and are reported to rebound, each with a speed of 2.0 m / s. Thus:

- a) momentum was not conserved; therefore, the report must be false
- b) if some other form of energy was changed into kinetic energy during the collision, the report could be true
- c) if the collision was elastic, the report could be true
- d) if friction is present, the report could be true
- e) if the duration of the collision were long enough, the report could be true

47. A projectile thrown straight up with initial speed v_0 , reaches elevation h_{\max} relative to its starting point before falling back. Neglecting atmospheric effects, if we want the projectile to reach elevation $2 h_{\max}$, its minimum initial speed should be

- a) $\sqrt{2} v_0$
- b) $2 v_0$
- c) $2\sqrt{2} v_0$
- d) $4 v_0$
- e) $v_0/\sqrt{2}$

48. If the speed of a particle in circular motion is doubled, and at the same time the radius of its orbit is halved, the centripetal force acting on the particle must be multiplied by the factor

- a) $1/2$
- b) 2
- c) $2\sqrt{2}$
- d) 4
- e) 8

49. Particle 1, initially sitting at the origin, is struck by particle 2 traveling in the +x direction, at 10.0 m / s. After the collision, the velocities of the particles are perpendicular to each other. If the speed of particle 2 is now 8.0 m / s, and its mass is twice that of particle 1, then the final speed of particle 1 is:

- a) 2.0 m / s
- b) 6.0 m / s
- c) 9.0 m / s
- d) 12 m / s
- e) 18 m / s

50. Suppose you exert an upward force of 30 N on a book (weighing 40 N) which is on the palm of your hand. The magnitude of the force that the book exerts on your palm is:

- a) 10 N
- b) 30 N
- c) 40 N
- d) 70 N
- e) 100 N