The Thirtieth Annual SLAPT Physics Contest
Washington University in Saint Louis
April 25, 2015

Mechanics Exam

$g = 9.8\ \mathrm{m/s^2}$ $\qquad\qquad$ $G = 6.67\times10^{-11}\mathrm{m^3kg^{-1}s^{-2}}$

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. A ball is rolling with a velocity of $\vec{v} = 3\hat{x} - 4\hat{y}$, its speed is
   A. $\vec{v} = 5\,\hat{z}$
   B. $v = 5$
   C. $\vec{v} = 2.23\,\hat{z}$
   D. $v = 2.23$

2. A particle is launched horizontally with an initial speed of 5 m/s and subsequently interacts only gravitationally with the earth. The horizontal component of the particle's velocity after a few seconds have passed is
   A. Somewhat greater than 5 m/s
   B. Essentially equal to 5 m/s
   C. Somewhat less than 5 m/s
   D. 0

3. In a test of a new missile defense system, a missile is fired on a trajectory that would directly strike a certain bunker. A laser flash from the bunker ignites the missile's fuel, causing it to explode in two fragments, one with 1.8 times the mass of the other. If the fragments land at the same time 45 m apart, by how much does the larger fragment miss hitting the bunker? Ignore the effects of air resistance.

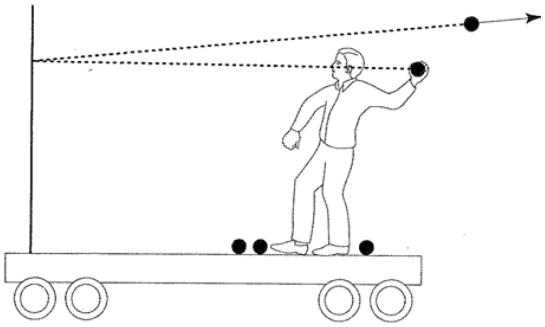
   A. 45 m
   B. 16 m
   C. 29 m
   D. It hits the bunker

4. In a reference frame fixed on the sun, which follows the smoothest path

   A. The earth
   B. The moon
   C. The center of mass of the earth-moon system
   D. All paths are equally smooth

5. Suppose you are on a cart, initially at rest on a track with very little friction. You throw a ball at a partition that is rigidly mounted on the cart. If the ball flies past you after it bounces off the partition, where will the cart be after the ball passes and how will you be moving?

A. Left of where it started, moving left
B. Right of where it started, moving right
C. Just where it started, and not moving
D. Just where it started, moving left
E. Just where it started, moving right

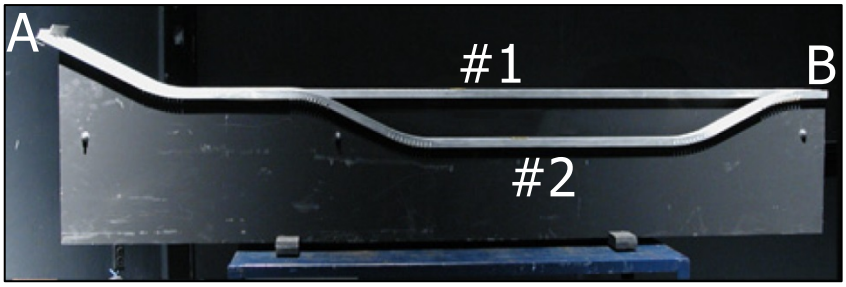


6. Two people slide on a frictionless, flat, horizontal plane of ice. Person A, whose mass is 54kg, is sliding due east at a speed of 2.5 m/s. Person B, whose mass is 68kg, is sliding due south at a speed of 1.8 m/s. These people collide and hold on to each other. What is the magnitude of their joint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

A. 1.5 m/s
B. 2.0 m/s
C. 2.5 m/s
D. 3.0 m/s

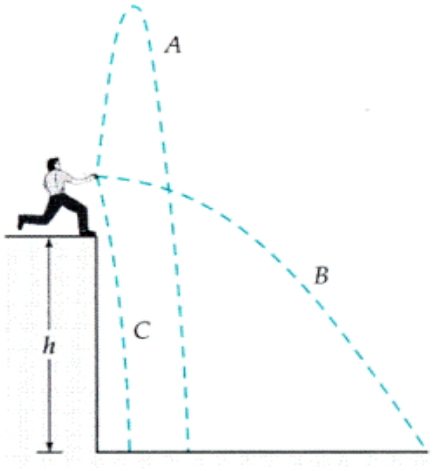
7. Two identical balls leave point A at the same time with the same initial speed. Which ball will arrive at the point B first?

A. The ball following path #1
B. The ball following path #2
C. They arrive at the same time
D. Impossible to tell



8. A person throws three identical rocks off a cliff of height h with exactly the same speed v_0 each time (see the drawing at the right). Rock *A* is thrown almost vertically upward, rock *B* is thrown horizontally, and rock *C* is thrown almost vertically downward. Which rock hits the ground with the greatest *speed*? (Ignore air friction)

A. Rock *A*.
B. Rock *B*.
C. Rock *C*.
D. all rocks hit with the same speed.



9. Assuming that $z = 0$ at the earth's surface, at roughly what value of z is the potential energy equation $V(r) = mgz$ (with $g = 9.80\ \mathrm{m/s}$) wrong by about 1%?

A. $z = 1\mathrm{km}$
B. $z = 15\mathrm{km}$
C. $z = 60\mathrm{km}$
D. $z = 250\mathrm{km}$
E. The equation is never in error: it is exact.

10. Two hockey pucks are initially at rest on a horizontal plane of frictionless ice. Puck *A* has twice the mass of puck *B*. Imagine that we apply the same constant force to each puck for the same interval of time dt. How do the pucks' kinetic energies compare at the end of this interval?

A. $K_A = 4K_B$
B. $K_A = 2K_B$
C. $K_A = K_B$
D. $2K_A = K_B$
E. $4K_A = K_B$

11. Two hockey pucks are initially at rest on a horizontal plane of frictionless ice. Puck *A* has twice the mass of puck *B*. Imagine that we apply the same constant force to each puck until each puck crosses a finish line 1m from its starting point. How do the pucks' kinetic energies compare when each crosses the finish line?

A. $K_A = 4K_B$
B. $K_A = 2K_B$
C. $K_A = K_B$
D. $2K_A = K_B$
E. $4K_A = K_B$

12. Four point particles, each with mass $^1/_4\,M$, are connected by massless rods so that they form a square whose sides have length L. What is the moment of inertia I of this object if it is spun around an axis going through the center of the square perpendicular to the plane of the square?

A. $^1/_{16}\,ML^2$
B. $^1/_8\,ML^2$
C. $^1/_4\,ML^2$
D. $^1/_2\,ML^2$
E. ML^2

13. 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 transfer involved in this interaction?

A. -35 W
B. -5 W
C. 0 W
D. $+5$ W
E. $+35$ W

14. A cylinder rolls without slipping down an incline directly toward you. The contact interaction between the cylinder and the incline exerts a friction torque on the cylinder about the cylinder's center of mass. What is the direction of this torque?

A. Toward you.
B. Away from you.
C. To your right.
D. To your left.

15. A child swings a 0.1-kg ball on a string in a horizontal circle of radius 2.0 m once every 0.63 s. The ball's angular momentum about the child has a magnitude of

A. $0.63\ \text{kg} \cdot \text{m}^2/\text{s}$
B. $2.0\ \text{kg} \cdot \text{m}^2/\text{s}$
C. $4.0\ \text{kg} \cdot \text{m}^2/\text{s}$
D. $10\ \text{kg} \cdot \text{m}^2/\text{s}$
E. $20\ \text{kg} \cdot \text{m}^2/\text{s}$

16. 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.

17. A person is sitting at rest on a stool that is free to rotate about a vertical axis while holding in one hand a bicycle wheel that is rapidly spinning counterclockwise when viewed from above. The person then stops the wheel with the other hand. What happens to the person?

A. The person must rotate counterclockwise.
B. The person must rotate clockwise.
C. The person will rotate in a direction that depends on which hand does the stopping.
D. Nothing; the wheel's angular momentum is carried away by external interactions.
E. Nothing; the wheel's angular momentum is simply dissipated by the friction interaction.

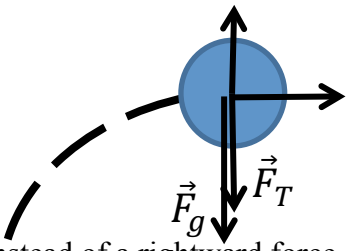
18. If global warming proceeds during the next century as anticipated, it is possible that the polar ice caps will melt, substantially raising sea levels around the world (and flooding coastal cities such as New York). Would this shorten, lengthen, or have strictly no effect on the duration of the day?

A. Lengthen the day slightly.
B. Shorten the day slightly.
C. Have strictly no effect on the length of the day.

19. A spaceship with a mass of 24,000 kg is traveling in a straight line at a constant speed of 320 km/s in deep space. What is the magnitude of the net thrust force acting on this spaceship?

A. 7.7 MN
B. 7.7 GN
C. 75 N
D. 0.075 N
E. 0

20. The free-body diagram below is supposed to represent a rock at the end of a string which is being whirled clockwise in a vertical circle. The rock is at the top of its circular path at the instant shown. How should we label the rightward force?



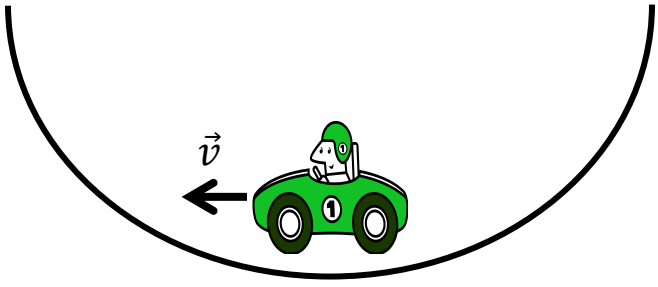
A. $\vec{F}_M$ (force of motion)
B. $\vec{F}_I$(force of inertia)
C. $\vec{F}_D$
D. The diagram is wrong: there is no rightward force
E. The diagram is wrong: there should be a leftward force instead of a rightward force.

21. An object falling vertically at a speed of 20 m/s lands in a snowbank and comes to rest 0.5 s later. What is the object's average acceleration during this interval?

A. 10 m/s^2 up
B. 10 m/s^2 down
C. 40 m/s^2 up
D. 40 m/s^2 down

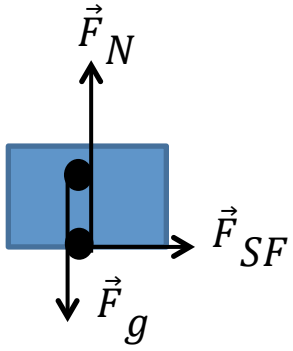
22. A car moving at a constant speed travels past a valley in the road, as shown. Which of the arrows shown most closely approximates the direction of the car's acceleration at the instant that it is at the position shown?

A. ↑ B. → C. ↓ D. ← E. ↖



23. The drawing below is supposed to be a free-body diagram of a box that sits without slipping inside a large truck that is moving to the right but is slowing down. Is the diagram correct?

A. Yes
B. No: F_{SF} should point leftward
C. No: the F_{SF} label should be F_{KF}.
D. No: there should be a leftward drag force
E. No: F_N should not be equal to F_g.



24. Imagine your car's acceleration is given as $a_x(t) = a_0 \sin(\omega t)$ for $0 \leq \omega t \leq \pi$ and $a_x = 0$ afterward. $a_0 = 5.0\text{m/s}^2$ and ω is a constant of value $\pi/5$ when expressed in appropriate SI units. When the car reaches its cruising speed at time t such that $\omega t = \pi$, the car's acceleration becomes zero. What are the car's x-velocity and x-position at time t=5.0s? Assume the car starts at rest from $x = 0$.

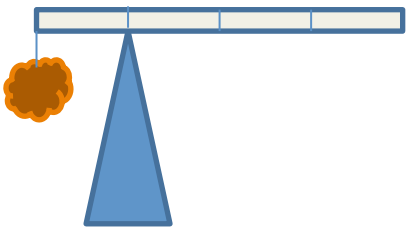
A. $v_x = 16$ m/s, $x = 20$ m
B. $v_x = 8$ m/s, $x = 20$ m
C. $v_x = 16$ m/s, $x = 40$ m
D. $v_x = 4$ m/s, $x = 40$ m
E. $v_x = 8$ m/s, $x = 40$ m

25. If a car's x-position at time $t = 0$ is $x(0) = 0$ and it has an x-velocity of $v_x(t) = b(t - T)^2$, where b and T are constants, which function below best describes $x(t)$?

A. $x(t) = 2\,b(t - T)$
B. $x(t) = 3\,b(t - T)^3$
C. $x(t) = (1/3)\,b(t - T)^3$
D. $x(t) = (1/2)\,b(t - T)$
E. $x(t) = (1/3)\,b[\,(t - T)^3 + T^3]$

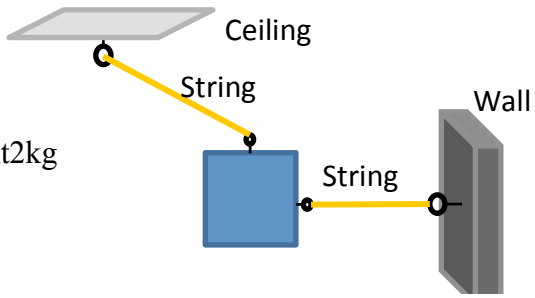
26. A 1-kg rock is suspended by a massless string from one end of a 1-m measuring stick. What is the mass of the measuring stick if it is balance by a support force at the 0.25-m mark?

A. 0.25 kg
B. 0.5 kg
C. 1kg
D. 2kg
E. 4 kg



27. A weight hangs from a string but is pulled to one side by a horizontal string, as shown. The tension force exerted by the angled string is

A. Less than the hanging object's weight.
B. Equal to the hanging object's weight.
C. Greater than the hanging object's weight2kg



28. You are pushing a wooden crate across the floor at constant speed. You decide to turn the crate on end, reducing by half the surface area in contact with the floor. In the new orientation, to push the same crate across the same floor with the same speed, compared to the force required before changing the crate's orientation, the force that you apply must be about (assuming no drag)

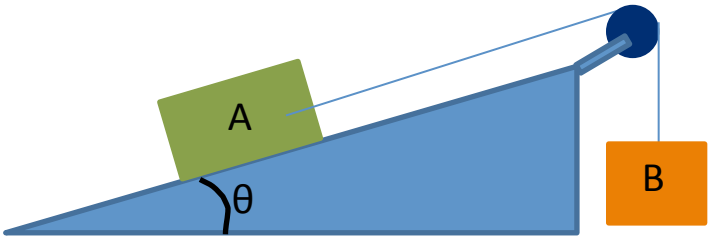
A. four times as great
B. twice as great
C. equally great
D. half as great
E. one-fourth as great

29. Two people are attempting to break a rope, which will break if the tension on the rope exceeds 360 N. If each person can exert a pull of 200 N,

A. they can break the rope if they each take an end and pull
B. they can break the rope if they tie one end to the wall and both pull on the other.
C. they can break the rope if they use either of the strategies above.
D. they cannot break the rope.

30. Block B (m_B=0.245 kg) is connected to a lightweight rope that passes over a lightweight, low-friction pulley. the other end of the rope is connected to Block A (m_A=0.49 kg), which is on a low-friction surface inclined at an angle $\theta = 30°$ above the horizontal. What is the acceleration of block A?

A. 2 m/s^2 up the ramp
B. 1 m/s^2 up the ramp
C. 0
D. 1 m/s^2 down the ramp
E. 2 m/^{2} down the ramp

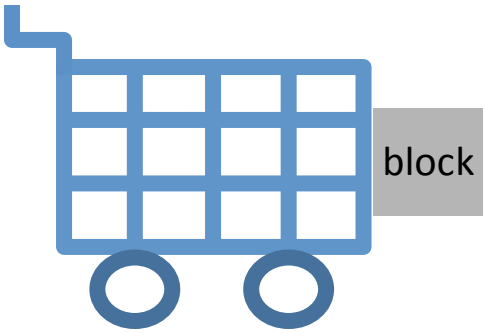


31. Object A ($m_A = 1.0$ kg) hangs at rest from an ideal string A connected to the ceiling. Object B ($m_B = 2.0$ kg) hangs at rest from an ideal string B connected to object A. The tension on string A is

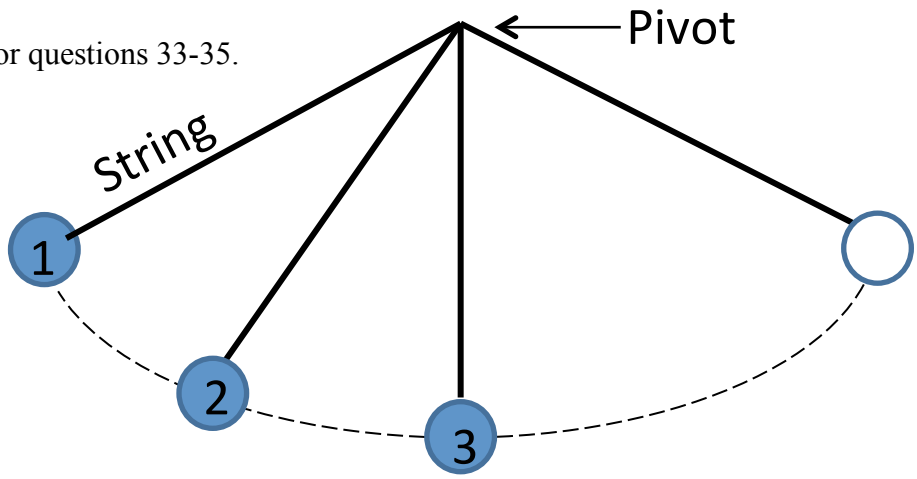
A. twice the tension on string B.
B. 3/2 times the tension on string B.
C. equal to the tension on string B.
D. 2/3 the tension on string B

32. A block is placed against the vertical front of a cart as shown below. What acceleration must the cart have for the block not to fall? The coefficient of static friction between the block and the cart is μ_s.

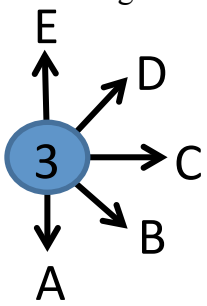
A. $a_x = 2g/\mu_s$
B. $a_x = g/2\mu_s$
C. $a_x = g/\mu_s$
D. The cart doesn't need to accelerate as long as it travels at a high enough speed.



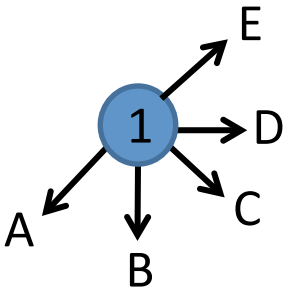
Use this figure for questions 33-35.



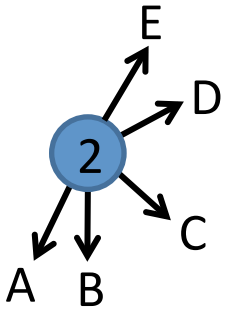
33. Which one of the arrows to the right most closely indicates the direction of the bob's acceleration when it is at point 3?



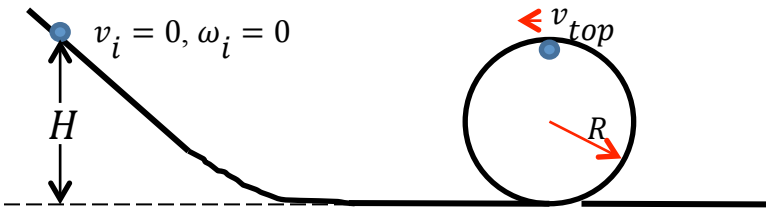
34. Which one of the arrows to the right most closely indicates the direction of the bob's acceleration when it is at point 1?



35. Which one of the arrows to the right most closely indicates the direction of the bob's acceleration when it is at point 2?



36. A solid ball of mass m and radius r starts at rest at the top of a hill of height H, rolls without slipping down the hill, then goes around a vertical loop of radius R. What is the minimum height H from which the ball can be released if it is to remain in contact with the track as it reaches the top of the loop?



A. $H_{min} = 2R$
B. $H_{min} = 2.3R$
C. $H_{min} = 2.5R$
D. $H_{min} = 2.7R$
E. $H_{min} = 3R$

37. An elevator moves downward with an acceleration of 6.2 m/s^2. A ball dropped from rest by a passenger will have what downward acceleration relative to the elevator?

A. 3.6 m/s^2
B. 6.2 m/s^2
C. 9.8 m/s^2
D. 16.0 m/s^2

38. Neglecting air resistance, if you drop a ball from the top of the Gateway Arch it will land

A. directly below where you drop it
B. East of where you drop it
C. West of where you drop it
D. North of where you drop it
E. South of where you drop it

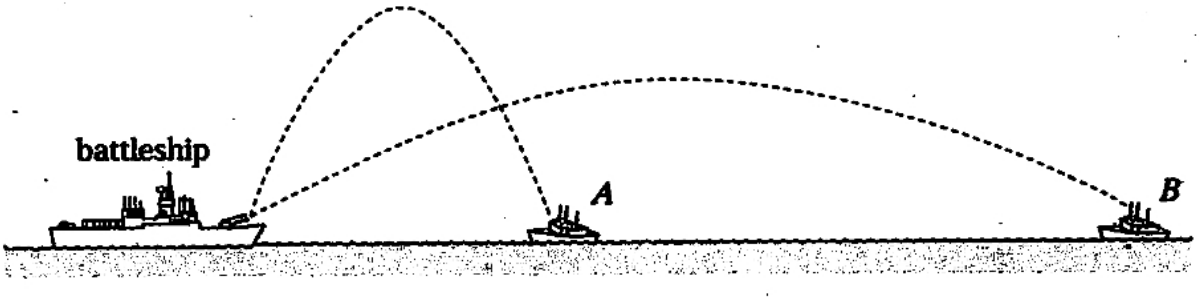
39. A tennis ball is dropped from rest at the exact same instant and height that a bullet is fired horizontally. Ignoring air resistance, which object hits the ground first?

A. The bullet hits first.
B. The ball hits first.
C. Both hit at the same time.

40. Imagine that we throw a baseball with an initial speed of 12 m/s in a direction 60^o upward from the horizontal. What is the baseball's speed at the peak of its trajectory?

A. 12 m/s
B. 10.4 m/s
C. 6 m/s
D. 3 m/s
E. 0 m/s

41. A battleship simultaneously fires two shells at enemy ships. If the shells follow the parabolic trajectories shown, which ship gets hit first?



A. A
B. B
C. Both are hit at the same time
D. Need more information

42. Consider a mass connected to a spring that is hanging vertically from a post. At $x = 0$ 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. $-\pi$

43. A glider on an air track is connected by a spring to the end of the air track. If it takes 0.30s for the glider to travel the distance of 12cm from one turning point to the other, its amplitude is

A. 12 cm
B. 6 cm
C. 24 cm
D. 36 cm
E. 3.6 cm

44. The sun's mass is about 1000 times that of Jupiter, and the radius of Jupiter's orbit is about 1100 times the sun's radius. The center of mass of the sun/Jupiter system is inside the sun, true or false?

A. True
B. False

45. The radius of Saturn's orbit is 9.53 times that of the earth. What is the period of Saturn's orbit (assuming that it is nearly circular)?

A. 9.53 y
B. 29.4 y
C. 91.3 y
D. 866 y

46. Since the laws of physics are the same in every reference frame, an object must have the same kinetic energy in all inertial reference frames, True or False?

A. True
B. False

47. Imagine that a satellite orbits the earth so closely that it experiences some drag due to the earth's upper atmosphere. This will drain away some of the orbital energy of this system, converting it to thermal energy. If this happens fairly slowly, the satellite's orbit will remain nearly circular. What happens to the radius of this satellite's orbit as time passes in this case?

A. It slowly decreases.
B. It remains the same: just the satellite's speed decreases.
C. It slowly increases

48. In the situation described in the previous problem, what do you think will happen to the satellite's speed as time passes?

A. It slowly decreases.
B. It remains the same.
C. It slowly increases.

49. An asteroid is in an orbit around the sun whose closet point to the sun has a radius R and whose most distant point has a radius $9R$, where R is equal to the radius of the earth's orbit = $1\text{AU} = 1.5 \times 10^{11}$ m. What is the period of this orbit, in years?

A. 1 y
B. 5. 2 y
C. 11.2 y
D. 24 y

50. A video game that incorporates real physics involves trying to shoot down various kinds of overhead aircraft and satellites. One kind of aircraft passes overhead at an altitude of 1.0 km. To be effective in damaging the aircraft, your bullets must hit it with a final speed of 20m/s. With what initial speed must the bullets leave the rifle to be able to hit the aircraft with this speed? (Ignore air friction.)

A. 20.5 m/s
B. 101 m/s
C. 141 m/s