The American Longrifle, invented in Pennsylvania and used in the 1700s and 1800s, was noted for its 0.9 m barrel, and its long range. The 16 gram bullets left its muzzle with a velocity \( v_0 \) of 490 m/s. An inventor is working on doubling \( v_0 \).

**A.** Assuming the force of the explosion is constant all the way down the barrel, how should the length \( L \) be changed to double \( v_0 \)?

- (A) 4 \( L \)
- (B) 2 \( L \)
- (C) \( \frac{L}{2} \)
- (D) \( \frac{L}{4} \)
- (E) \( \frac{3}{4} \) \( L \)

**B.** Suppose the muzzle velocity became 2\( v_0 \), but nothing else was different. When fired horizontally, the bullet would take

- (A) longer to hit the ground
- (B) the same time to hit the ground
- (C) less time to hit the ground

**C.** To double \( v_0 \) by increasing gunpowder, how much gunpowder should you put into it?

- (A) 1.4 times as much as before
- (B) 2 times as much as before
- (C) 3 times as much as before
- (D) 4 times as much as before
- (E) 16 times as much as before

**C.** If you double \( v_0 \) and fire horizontally, what happens to the distance \( R \) you can fire the bullet?

- (A) It stays the same
- (B) It becomes \( 1.4 \) \( R \)
- (C) It becomes \( 2 \) \( R \)
- (D) It becomes \( 4 \) \( R \)

**FREE RESPONSE (one question)** SHOW ALL WORK IN THE SPACE BELOW. NO CREDIT FOR AN ANSWER, EVEN IF CORRECT, WITHOUT CLEAR WORK OR AN EXPLANATION.

5. Estimate how far you would expect the Longrifle to shoot a bullet if fired horizontally from your shoulder (with \( v_0 \))?

\[
\text{TIME TO FALL} \\
y = \frac{1}{2} a t^2 \\
t = \sqrt{\frac{2y}{g}} \\
= \sqrt{\frac{2(1.5 \text{ m})}{9.8 \text{ m/s}^2}} = 0.55 \text{ sec} \\
\text{NEED A REASONABLE} \ y, \ \\
\text{1 m IS NOT REASONABLE.} \\

v = \Delta x / \Delta t \\
\Delta x = v \Delta t = \\
(490 \text{ m/s})(0.55 \text{ s}) = 271 \text{ m}
\]
A detective has parked her 1000 kg sportscar at the top of a garage that has a spiral ramp; it's 12 m above ground. The total length of the spiral ramp is 160 m and the radius of curvature of the ramp is 6 m. As she begins to drive down the ramp, she discovers that her brakes have been disabled, and though she can steer, she can't slow the car down. The coefficient of friction from the tires on the ramp is 0.56. The initial velocity of the car as it starts down the ramp is zero.

A.6. Which is the direction of the centripetal force?
   (A) Toward the center of the spiral  (B) Away from the center of the spiral
   (C) In the direction of the car's travel  (D) Opposite the direction of the car's travel

A.7. Which is the direction of the force of friction?
   (A) Toward the center of the spiral  (B) Away from the center of the spiral
   (C) In the direction of the car's travel  (D) Opposite the direction of the car's travel

C.8. Which is true? (A) The centripetal force is greater than the force of friction  (B) The centripetal force is less than the force of friction  (C) The centripetal force equals the force of friction in all respects.  (D) The centripetal force is equal in magnitude to the force of friction, but opposite in direction.

B.9. If the car made it down the ramp without hitting the walls, how fast would it be travelling at the bottom?
   (A) 11 m/s  (B) 15 m/s  (C) 40 m/s  (D) 56 m/s  (E) 235 m/s

C.10. If the ramp were not curved but straight, how fast would she be travelling at the bottom (assuming she made it without hitting the walls)?  (A) Faster than taking the spiral ramp  (B) Slower than taking the spiral ramp  (C) At the same speed as taking the spiral ramp.

A.11. Which is true? (A) She will hit the outside wall no matter what  (B) She will hit the inside wall no matter what
   (C) If she is a good driver she can avoid hitting the walls by clever steering  (D) If she begins in the right direction she will naturally avoid the walls.

FREE RESPONSE (three questions) SHOW ALL WORK IN THE SPACE BELOW. NO CREDIT FOR AN ANSWER, EVEN IF CORRECT, WITHOUT CLEAR WORK OR AN EXPLANATION.

12. \( F = ma_c = \frac{mv^2}{R} \)  also  \( F = \mu N = \mu mg \).

   \[ \text{so} \quad \frac{mv^2}{R} = \mu mg \]
   \[ v = \sqrt{\mu g R} = \sqrt{0.56 \times 9.8 \text{ m/s}^2 \times 6 \text{ m}} = 5.7 \text{ m/s} \]

13. \((KE + PE)_f = (KE + PE)_{final}\)
   \[ mgh = \frac{1}{2} mv^2 \]
   \[ h = \frac{v^2}{2g} = \left(\frac{33 \text{ m}^2}{\text{s}^2}\right) / 2 \times 9.8 \text{ m/s}^2 = 1.6 \text{ m \ BELOW \ ROOF} \]

14. \( W = F \cdot s \cos \theta = mgh \) (ALL PE REMOVED BY WORK OF FRICTION)
   \[ \mathcal{E} = \frac{mgh}{s} = \frac{(10^3 \text{ kg} )(9.8 \text{ m/s}^2)(12 \text{ m})}{160 \text{ m}} = 735 \text{ N} \).
Martin, a 46.5 kg kid, is gliding along the sidewalk on his 3.5 kg skateboard, travelling at an even 2.0 m/s, when his friend Jack shouts “Heads Up!” and tosses a 3.0 kg basketball at him. Jack, of mass 70 kg, is not directly in front of Martin’s path, but is 30° ahead to the right. The basketball is travelling horizontally at 6 m/s, and Martin catches it cleanly and holds it. Note that the skateboard is essentially frictionless going along the sidewalk, but can’t really move perpendicular to the sidewalk (i.e. can’t slip sideways).

B. 15. If the angle toward his friend had been greater, but everything else the same, then after the catch Martin would be travelling
   (A) slower than the original problem (B) faster than the original problem (C) the same as the original problem

A. 16. If the ball had bounced off Martin’s hands back toward Jack, but everything else was the same, then Martin would be travelling
   (A) slower than the original problem (B) faster than the original problem (C) the same as the original problem

D. 17. The essential information I would need to figure out how much force was exerted on Martin is
   (A) How long it took the ball to be caught, only.
   (B) The final momentum only.
   (C) The initial and final momentum, but just those two things.
   (D) The initial and final momentum, and how long it took the ball to stop.
   (E) None of the above because there was no force exerted on Martin.

A. 18. Martin does work on the ball
   (A) in catching it only.
   (B) in carrying it after the catch on the skateboard, only
   (C) in catching it and in carrying it after the catch.
   (D) at no point in the story.
   (E) only if he throws it back.

FREE RESPONSE (two questions, 6 points each) SHOW ALL WORK IN THE SPACE BELOW. NO CREDIT FOR AN ANSWER, EVEN IF CORRECT, WITHOUT CLEAR WORK OR AN EXPLANATION.
19. How fast is Martin moving after the catch?
20. By comparing values before and after, is mechanical energy conserved in the catch?

19. CONSERVATION MOMENTUM IN DIRECTION OF SKATEBOARD.
   \[ p_0 = p_f \]
   \[ Mv_0 + mv \cos 60° = (m + M)v_f \]
   \[ (46.5 \text{ kg} + 3.5 \text{ kg})(2 \text{ m/s}) - (3 \text{ kg})(6 \text{ m/s})(\cos 30°) = \]
   \[ (46.5 \text{ kg} + 3.5 \text{ kg} + 3 \text{ kg}) \times v_f \]
   \[ 100 - 9 \text{ kg m/s} - 15.6 \text{ kg m/s} = 53 \text{ kg} \times v_f \]
   \[ 1.6 \text{ m/s} = v_f \]

20. COMPARE KE BEFORE AND AFTER.
   \[ KE_0 = \frac{1}{2} (46.5 \text{ kg} + 3.5 \text{ kg})(2 \text{ m/s})^2 + \frac{1}{2}(3 \text{ kg})(6 \text{ m/s} \cdot 0.866)^2 \]
   \[ = 100 \text{ J} + 40.5 \text{ J} = 140.5 \text{ J} \]
   \[ KE_f = \frac{1}{2} (46.5 \text{ kg} + 3.5 \text{ kg} + 3 \text{ kg})(1.6 \text{ m/s})^2 \]
   \[ = 68 \text{ J} \]
   \[ \therefore \text{ NOT CONSERVED} \]