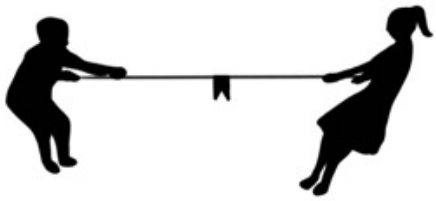
1. Two children are playing tug of war. There is a flag marking the middle of the rope as shown in the diagram. Currently, the children are pulling in opposite directions at magnitudes such that the flag translates to the left with a constant speed $v_0$.



The pulling force of the child on the left:

(A) has the same magnitude as the weight of the other child.
(B) is greater than the weight of the other child.
(C) has the same magnitude as the pulling force of the other child.
(D) is greater than the pulling force of the other child.
(E) is greater than both the weight of the other child and the pulling force of the other child.

2. If the child on the right suddenly increases her pulling force by 50%, the flag will move:

(A) with a constant speed to the left that is 50% slower than $v_0$.
(B) with a constant speed to the left that is slower than $v_0$, but not necessarily 50% slower.
(C) for a while the speed remains constant at $v_0$. Then the speed slows down to a stop, reverses direction, and speeds up in the opposite direction.
(D) with continually decreasing speed, until the flag reverses direction, then continually increasing speed.
(E) for a while with decreasing speed, then a constant speed thereafter.

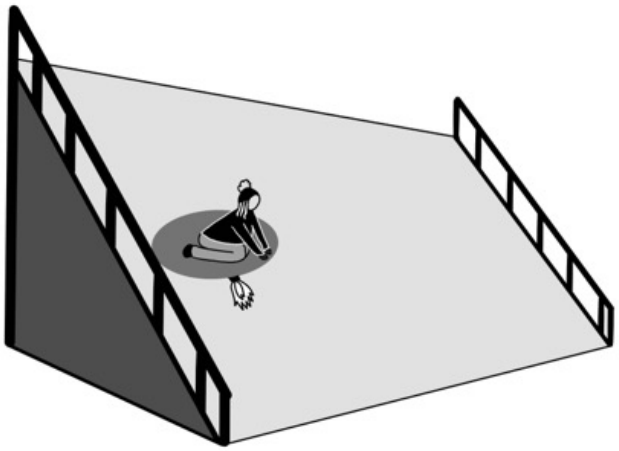
3. In a softball game, the pitcher winds up to throw a pitch. During the period when they are accelerating the ball, but before the ball has left their hand:

(A) Neither the pitcher nor the ball exerts a force on the other.
(B) The pitcher's hand exerts a force on the ball, but the ball does not exert a force on the pitcher's hand.
(C) The pitcher's hand and the ball exert a force on one another, but the pitcher's hand exerts a greater force.
(D) The pitcher's hand and the ball exert a force on one another, but the pitcher's hand exerts a lesser force.
(E) The pitcher's hand and the ball exert the same amount of force on each other.

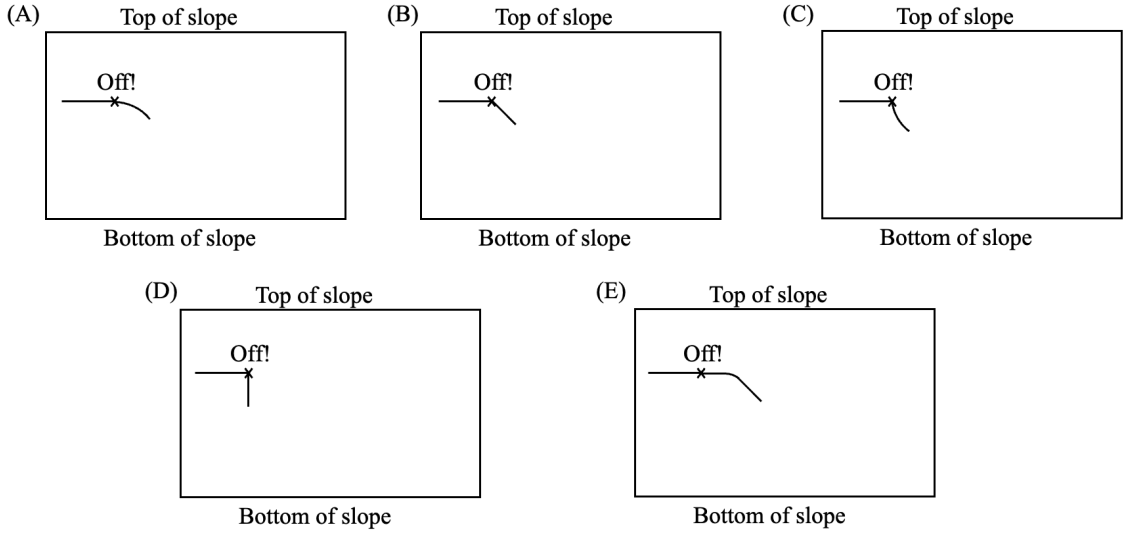
**USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS**

A person is sitting on a sled which is on a slope so icy that friction is negligible. They are trying to cross from one side of the slope to the other without falling down the slope. To do this, they have mounted a rocket on the sled which provides a force up the slope, against the direction they would fall.

Suppose the person kicks off from the side rail towards the opposite side rail. The rocket is firing with force $F_{rocket}$, hard enough to keep them from falling down the slope. They have an initial speed v moving directly across the slope.

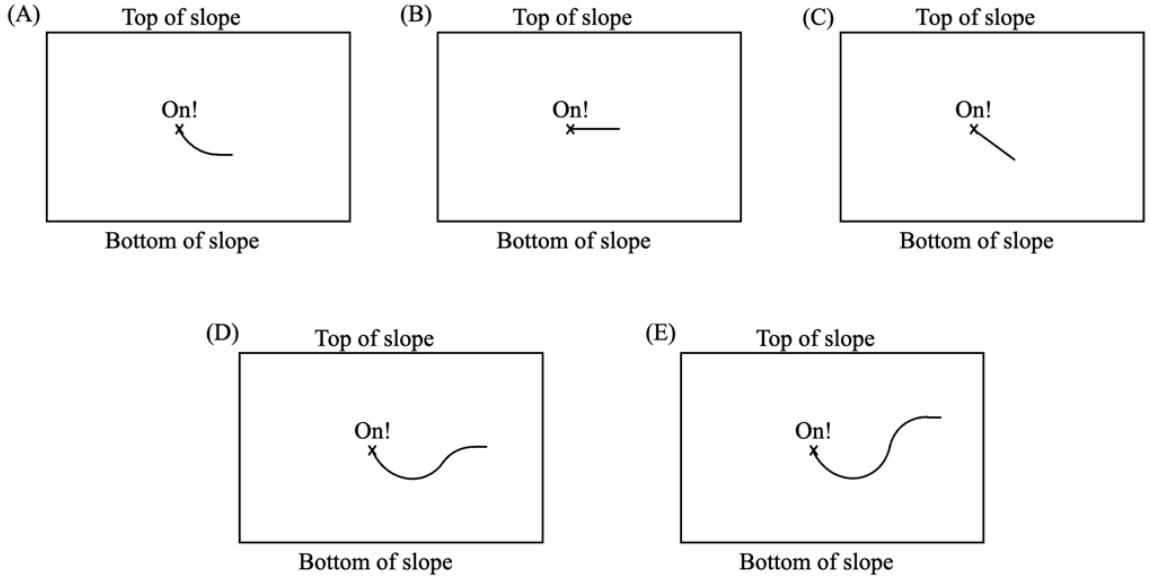


4. The rocket suddenly turns off for two seconds. Which path describes the motion of the sled, as viewed normal to the slope?



5. What is happening to the sled's speed during the period after the rocket shut off?
   (A) Constant
   (B) Continuously increasing
   (C) Continuously decreasing
   (D) Increasing for a while, then constant thereafter
   (E) Decreasing for a while, then constant thereafter

6. The rocket then turns back on at its original force $F_{rocket}$. Which path describes the motion of the sled, as viewed normal to the slope?




7. What is happening to the sled's speed during the period after the rocket turns back on?
   (A) Constant
   (B) Continuously increasing
   (C) Continuously decreasing
   (D) Increasing for a while, then constant thereafter
   (E) Decreasing for a while, then constant thereafter

8. A boat is in a river trying to go upstream. The river water flows at a constant speed. The motor is running hard enough that it is able to move upstream at a constant velocity as viewed from a person on shore. At any instant in time, what can be said about the relationship between the boat and the water with which it is in contact?

(A) The force exerted by the water on the boat is equal to the force exerted by the boat on the water.
(B) The force exerted by the water on the boat is greater than the force exerted by the boat on the water.
(C) The force exerted by the water on the boat is less than the force exerted by the boat on the water.
(D) The boat applies force to the water because its motor is actively running. The river water passively flows and does not exert force on the boat.
(E) Neither the water nor the boat exert force on the other.

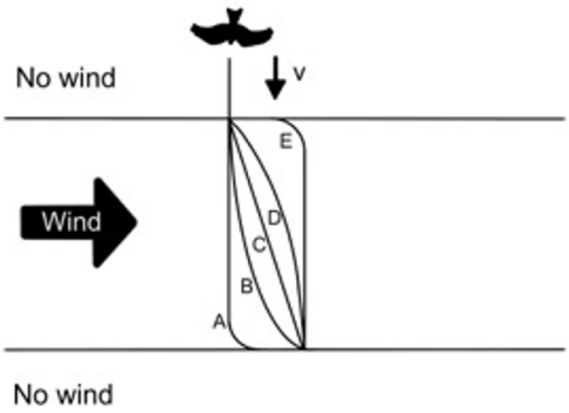
9. When the boat turns off its engine and begins to slow down as observed from the shore, what can be said about the relationship between the boat and the water with which it is in contact?

(A) The force exerted by the water on the boat is equal to the force exerted by the boat on the water.
(B) The force exerted by the water on the boat is greater than the force exerted by the boat on the water.
(C) The force exerted by the water on the boat is less than the force exerted by the boat on the water.
(D) The boat with its motor off is now a passive body and does not exert force on the water. The river water passively flows and does not exert force on the boat.
(E) Neither the water nor the boat exert force on the other.

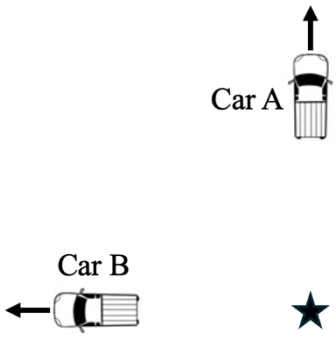
10. The boat eventually starts flowing downstream exactly at the speed of the river water. What can be said about the relationship between the boat and the water with which it is in contact?

(A) The force exerted by the water on the boat is equal to the force exerted by the boat on the water.
(B) The force exerted by the water on the boat is greater than the force exerted by the boat on the water.
(C) The force exerted by the water on the boat is less than the force exerted by the boat on the water.
(D) The boat with its motor off is now a passive body and does not exert force on the water. The river water passively flows and does not exert force on the boat.
(E) Neither the water nor the boat exert force on the other.

11. A bird is gliding in the air with constant speed v. You are on a bridge, looking down at the bird and watching its flight path. It starts out gliding in a region with no wind. There is an airstream blowing air at constant speed $v_w$ perpendicular to the bird's initial motion. When it enters the stream, which path best describes the bird's motion?

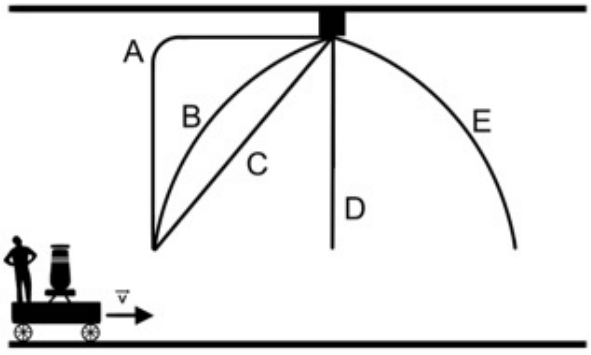



12. Two cars, A and B, start at rest at the star shown in the diagram. They begin driving away from the star simultaneously in orthogonal directions. They travel at the same speed. After two seconds, they are both traveling at speed v. At that moment, if you are in car A and you lean out the window to use a radar speed gun to measure the speed of the other car relative to yours, what will the speed gun report?

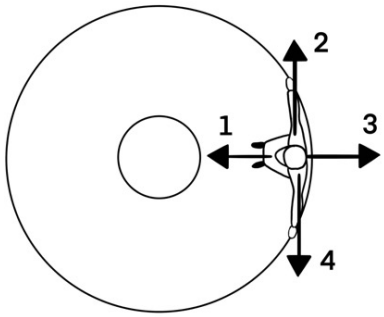



(A) The speed of car B is less than v
(B) The speed of car B is v
(C) The speed of car B is between v and 2 v
(D) The speed of car B is 2 v
(E) The speed of car B is greater than 2 v

13. A cannon is on a cart. The cart is moving with constant speed. The cannon is aimed directly vertical. The cannoneer is attempting to time the shot such that the shot hits a block on the ceiling. Which path describes the correctly timed shot and trajectory?



14. A merry-go-round is spinning counterclockwise as viewed from above. It has bars at the edge of its platform. A person is braced against one of the bars at the edge of the platform as it spins at a constant rate. Neglect friction or air resistance. In which direction(s) is (are) force being applied to the person?

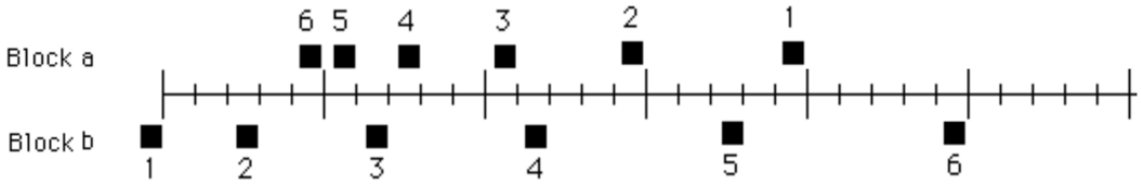



(A) 1 only
(B) 1 and 2
(C) 1 and 3
(D) 3 only
(E) 1, 2 and 4

15. In a 400 m race, runner A and B start simultaneously. A gains a lead on B for the first half of the race. Then B catches up and passes runner A. Eventually, B runs out of energy. A catches up and passes B near the end to win the race. What can be said about their speeds during the race?

(A) They never had the same speed.
(B) They had the same speed when B caught up with A in the second half.
(C) They had the same speed when A caught up with B near the end of the race.
(D) They had the same speed when B caught up with A AND when A caught up with B.
(E) They had the same speed at some point when B was behind A. They also had the same speed at some point when A was behind B.

16. The positions of two blocks at successive 0.20-second time intervals are represented by the numbered squares in the figure below. The block on top of the scale moves to the left. The block on bottom moves to the right.




The accelerations of the blocks are related as follows:

(A) Block A has lower acceleration than block B.
(B) Block A has higher acceleration than block B.
(C) Both blocks have equal acceleration, but in opposite directions.
(D) Both blocks have equal acceleration in the same direction.
(E) Not enough information is given to answer the question.

17. A child expels his breath completely so that he sinks to the bottom of a pool and sits there for a brief period. During that period, consider the following forces:

1. A downward force of gravity
2. An upward force exerted by the floor
3. A net downward force exerted by the water

Which of the forces is (are) acting on the child?

(A) 1 only
(B) 1 and 2
(C) 2 and 3
(D) 1, 2, and 3
(E) None of the forces since the child is at rest.

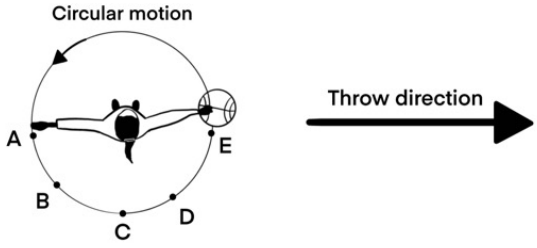
18. A curling stone collides with another curling stone on ice. Once the second stone is hit, it continues to slide for some time before coming to a stop. Consider the following forces:

1. The force of the collision with the first stone
2. An upward force exerted by the ice
3. A downward force of gravity
4. A force of friction against the stone's motion

While it slides, which of the forces is (are) acting on the stone?

(A) 3 only
(B) 1, 3, and 4
(C) 2, 3, and 4
(D) 1 and 4
(E) 1, 2, 3, and 4

19. An athlete is attempting to throw a discus as far as possible in the direction of the large arrow shown. They begin spinning in a circle with the discus in their outstretched hand. Their rotation rate is continuously increasing. At which point should they release the discus such that it flies in the direction shown?




20. A bowling ball knocks a pin over. While the ball and the pin were in contact:

(A) the ball and the pin exerted equal amounts of force on each other.
(B) the ball exerted a greater amount of force on the pin than the pin exerted on the ball.
(C) the pin exerted a greater amount of force on the ball than the ball exerted on the pin.
(D) the ball exerted a force on the pin, but the pin did not exert a force on the ball.
(E) neither exerted a force on the other, the pin was knocked over because it was in the way of the ball.

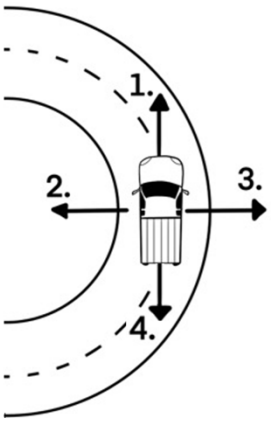
21. There is a flag on a flagpole marking 30 m above ground. Two cannonballs, one four times heavier than the other, are simultaneously fired straight up from the ground with identical initial velocities. What can you say about the time each cannonball takes to reach the flag's height? Ignore air resistance.

(A) The heavier ball takes approximately one-fourth the time of the lighter ball.
(B) The lighter ball takes approximately one-fourth the time of the heavier ball.
(C) Both balls take approximately the same amount of time.
(D) The heavier ball takes considerably less time, but not necessarily one-fourth.
(E) The lighter ball takes considerably less time, but not necessarily one-fourth.

22. If the cannons are now angled at 45 degrees from vertical and the cannonballs are fired with the same initial velocities, how do the horizontal distances to where each ball lands compare?

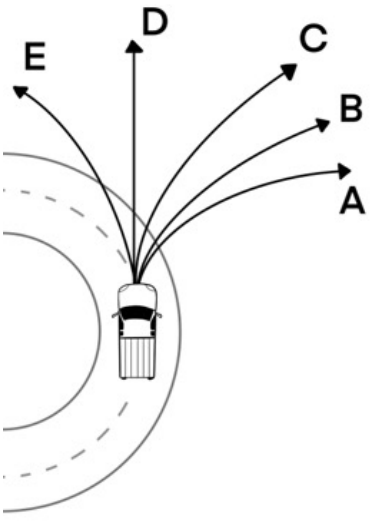
(A) Both balls land at the same horizontal distance from the cannons.
(B) The heavier ball lands four times farther than the lighter ball.
(C) The lighter ball lands four times farther than the heavier ball.
(D) The heavier ball lands much farther than the lighter ball, but not necessarily four times farther.
(E) The lighter ball lands much farther than the heavier ball, but not necessarily four times farther.

23. A car rounds a circular bend in the road. As it rounds the bend, it is also slowing down. Forces are acting on the car in which of the directions shown?




(A) 1 and 2
(B) 1 and 3
(C) 1, 2, and 4
(D) 2 and 4
(E) 1, 2, and 3

24. Suddenly the car enters an icy section of the road and loses traction. The ice is effectively frictionless. Which path will the car follow after it loses traction?



25. A truck is pulling a cart up a steep hill at a constant speed $v_0$. The cart suddenly detaches from the truck. When the cart detaches, it will:

(A) Immediately stop, then begin rolling down the hill with increasing speed.
(B) Continue moving up the hill at the speed $v_0$ for a period of time, stop, then begin rolling down the hill with increasing speed.
(C) Immediately begin to slow down, until it reverses direction and rolls down the hill with increasing speed.
(D) Increase its speed for a period of time, then reverse direction and roll down the hill with increasing speed.
(E) Immediately reverse direction and roll down the hill.

26. A basketball player is standing on a court, dribbling a ball. What can be said about the force(s) on the ball during the periods of time when it is traveling from the ground to the player's hand?

(A) There is a steadily decreasing upward force.
(B) There is a constant downward force of gravity.
(C) There is a downward force of gravity and a steadily decreasing upward force.
(D) There is a downward force which is steadily increasing as the ball approaches the player's hand.
(E) There is a downward force which is steadily increasing as the ball approaches the player's hand, and a steadily decreasing upward force.

27. What can be said about the periods of time when it has left the player's hand and is traveling toward the ground?

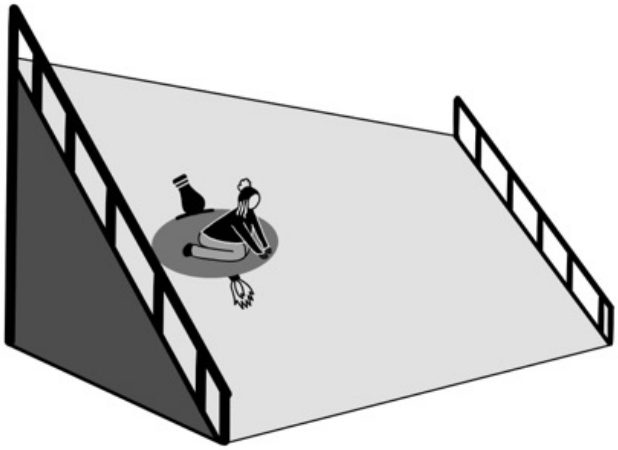
(A) It travels at constant speed.
(B) It speeds up for a moment, then goes the rest of the way at constant speed.
(C) It falls because of the natural tendency of objects to rest on the ground.
(D) It speeds up from a nearly constant gravitational force.
(E) The ball speeds up from the force of the player's hand, and from the force of gravity.

**USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT THREE QUESTIONS**

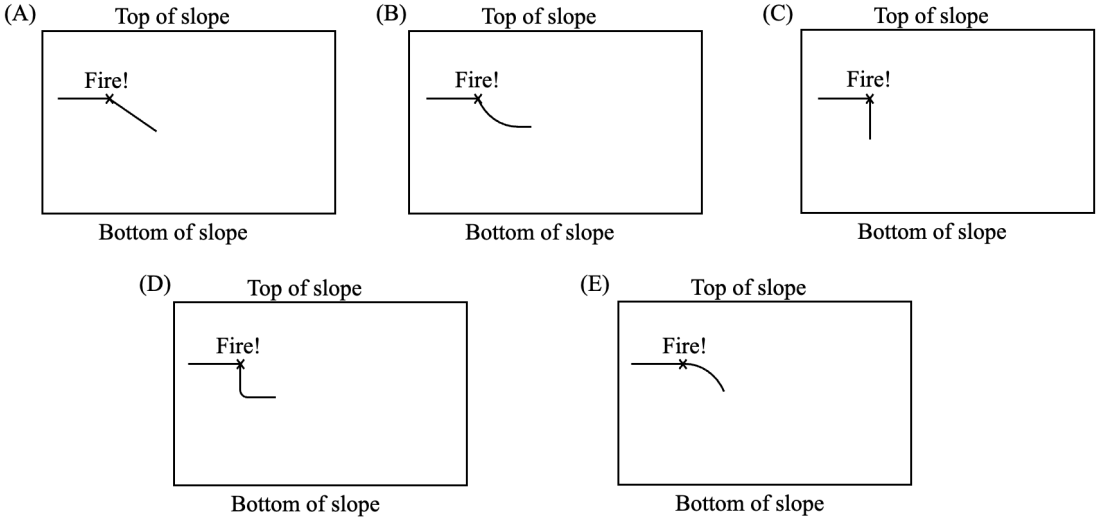
A person is sitting on a sled which is on a slope so icy that friction is negligible. They are trying to cross from one side of the slope to the other without falling down the slope. To do this, they have mounted a rocket on the sled which provides a force up the slope, against the direction they would fall.

Suppose the person kicks off from the side rail towards the opposite side rail. The rocket is firing with force $F_{rocket}$, hard enough to keep them from falling down the slope. They have an initial speed v moving directly across the slope.

*This time however, they have equipped the sled with a cannon aimed directly up the slope.*



28. The person on the sled fires the cannon pointed directly up the slope. Which path describes the trajectory of the sled as viewed normal to the slope?



29. The speed of the sled after the canon fires is
    (A) continuously increasing
    (B) continuously decreasing
    (C) increases for a moment, then decreases thereafter
    (D) increases for a moment, then remains constant
    (E) constant

30. Consider the following forces:
    1. The downward force of gravity
    2. A force from the ground
    3. A force from the rocket up the slope
    4. A force directly down the slope
    5. A force in the direction of motion

    Which of these forces is (are) acting on the sled after the canon fires?
    (A) 1 and 4
    (B) 1 and 5
    (C) 1, 2, 3, and 4
    (D) 1, 2, and 3
    (E) No forces are acting on the sled.