

**Question 4.1a Firing Balls I**



A small cart is rolling at constant velocity on a flat track. It fires a ball straight up into the air as it moves. After it is fired, what happens to the ball?

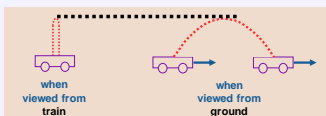
- a) it depends on how fast the cart is moving
- b) it falls behind the cart
- c) it falls in front of the cart
- d) it falls right back into the cart
- e) it remains at rest

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In the frame of reference of the cart, the ball only has a vertical component of velocity. So it goes up and comes back down. To a ground observer, both the cart and the ball have the same horizontal velocity, so the ball still returns into the cart.



**Question 4.1b Firing Balls II**



Now the cart is being pulled along a horizontal track by an external force (a weight hanging over the table edge) and accelerating. It fires a ball straight out of the cannon as it moves. After it is fired, what happens to the ball?

- a) it depends upon how much the track is tilted
- b) it falls behind the cart
- c) it falls in front of the cart
- d) it falls right back into the cart
- e) it remains at rest

**Question 4.1b Firing Balls II**

Now the cart is being pulled along a horizontal track by an external force (a weight hanging over the table edge) and accelerating. It fires a ball straight out of the cannon as it moves. After it is fired, what happens to the ball?

- a) it depends upon how much the track is tilted
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Now the acceleration of the cart is completely unrelated to the ball. In fact, the ball does not have any horizontal acceleration at all (just like the first question), so it will lag behind the accelerating cart once it is shot out of the cannon.

**Question 4.1c Firing Balls III**



The same small cart is now rolling down an inclined track and accelerating. It fires a ball straight out of the cannon as it moves. After it is fired, what happens to the ball?

- a) it depends upon how much the track is tilted
- b) it falls behind the cart
- c) it falls in front of the cart
- d) it falls right back into the cart
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### Question 4.1c Firing Balls III

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- a) it depends upon how much the track is tilted
- b) it falls behind the cart
- c) it falls in front of the cart
- d) it falls right back into the cart
- e) it remains at rest

Because the track is inclined, the cart accelerates. However, the ball has the *same component of acceleration* along the track as the cart does! This is essentially the component of  $g$  acting parallel to the inclined track. So the ball is effectively accelerating down the incline, just as the cart is, and it falls back into the cart.

### Question 4.2 Dropping a Package

You drop a package from a plane flying at constant speed in a straight line. Without air resistance, the package will:

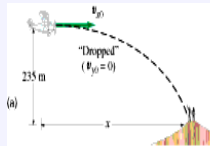
- a) quickly lag behind the plane while falling
- b) remain vertically under the plane while falling
- c) move ahead of the plane while falling
- d) not fall at all

### Question 4.2 Dropping a Package

You drop a package from a plane flying at constant speed in a straight line. Without air resistance, the package will:

- a) quickly lag behind the plane while falling
- b) remain vertically under the plane while falling
- c) move ahead of the plane while falling
- d) not fall at all

Both the plane and the package have the *same horizontal velocity* at the moment of release. They will *maintain* this velocity in the  $x$ -direction, so they stay aligned.



Follow-up: what would happen if air resistance is present?

### Question 4.3a Dropping the Ball I

From the *same height* (and at the *same time*), one ball is *dropped* and another ball is *fired horizontally*. Which one will hit the ground first?

- a) the "dropped" ball
- b) the "fired" ball
- c) they both hit at the same time
- d) it depends on how hard the ball was fired
- e) it depends on the initial height

### Question 4.3a Dropping the Ball I

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- d) it depends on how hard the ball was fired
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Both of the balls are falling vertically under the influence of gravity. They both fall from the *same height*. Therefore, they will *hit the ground at the same time*. The fact that one is moving horizontally is irrelevant—remember that the  $x$  and  $y$  motions are completely independent !!

Follow-up: is that also true if there is air resistance?

### Question 4.3b Dropping the Ball II

In the previous problem, which ball has the greater velocity at ground level?

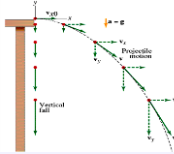
- a) the "dropped" ball
- b) the "fired" ball
- c) neither—they both have the same velocity on impact
- d) it depends on how hard the ball was thrown

**Question 4.3b Dropping the Ball II**

In the previous problem, which ball has the greater velocity at ground level?

- a) the "dropped" ball
- b) the "fired" ball**
- c) neither—they both have the same velocity on impact
- d) it depends on how hard the ball was thrown

Both balls have the same vertical velocity when they hit the ground (since they are both acted on by gravity for the same time). However, the "fired" ball also has a horizontal velocity. When you add the two components vectorially, the "fired" ball has a larger net velocity when it hits the ground.



Follow-up: what would you have to do to have them both reach the same final velocity at ground level?

**Question 4.3c Dropping the Ball III**

A projectile is launched from the ground at an angle of 30°. At what point in its trajectory does this projectile have the least speed?

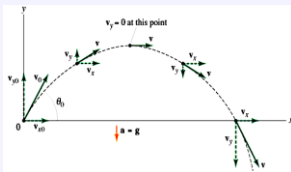
- a) just after it is launched
- b) at the highest point in its flight
- c) just before it hits the ground
- d) halfway between the ground and the highest point
- e) speed is always constant

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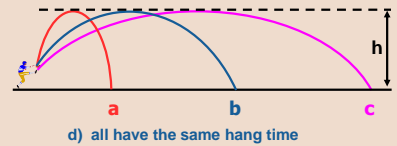
- a) just after it is launched
- b) at the highest point in its flight**
- c) just before it hits the ground
- d) halfway between the ground and the highest point
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The speed is smallest at the highest point of its flight path because the y-component of the velocity is zero.



**Question 4.4a Punts I**

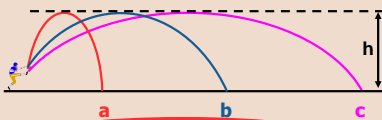
Which of the three punts has the longest hang time?



d) all have the same hang time

**Question 4.4a Punts I**

Which of the three punts has the longest hang time?



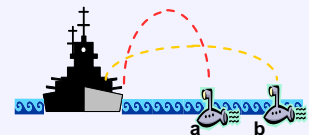
**d) all have the same hang time**

The time in the air is determined by the vertical motion! Because all of the punts reach the same height, they all stay in the air for the same time.

Follow-up: Which one had the greater initial velocity?

**Question 4.4b Punts II**

A battleship simultaneously fires two shells at two enemy submarines. The shells are launched with the same initial velocity. If the shells follow the trajectories shown, which submarine gets hit first?

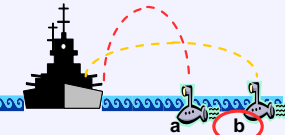


**c) both at the same time**

**Question 4.4b Punts II**

A battleship simultaneously fires two shells at two enemy submarines. The shells are launched with the **same** initial velocity. If the shells follow the trajectories shown, which submarine gets hit **first** ?

The flight time is fixed by the motion in the y-direction. The **higher** an object goes, the **longer** it stays in flight. The shell hitting submarine #2 goes **less high**, therefore it stays in flight for **less time** than the other shell. Thus, submarine #2 is hit first.

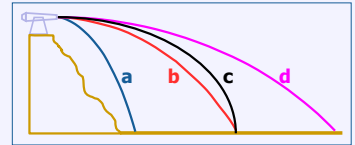


c) both at the same time

Follow-up: which one traveled the greater distance?

**Question 4.5 Cannon on the Moon**

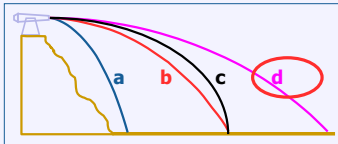
For a cannon on **Earth**, the cannonball would follow **path 2**. Instead, if the same cannon were on the **Moon**, where  $g = 1.6 \text{ m/s}^2$ , which path would the cannonball take in the same situation?



**Question 4.5 Cannon on the Moon**

For a cannon on **Earth**, the cannonball would follow **path 2**. Instead, if the same cannon were on the **Moon**, where  $g = 1.6 \text{ m/s}^2$ , which path would the cannonball take in the same situation?

The ball will spend **more time** in flight because  $g_{\text{Moon}} < g_{\text{Earth}}$ . With more time, it can travel **farther** in the horizontal direction.



Follow-up: which path would it take in outer space?

**Question 4.6 Spring-Loaded Gun**

The spring-loaded gun can launch projectiles at different angles with the same launch speed. At what angle should the projectile be launched in order to travel the greatest distance before landing?

- a) 15°
- b) 30°
- c) 45°
- d) 60°
- e) 75°

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- c) 45°
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A steeper angle lets the projectile stay in the air longer, but it does not travel so far because it has a small x-component of velocity. On the other hand, a shallow angle gives a large x-velocity, but the projectile is not in the air for very long. The compromise comes at 45°, although this result is best seen in a calculation of the "range formula" as shown in the textbook.

**Question 4.7a Shoot the Monkey I**

You are trying to hit a friend with a water balloon. He is sitting in the window of his dorm room directly across the street. You aim straight at him and shoot. Just when you shoot, he falls out of the window! Does the water balloon hit him?

- a) yes, it hits
- b) maybe—it depends on the speed of the shot
- c) no, it misses
- d) the shot is impossible
- e) not really sure



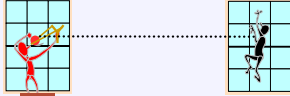
Assume that the shot does have enough speed to reach the dorm across the street.

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- d) the shot is impossible
- e) not really sure

Your friend falls under the influence of gravity, just like the water balloon. Thus, they are both undergoing free fall in the  $y$ -direction. Since the slingshot was accurately aimed at the right height, the water balloon will fall exactly as your friend does, and it will hit him!!



Assume that the shot does have enough speed to reach the dorm across the street.

### Question 4.7b Shoot the Monkey II

You're on the street, trying to hit a friend with a water balloon. He sits in his dorm room window above your position. You aim straight at him and shoot. Just when you shoot, he falls out of the window! Does the water balloon hit him??

- a) yes, it hits
- b) maybe—it depends on the speed of the shot
- c) the shot is impossible
- d) no, it misses
- e) not really sure



Assume that the shot does have enough speed to reach the dorm across the street.

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- a) yes, it hits
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This is really the same situation as before!! The only change is that the initial velocity of the water balloon now has a  $y$ -component as well. But both your friend and the water balloon still fall with the same acceleration— $g$ !!



Assume that the shot does have enough speed to reach the dorm across the street.

### Question 4.7c Shoot the Monkey III

You're on the street, trying to hit a friend with a water balloon. He sits in his dorm room window above your position and is aiming at you with HIS water balloon! You aim straight at him and shoot and he does the same in the same instant. Do the water balloons hit each other?

- a) yes, they hit
- b) maybe—it depends on the speeds of the shots
- c) the shots are impossible
- d) no, they miss
- e) not really sure



### Question 4.7c Shoot the Monkey III

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- a) yes, they hit
- b) maybe—it depends on the speeds of the shots
- c) the shots are impossible
- d) no, they miss
- e) not really sure



This is still the same situation!! Both water balloons are aimed straight at each other and both still fall with the same acceleration— $g$ !!



Follow-up: when would they NOT hit each other?