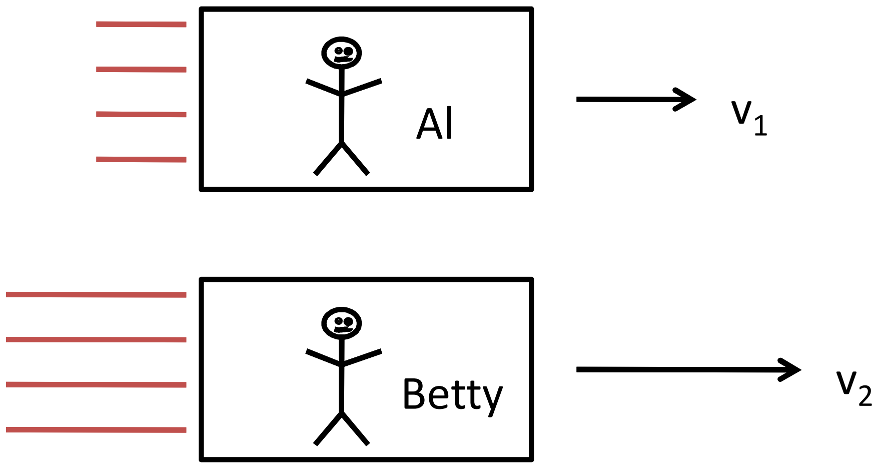
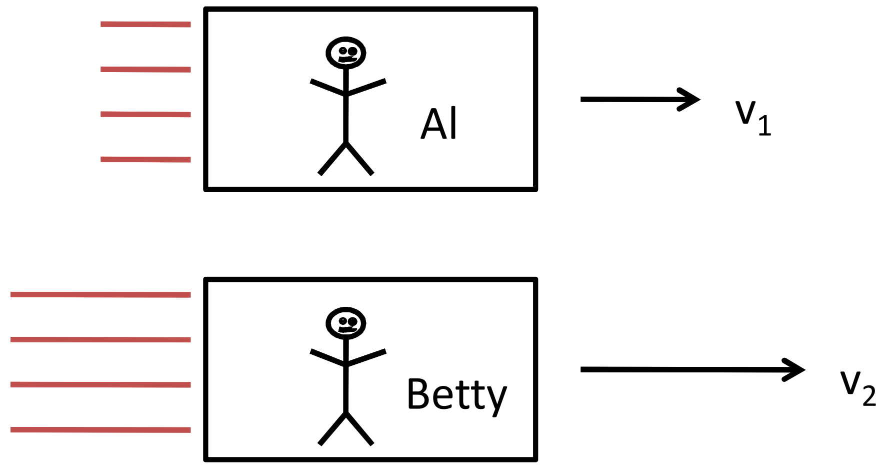


Al and Betty are hurtling through space on windowless spacecraft. Is there an experiment each of them can perform within their ships that would indicate that Betty is travelling faster (i.e. it would give a larger result for Betty than for Al)?

A) Yes
B) No

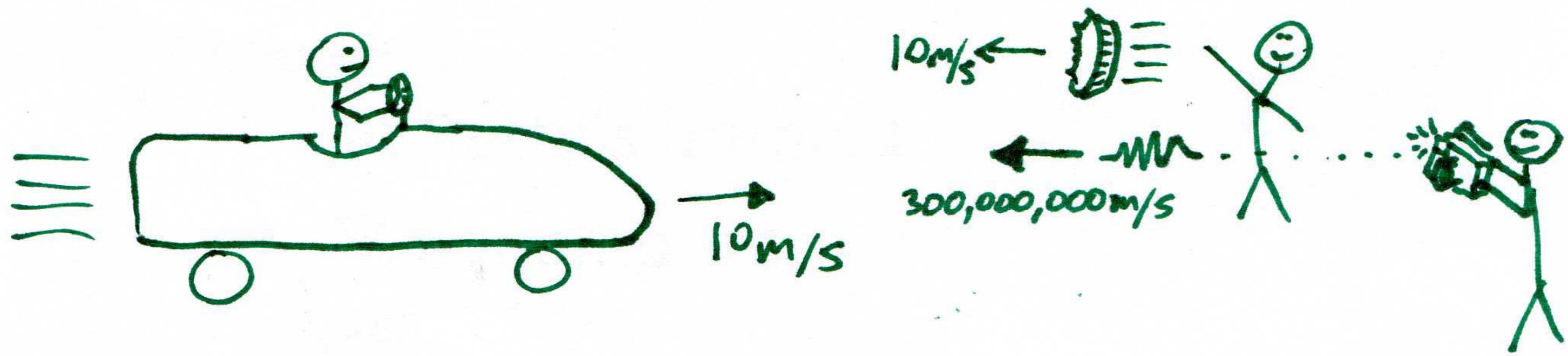
Be prepared to explain your answer.



Al and Betty are hurtling through space on windowless spacecraft. Is there an experiment each of them can perform within their ships that would indicate that Betty is travelling faster (i.e. it would give a larger result for Betty than for Al)?

A) Yes
B) No

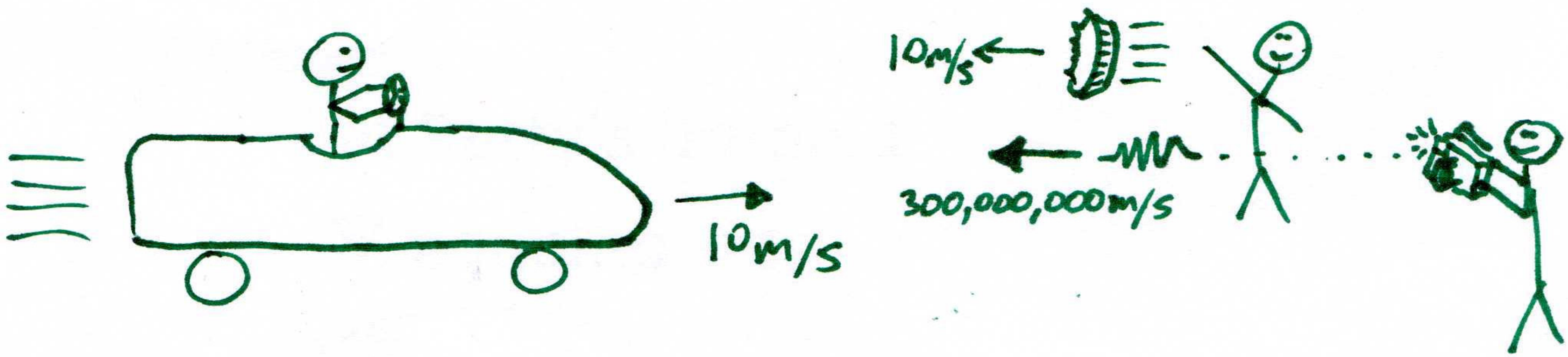
Any identical experiments performed by both Al and Betty must give the same result.



Justin Bieber is driving home from his concert at 10m/s. A “fan” on the sidewalk throws a pie in his direction, also at 10m/s while another fan takes a photo, with the flash sending light towards his at 300,000,000m/s (both as measured in the frame of reference of the road). According to Einstein, in Justin’s frame of reference,

A) The pie hits Justin at 20m/s and the light hits Justin at 300,000,010 m/s
B) The pie hits Justin at 20m/s and the light hits Justin at 300,000,000 m/s
C) The pie hits Justin at 10m/s and the light hits Justin at 300,000,010 m/s
D) The pie hits Justin at 10m/s and the light hits Justin at 300,000,000 m/s

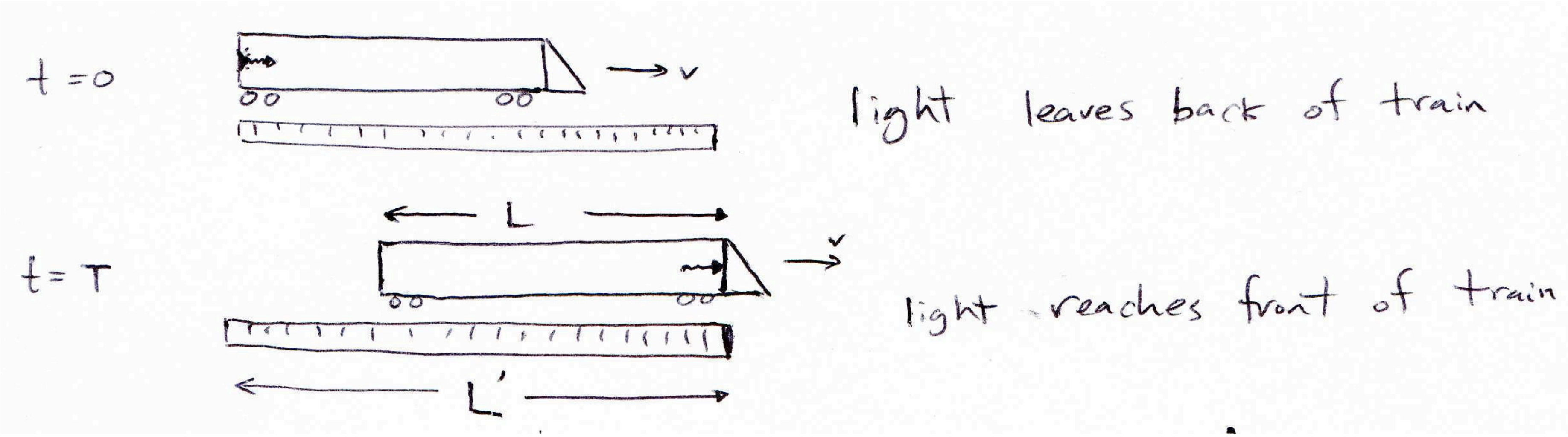
Choose the answer which is most nearly correct.



Justin is driving home from his concert at 10m/s. A “fan” on the sidewalk throws a pie in his direction, also at 10m/s while another fan takes a photo, with the flash sending light towards his at 300,000,000m/s (both as measured in the frame of reference of the road). According to Einstein, in Justin’s frame of reference,

A) The pie hits Justin at 20m/s and the light hits Justin at 300,000,010 m/s
B) **The pie hits Justin at 20m/s and the light hits Justin at 300,000,000 m/s**
C) The pie hits Justin at 10m/s and the light hits Justin at 300,000,010 m/s
D) The pie hits Justin at 10m/s and the light hits Justin at 300,000,000 m/s

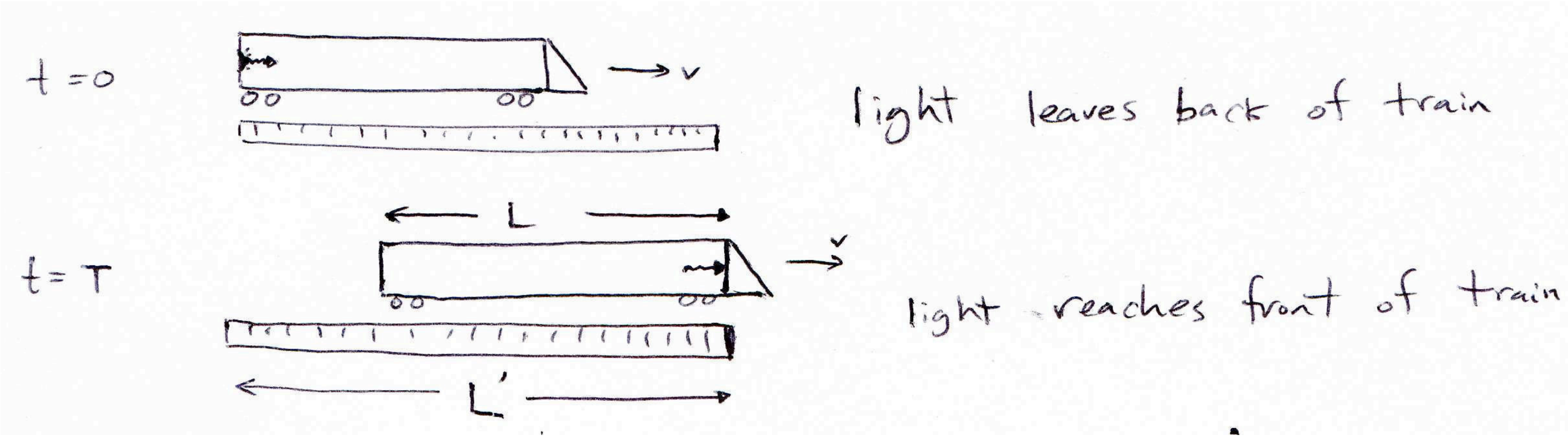
Choose the answer which is most nearly correct.



A train of length L moves along a track at speed **v**. At time t=0, a pulse of light leaves the back of the train. At time t=T, the pulse of light reaches the front of the train, as shown.

Using *conventional reasoning*, calculate the speed of light in the frame of the train and in the frame of the track, in terms of L, L', and T.

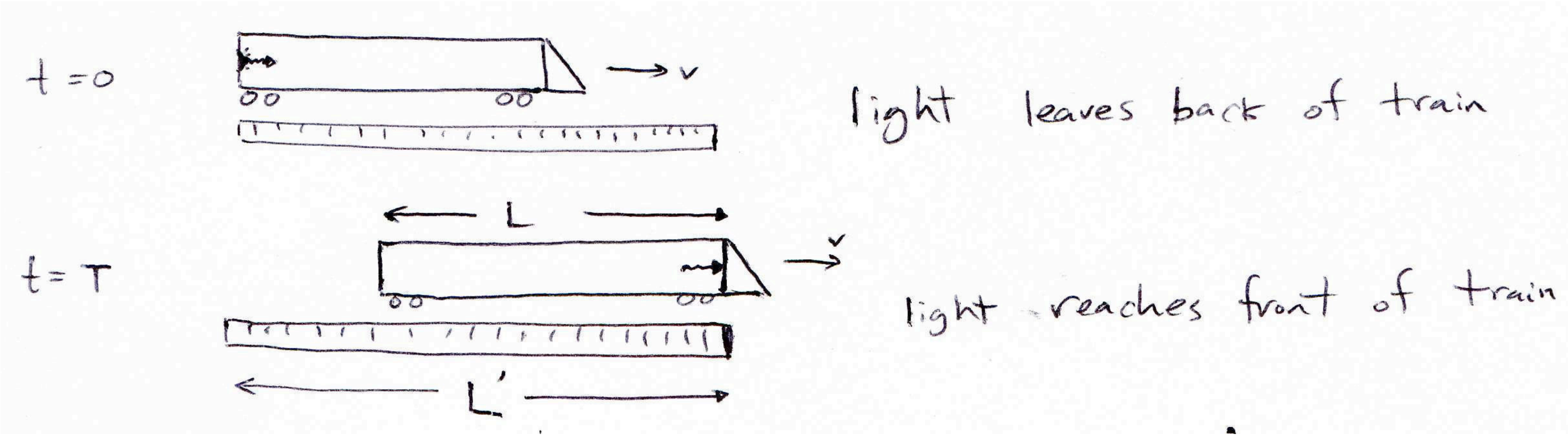
extra: what assumptions are we using here, and what assumptions must be changed in order for the results to agree with the Principle of Relativity?



Using conventional reasoning, calculate the speed of light in the frame of the train and in the frame of the track, in terms of L, L', and T.

choices:

A) L/T in both frames
B) L'/T in both frames
C) L/T in the frame of the train and L'/T in the frame of the track.
D) L'/T in the frame of the train and L/T in the frame of the track.
E) None of the above

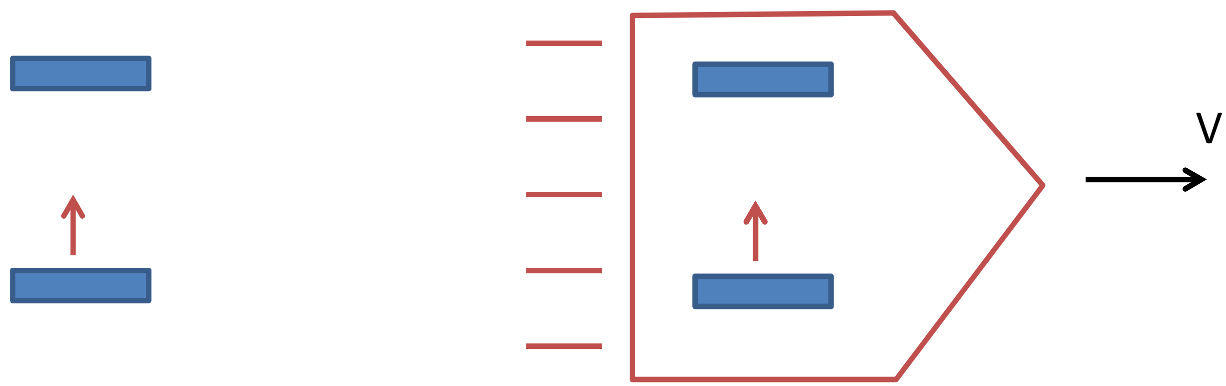


Using conventional assumptions, calculate the speed of light in the frame of the train and in the frame of the track, in terms of L, L', and T.

answer:

C) L/T in the frame of the train and L'/T in the frame of the track.

Assumptions: that observers on the track and in the train agree on times. For the results to be consistent with Einstein's Principle of Relativity, we must give up this assumption and/or the assumption that observers in relative motion agree on distances.

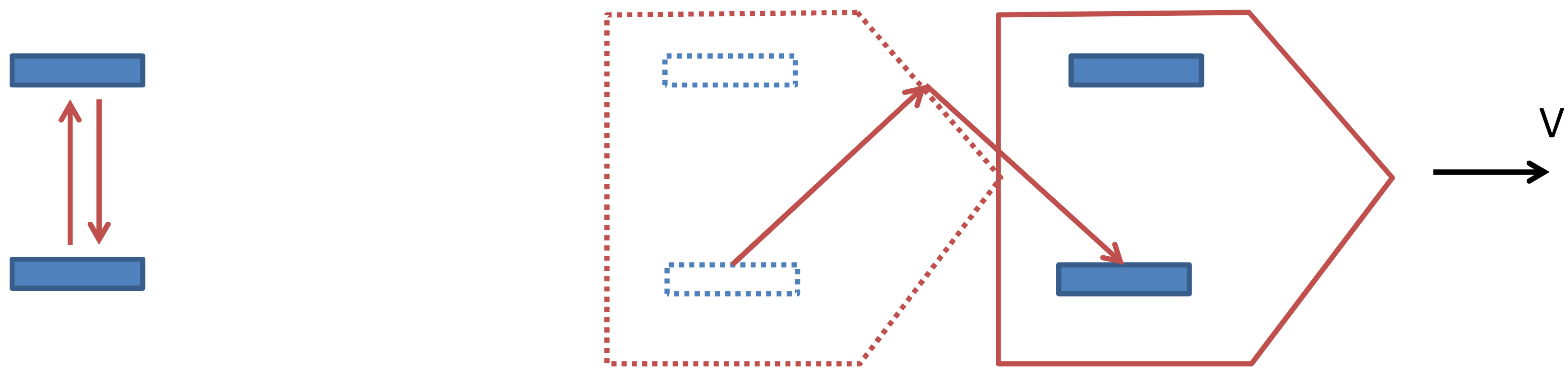


We observe a pulse of light move up and down once in two identical light clocks, one aboard a rocket and one at rest in our frame of reference. Compared to the path taken by the light in the stationary clock, we will measure that

A) The path taken by the light in the moving clock is longer.
B) The path taken by the light in the moving clock is shorter.
C) The path taken by the light in the moving clock is the same.

Extra: What can we say about the observed time for the light to go up and down in the two clocks?

In terms of v and the height L of the clocks, what is the ratio of the path lengths?



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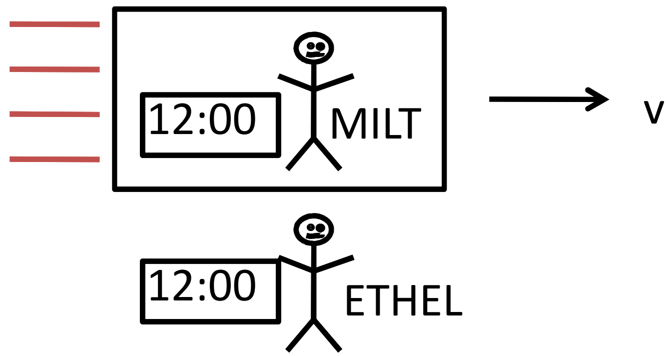
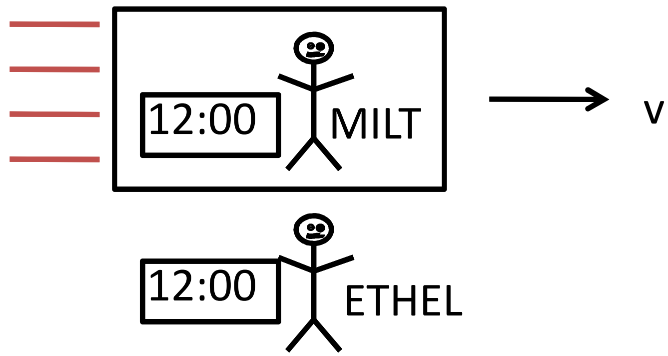


Milt and Ethel’s clocks both read noon when they pass each other. According to Milt, when his clock changes to 12:01, Ethel’s clock will read:

A) 12:01 exactly
B) An earlier time
C) A later time



Milt and Ethel's clocks both read noon when they pass each other. According to Milt, when his clock changes to 12:01, Ethel's clock will read:

A) 12:01 exactly
B) An earlier time
C) A later time

Milt sees Ethel moving, so he sees her clock running slow. So when his clock reads 12:01, he (or other observers in his frame of reference) will observe that less than one minute has passed on Ethel's clock.

Wonder Woman and Batman set their alarm clocks to ring at 8:00 and 8:01 respectively. Superman is flying at $v=3/5c$ relative to the clocks. What is the time interval between the alarms in Superman's frame of reference?

A) 1 minute

B) 1.25 minutes

C) 0.8 minutes

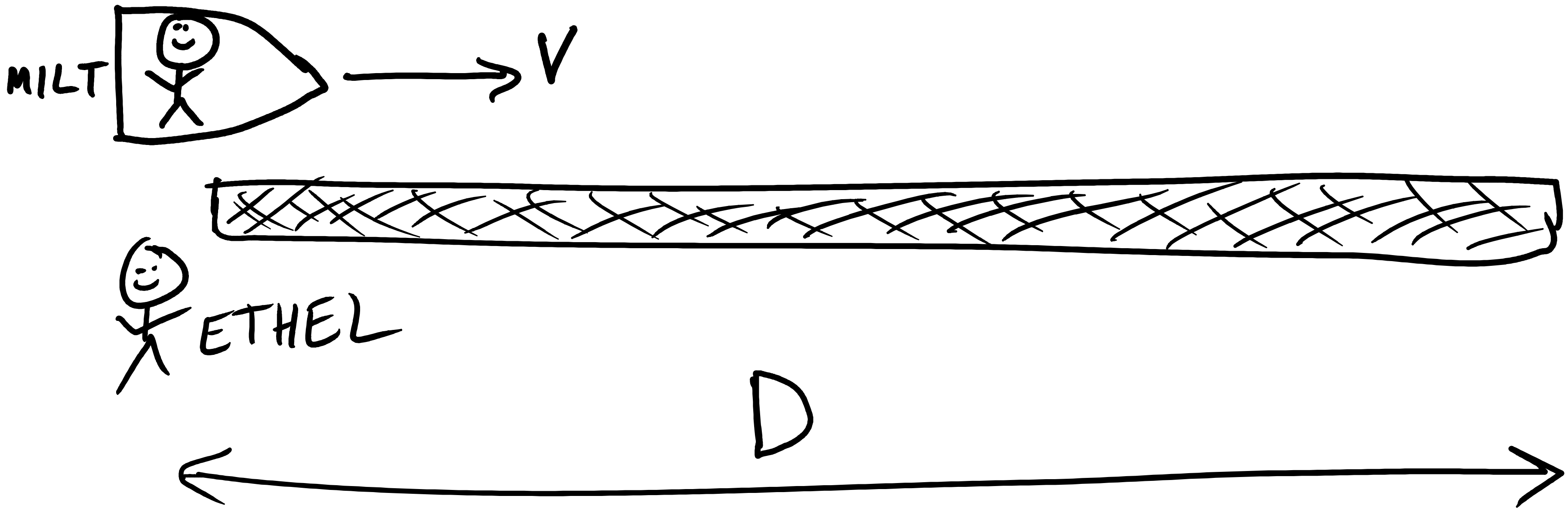
D) Not enough information to answer

E) The principle of relativity does not apply to superheroes as they have the power to be in several different reference frames at once. The time interval that Superman observes can be anything he wants it to be.

Wonder Woman and Batman set their alarm clocks to ring at 8:00 and 8:01 respectively. Superman is flying at v=3/5c relative to the clocks. What is the time interval between the alarms in Superman's frame of reference?

D) Not enough information to answer

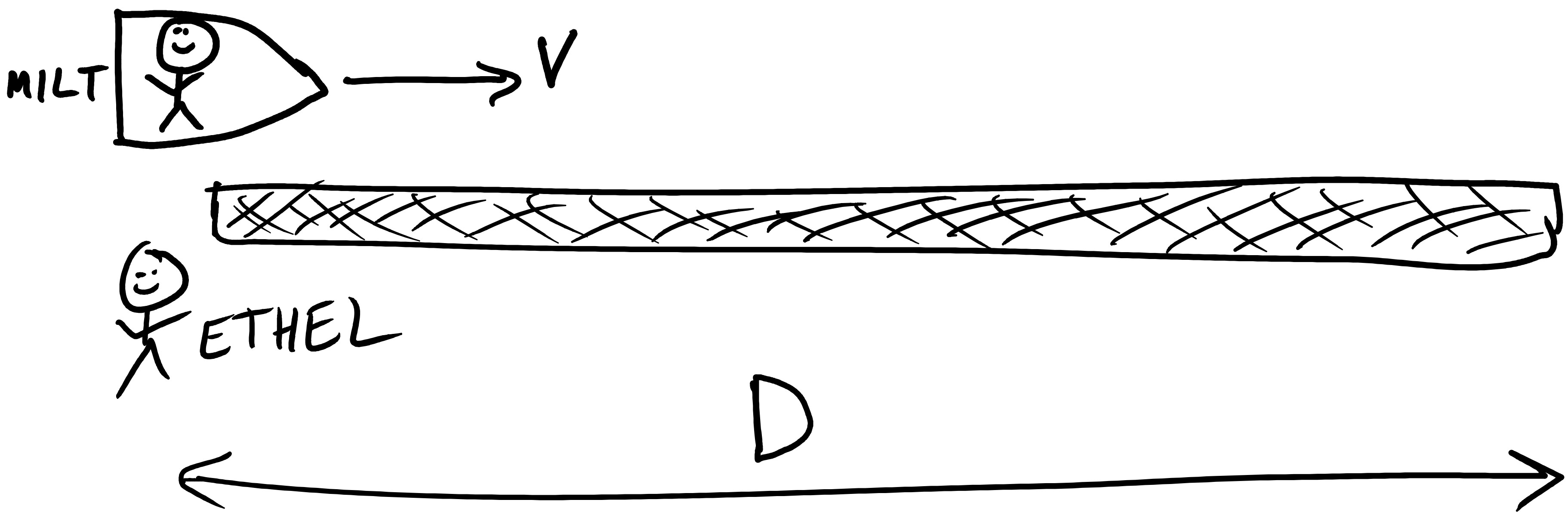
To use time dilation, the two events must be *at the same place* in one frame. Then we can say that these events will appear to be further apart in time to an observer moving relative to that frame.



Milt's and Ethel's clocks both read time 0 in the picture shown. In this same frame of reference (i.e. Ethel's) what do their clocks read when Milt reaches the far end of the long object?

A) Ethel's clock reads D/v and Milt's clock reads D/(v γ)
B) Ethel's clock reads D/(v γ) and Milt's clock reads D/v
C) Ethel's clock reads D/v and Milt's clock reads D γ /v
D) Ethel's clock reads D γ /v and Milt's clock reads D/v
E) Both clocks read D/v

Extra: In Milt's frame of reference, the object is passing by Milt at speed v. How could Milt figure out how the length of the object?

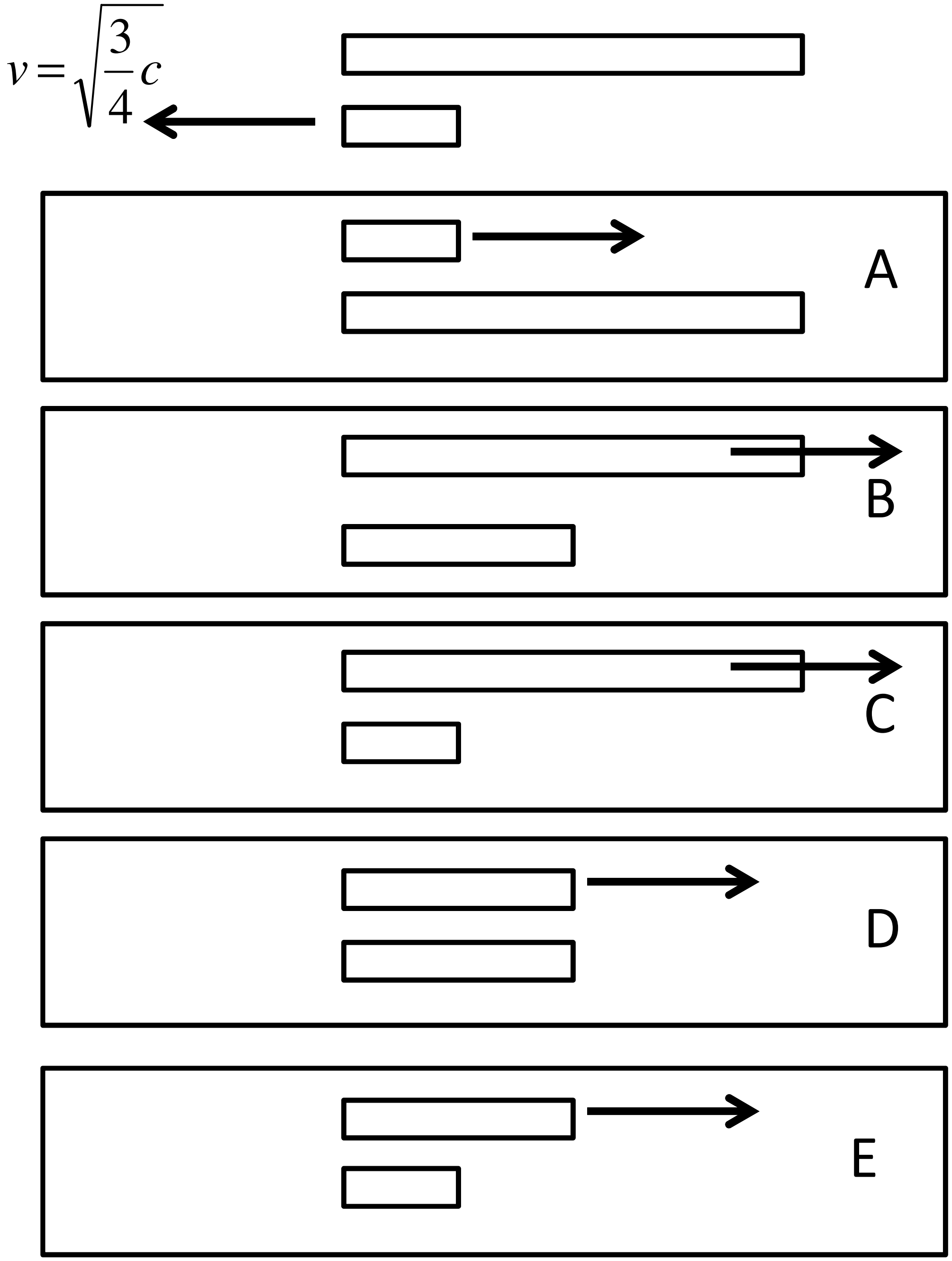


Milt's and Ethel's clocks both read time 0 in the picture shown. In this same frame of reference (i.e. Ethel's) what do their clocks read when Milt reaches the far end of the long object?

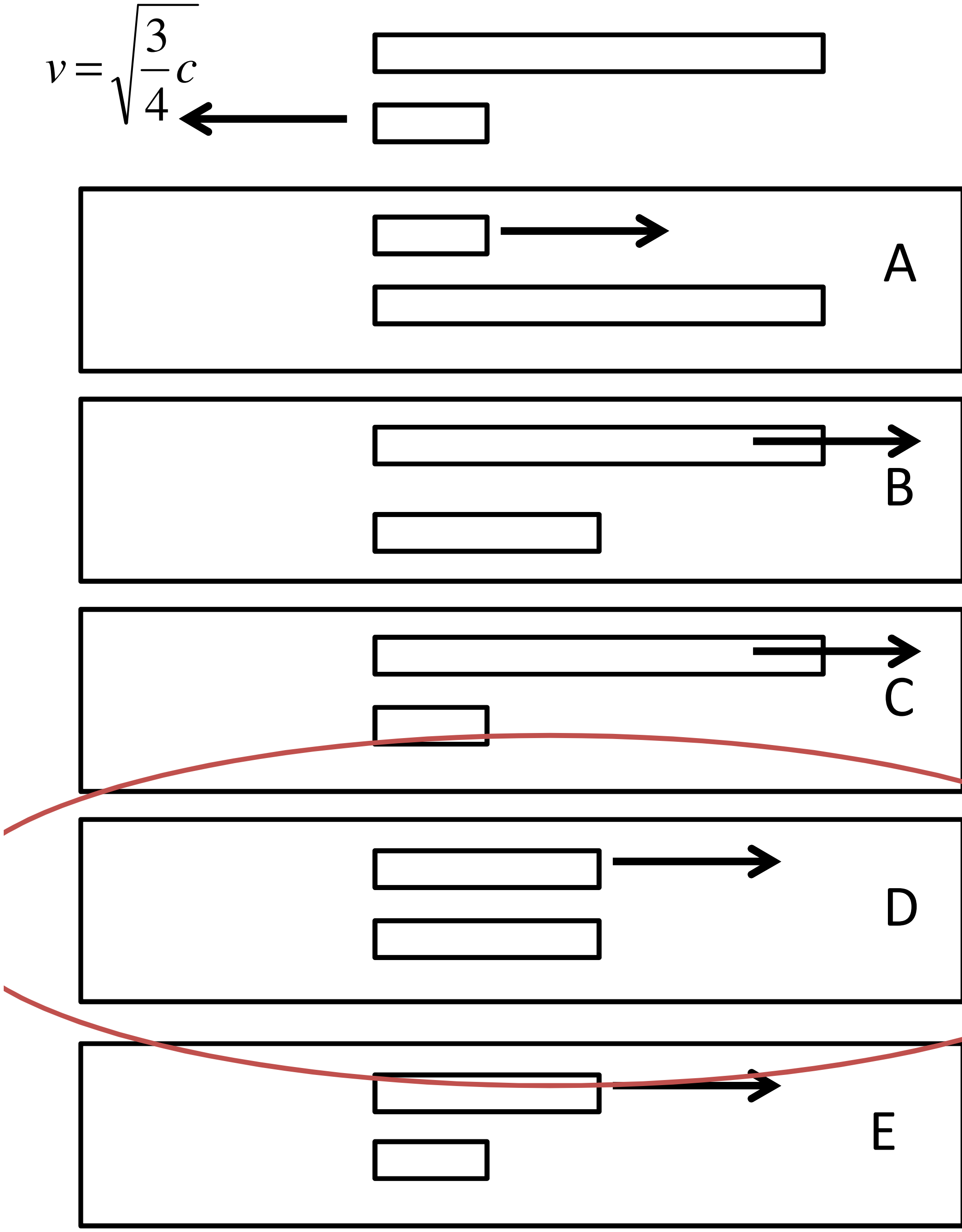
A) Ethel's clock reads D/v and Milt's clock reads D/(v γ)

In the frame of the picture, we just use the usual time = distance / speed. Ethel observes Milt's clock to run slow, so the time on Milt's clock when he reaches the end is less than Ethel's time by a factor of gamma.

Extra: to determine the length of the object (in his frame of reference, Milt can multiply its speed by the time it takes to pass him).



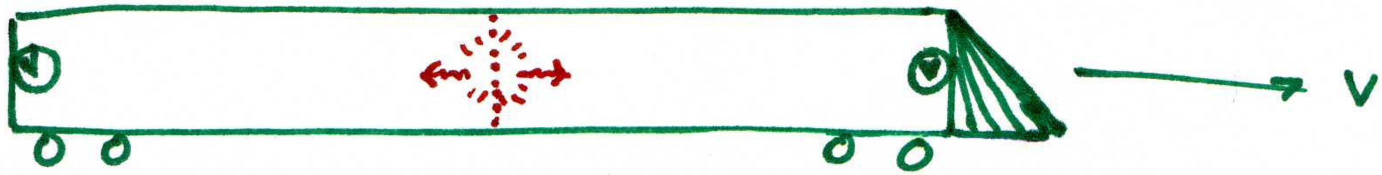
The top picture shows two rods, as observed in the frame of the upper rod. Which of the pictures below it represents an observation of the same rods in the frame of the lower rod?



The top picture shows two rods, as observed in the frame of the upper rod. Which of the pictures below it represents an observation of the same rods in the frame of the lower rod?

gamma is 2, so the the lower ruler's Proper length is twice as long as it appears in the 1st picture.

Upper ruler will appear half as long in the frame of the lower ruler.

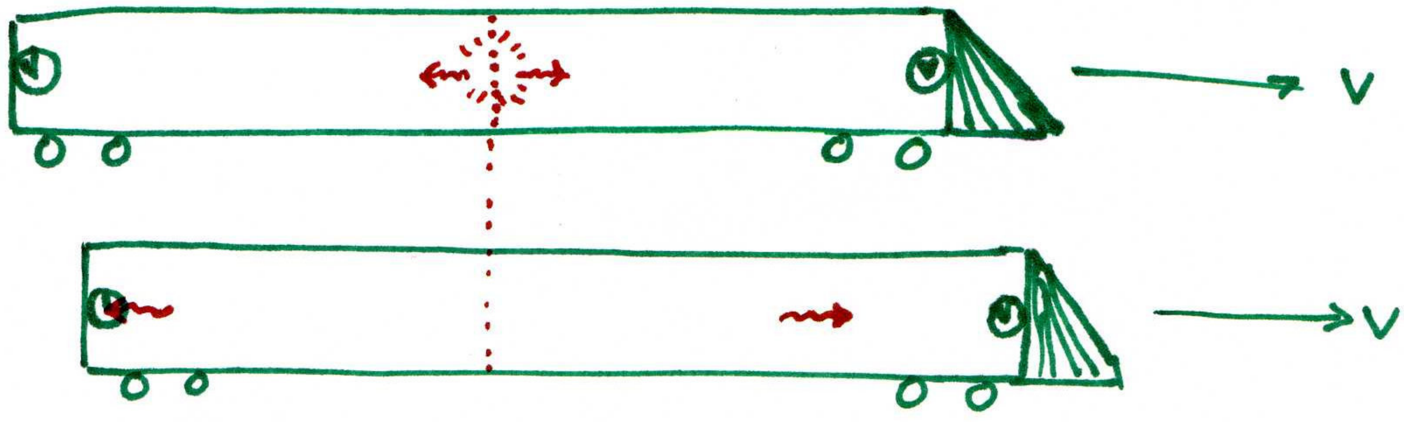


A light flashes exactly in the middle of a train moving along a track. Observers in the train measure the light to hit each end of the train at exactly noon. According to observers on the track:

A) Light hits the front of the train before the back of the train.
B) Light hits the back of the train before the front of the train.
C) Light hits the front and back at the same time.

Extra: Do people on the track observe the clocks at either end of the train to read the same time?

If not, which one appears to read an earlier time and how much do the times differ by?

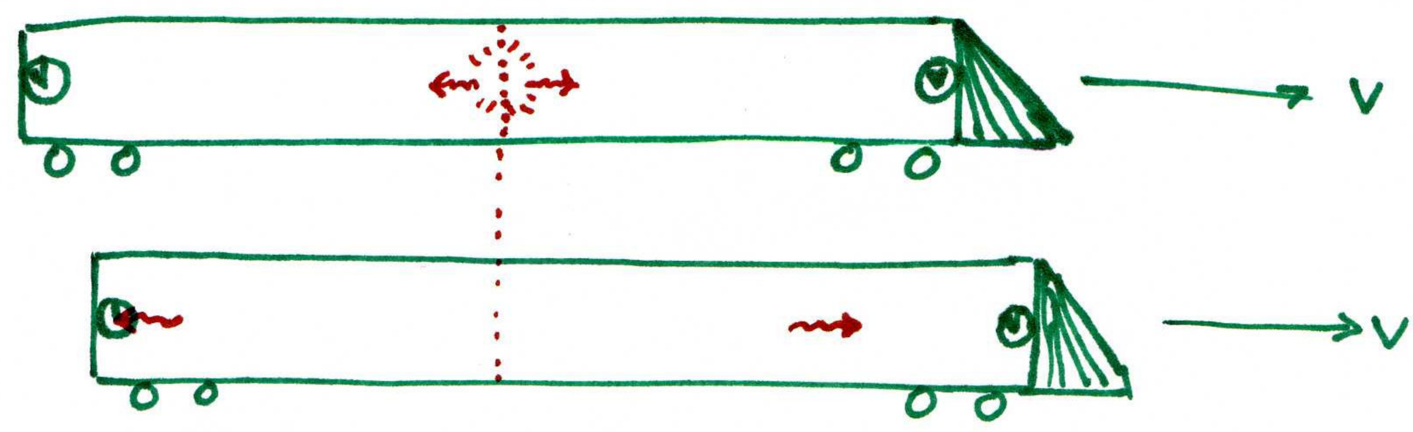


Answer:

D) Light hits the back of the train before the front of the train.

According to observers on the track, when the light hits the back of the train, the front of the train is further from the place where the light flashed, so the light cannot have reached it yet.

In the second picture, the back clock reads noon, but the front clock reads earlier than noon, since the light hasn't hit it yet.

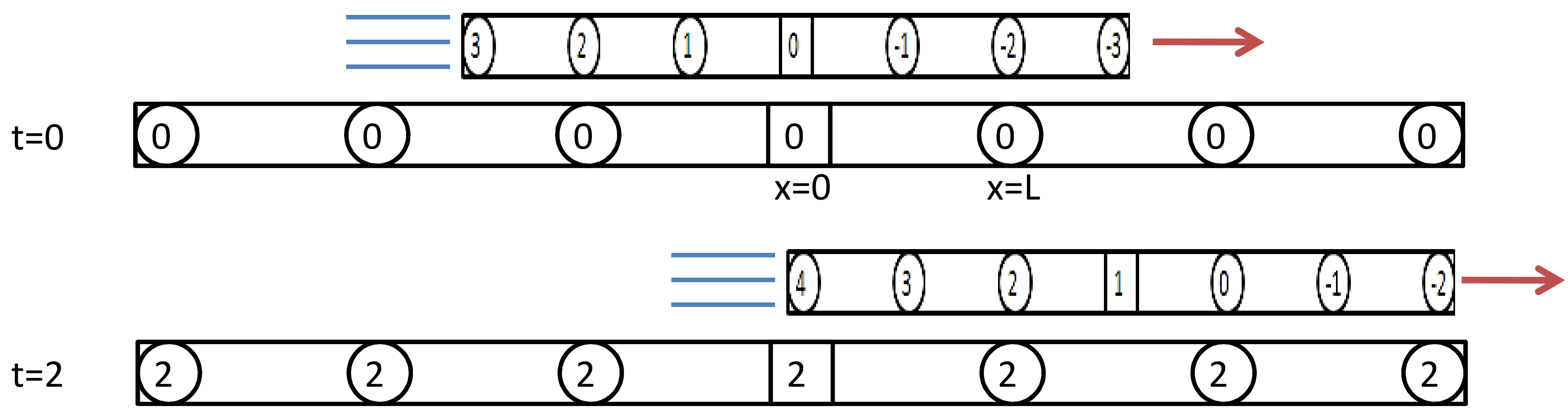


Answer:

D) Light hits the back of the train before the front of the train.

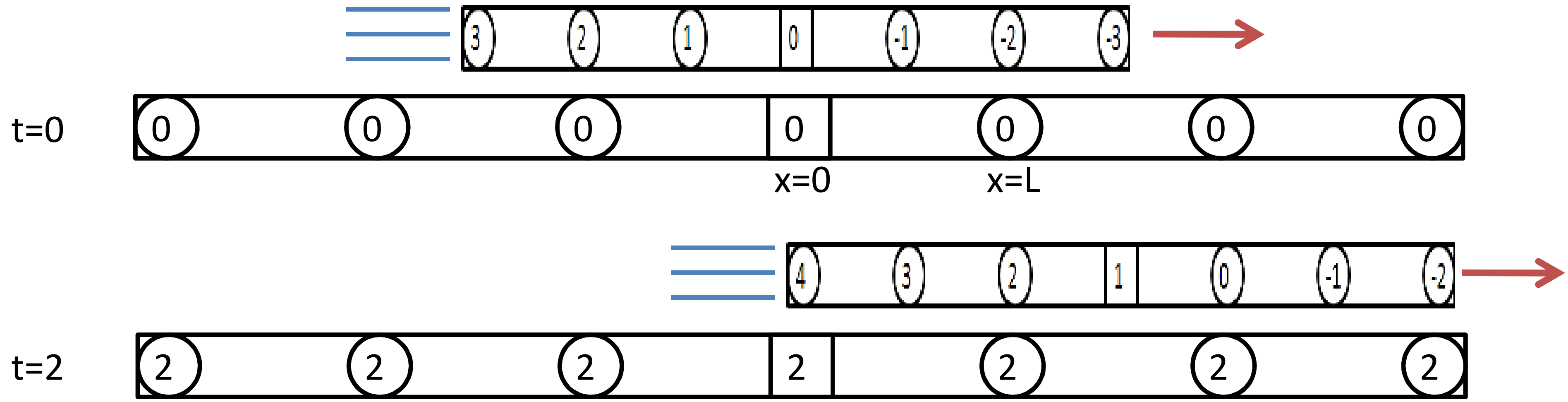
According to observers on the track, when the light hits the back of the train, the front of the train is further from the place where the light flashed, so the light cannot have reached it yet.

In the second picture, the back clock reads noon, but the front clock reads earlier than noon, since the light hasn't hit it yet.
Earlier by $v L/c^2$ to be precise.



A firecracker explodes at position x=2L and time t=2 in the frame of the lower ruler. Where and when does this event occur in the frame of the upper ruler?

A) x'=2L, t'=0
B) x'=4L, t'=1
C) x'=L, t'=1
D) x'=L, t'=0
E) x'=L, t'=4



A firecracker explodes at position x=2L and time t=2 in the frame of the lower ruler. Where and when does this event occur in the frame of the upper ruler?

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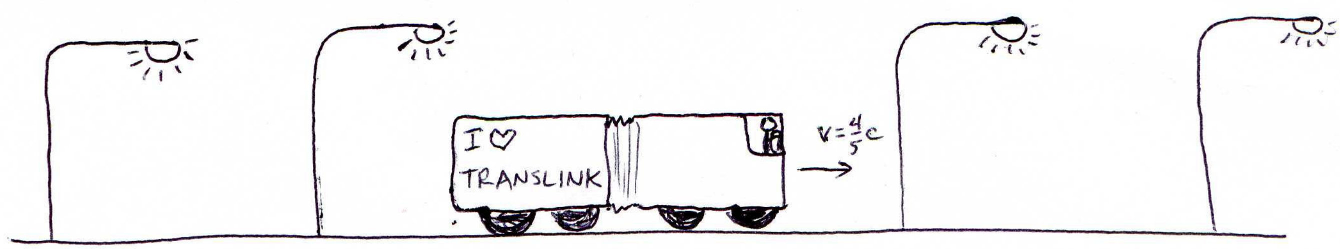
B) x'=4L, t'=1

C) x'=L, t'=1

D) x'=L, t'=0

E) x'=L, t'=4



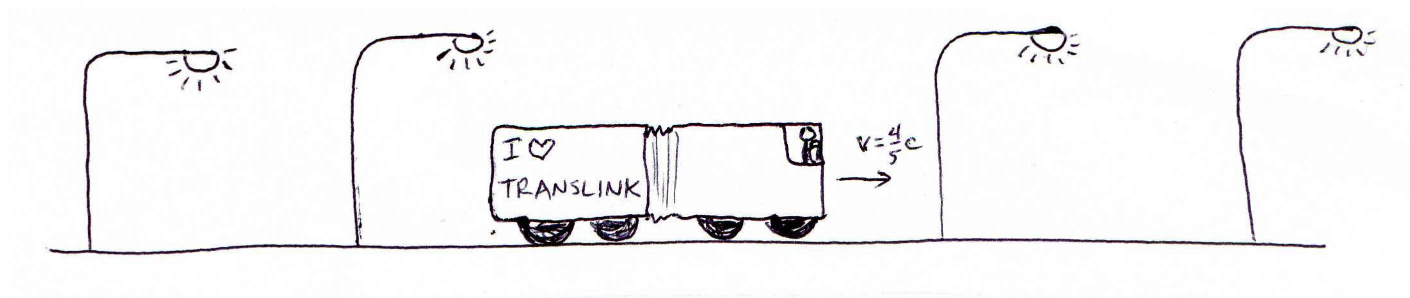
The 99 B-Line bus travels down Broadway Street at speed 4/5c. At 7:00pm, streetlights on Broadway all turn on simultaneously (in the frame of the street). In the reference frame of the bus, the streetlights ahead of the bus turn on:

A) At the same time as the streetlights behind the bus

B) After the streetlights behind the bus

C) Before the streetlights behind the bus

D) There are way too many people on the bus and there is no way to
tell which lights come on first since you can't see out any of the windows.



The 99 B-Line bus travels down Broadway Street at speed 4/5c. At 7:00pm, streetlights on Broadway all turn on simultaneously (in the frame of the street). In the reference frame of the bus, the streetlights ahead of the bus turn on:

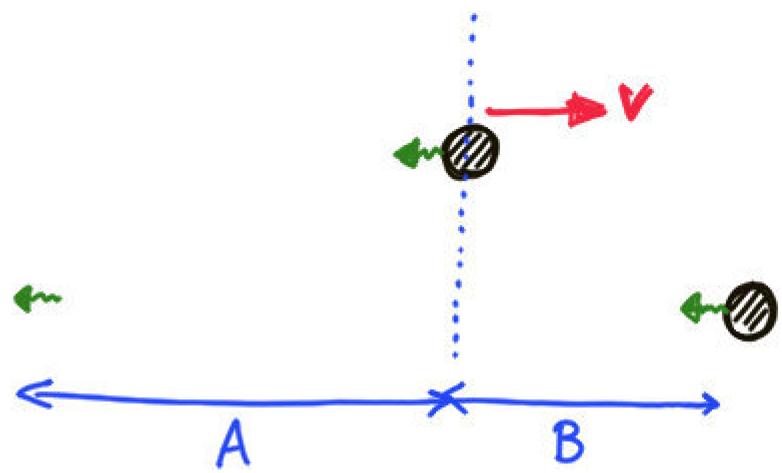
A) At the same time as the streetlights behind the bus

B) After the streetlights behind the bus

C) Before the streetlights behind the bus

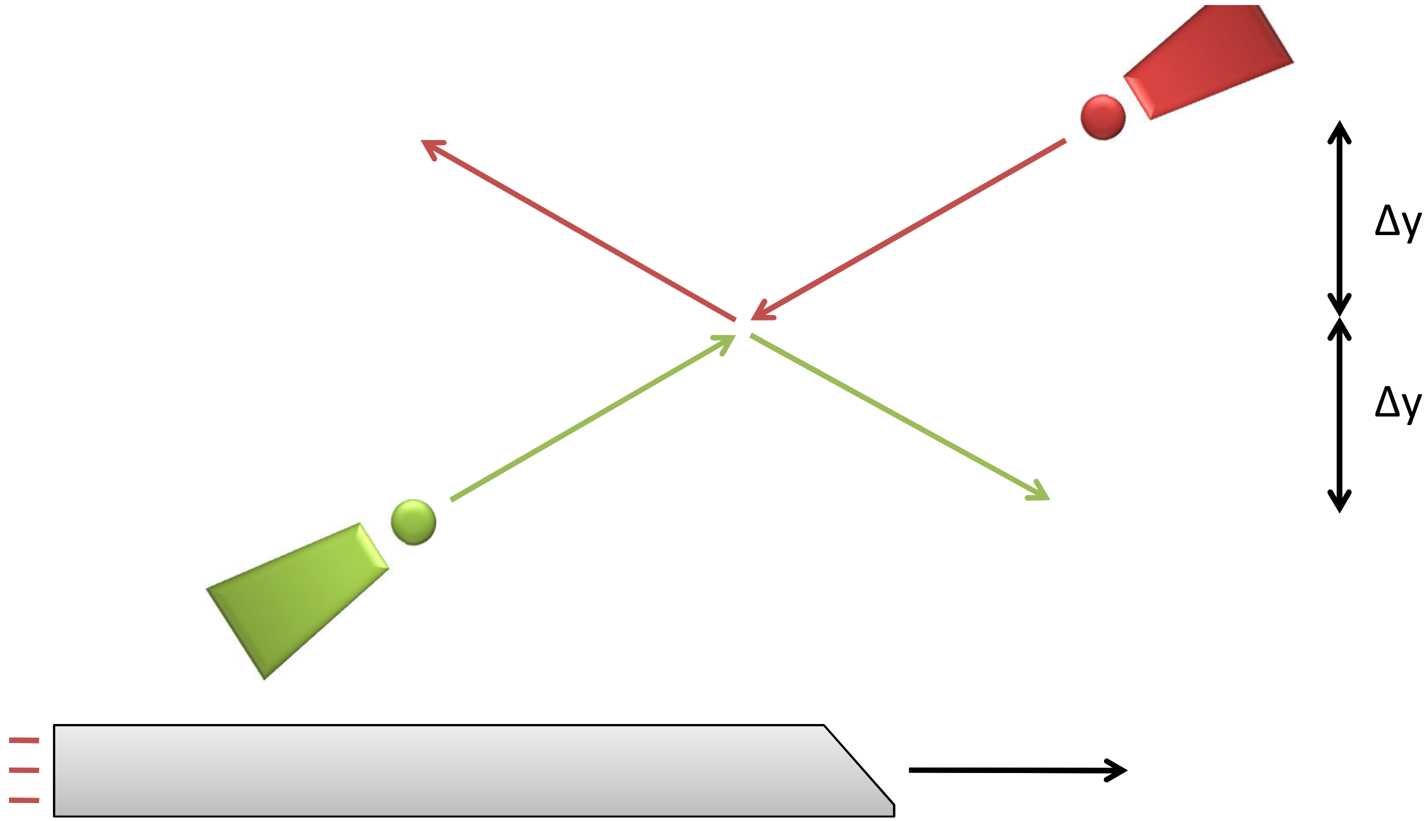
D) There are way too many people on the bus and there is no way to tell which lights come on first since you can't see out any of the windows.

If (x,t) are the coordinates of an event in the frame of the street, the time in the frame of the bus is $t' = \gamma\,(t - v/c^2 x)$. The time t is the same for all the lights turning on, but the position x is larger in front of the bus, so these lights turn on at smaller t' (i.e. before)



A ball sends out a pulse of light to the left every T seconds as measured in its own frame of reference. If the ball is now moving to the right at speed v, what will be the spatial distance between two successive pulses (distance A plus distance B in the figure above)?

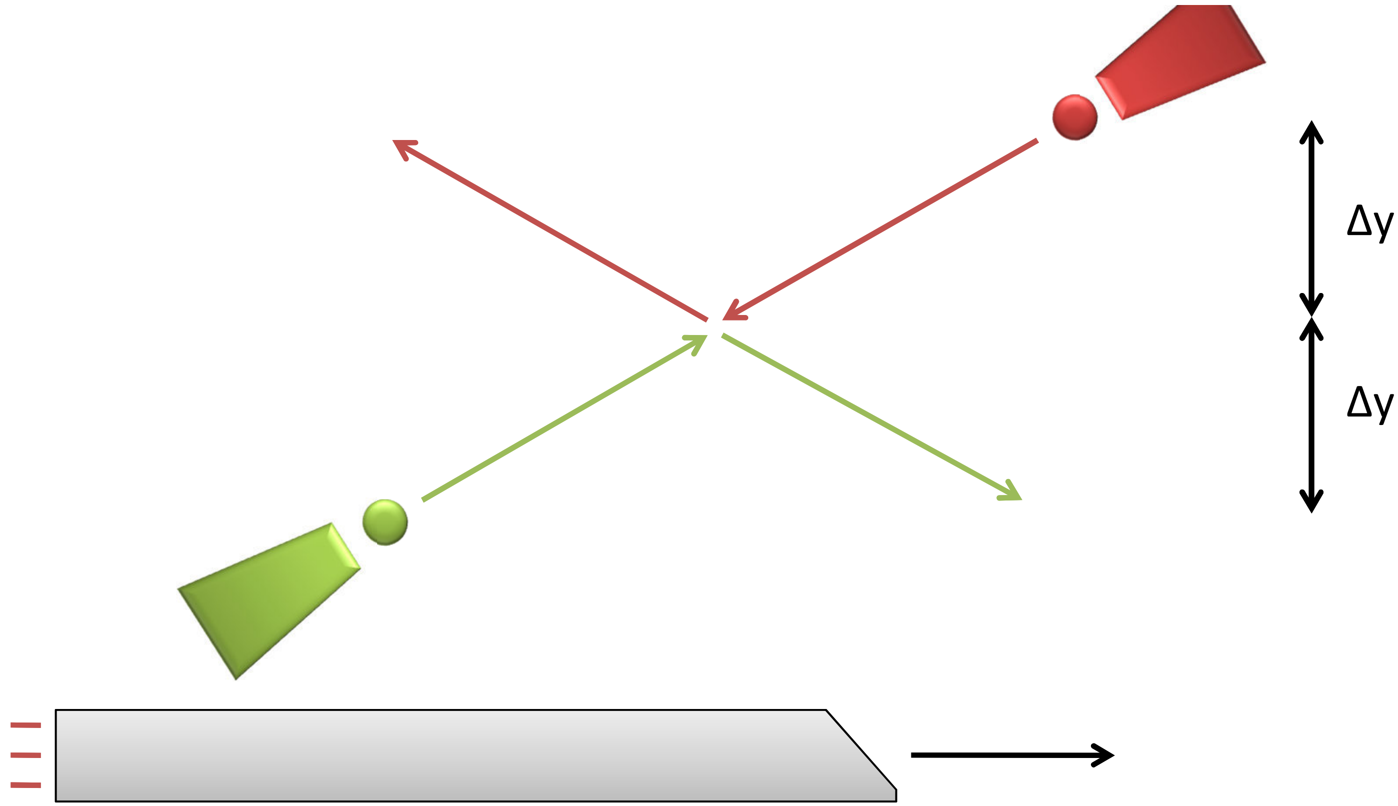
A) $c\,T/\gamma + v\,T/\gamma$
B) $c\,T + v\,T/\gamma$
C) $c\,T + v\,T$
D) $c\,T + v\,T\,\gamma$
E) $c\,T\,\gamma + v\,T\,\gamma$



Two cannons fire simultaneously (in the frame of the picture), and the cannonballs collide and bounce off elastically in a symmetrical collision. In the frame of the train:

A) The green cannon fires first
B) The red cannon fires first
C) Both cannonballs fire at the same time
D) The answer depends on where on the train the observer is located

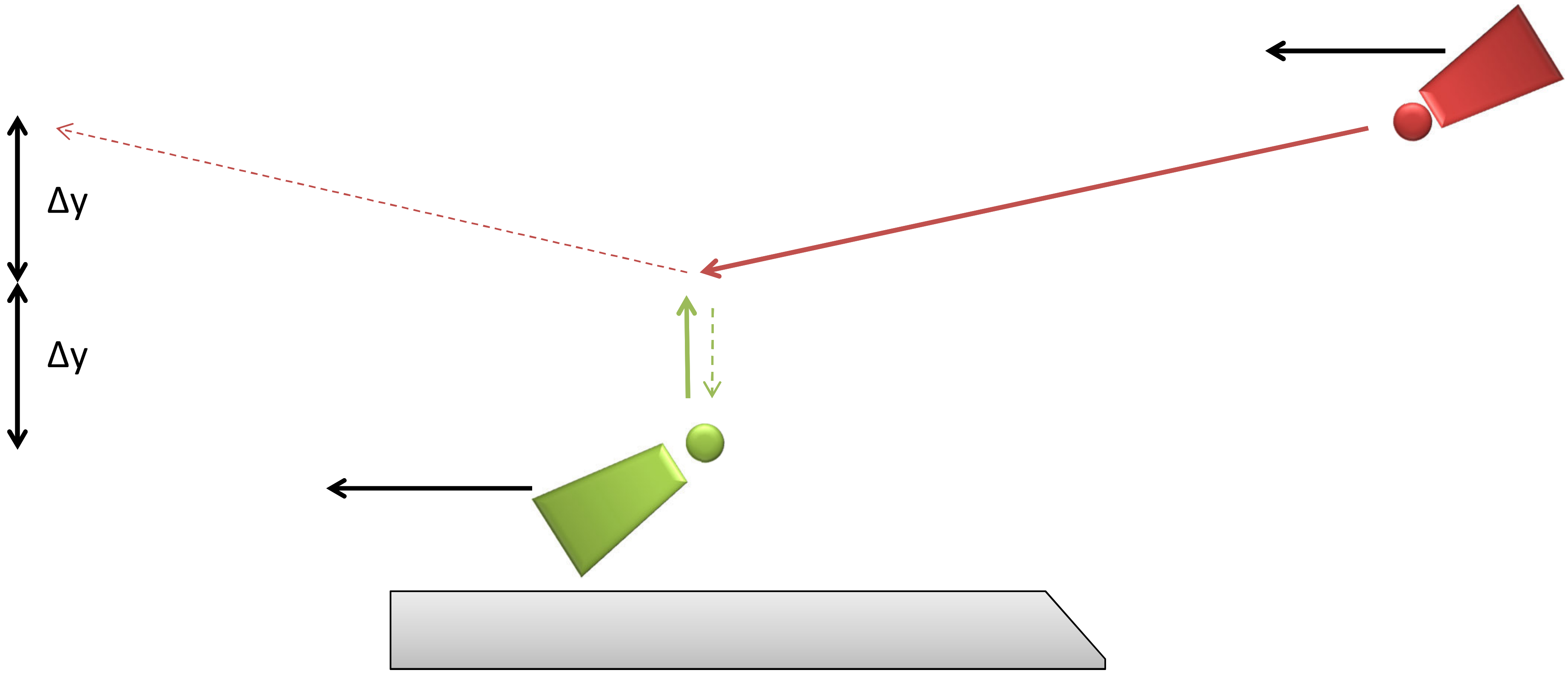
Extra: draw the trajectory of the two balls in the frame of the train if the train has the same horizontal velocity as the green ball.



Two cannons fire simultaneously (in the frame of the picture), and the cannonballs collide and bounce off elastically in a symmetrical collision. In the frame of the train:

B) The red cannon fires first

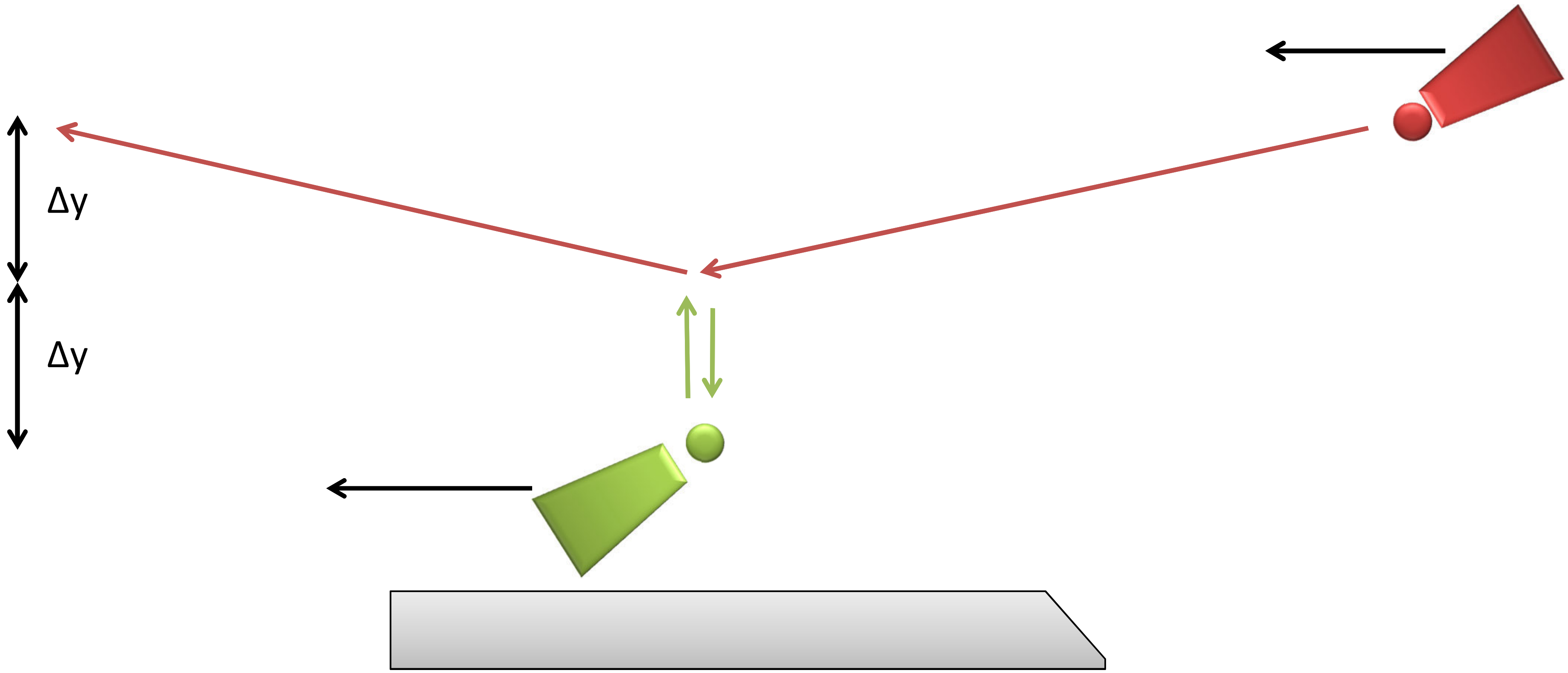
We saw last time that the clocks toward the front of the train will be observed to read an earlier time. So when the cannons fire, the clock near the red cannon will be observed to have an earlier time than the clock near the green cannon. This means that in the frame of the train, the red cannon is observed to fire first.



In the new frame, we can say that magnitude of M $\Delta y/\Delta t$ between firing and collision:

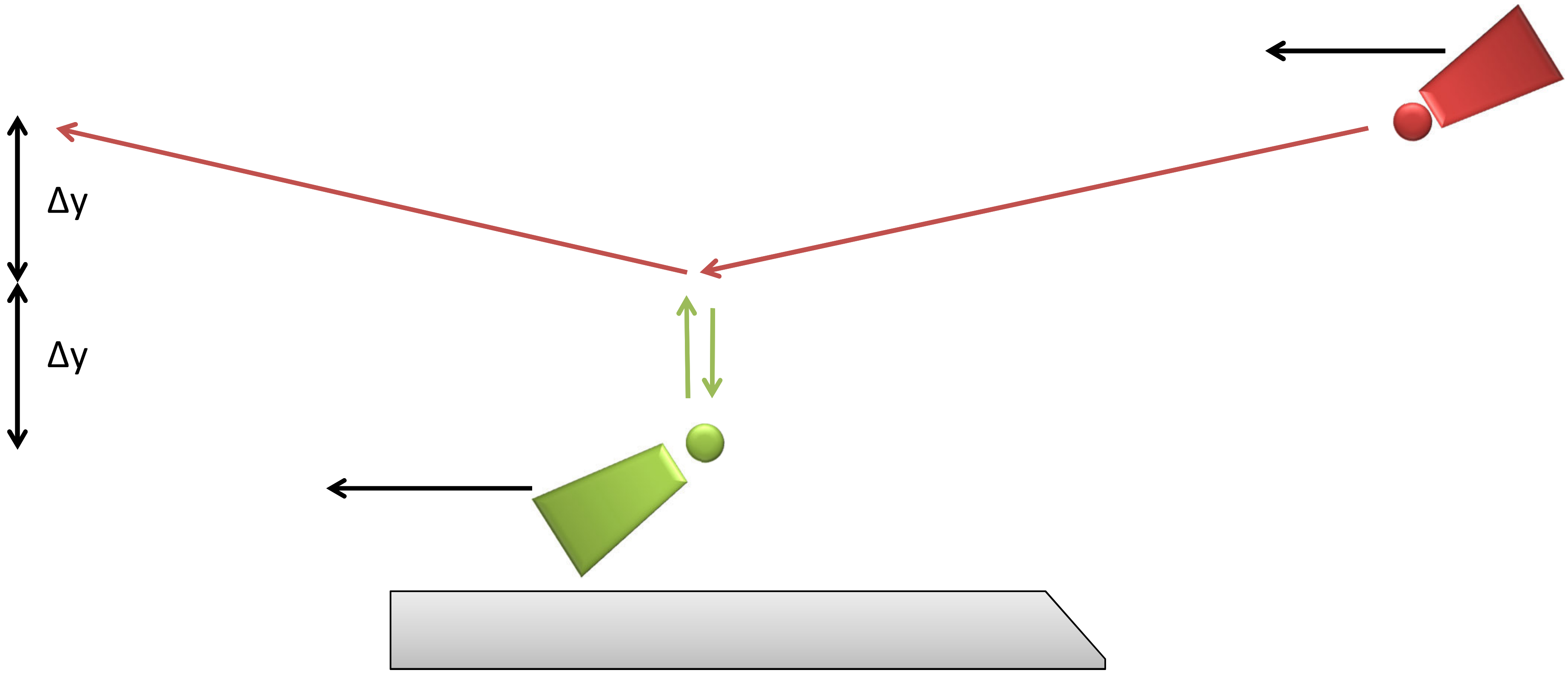
A) Is greater for the red ball
B) Is greater for the green ball
C) Is the same for both balls

Extra: Based on your answer, is y-momentum conserved here?



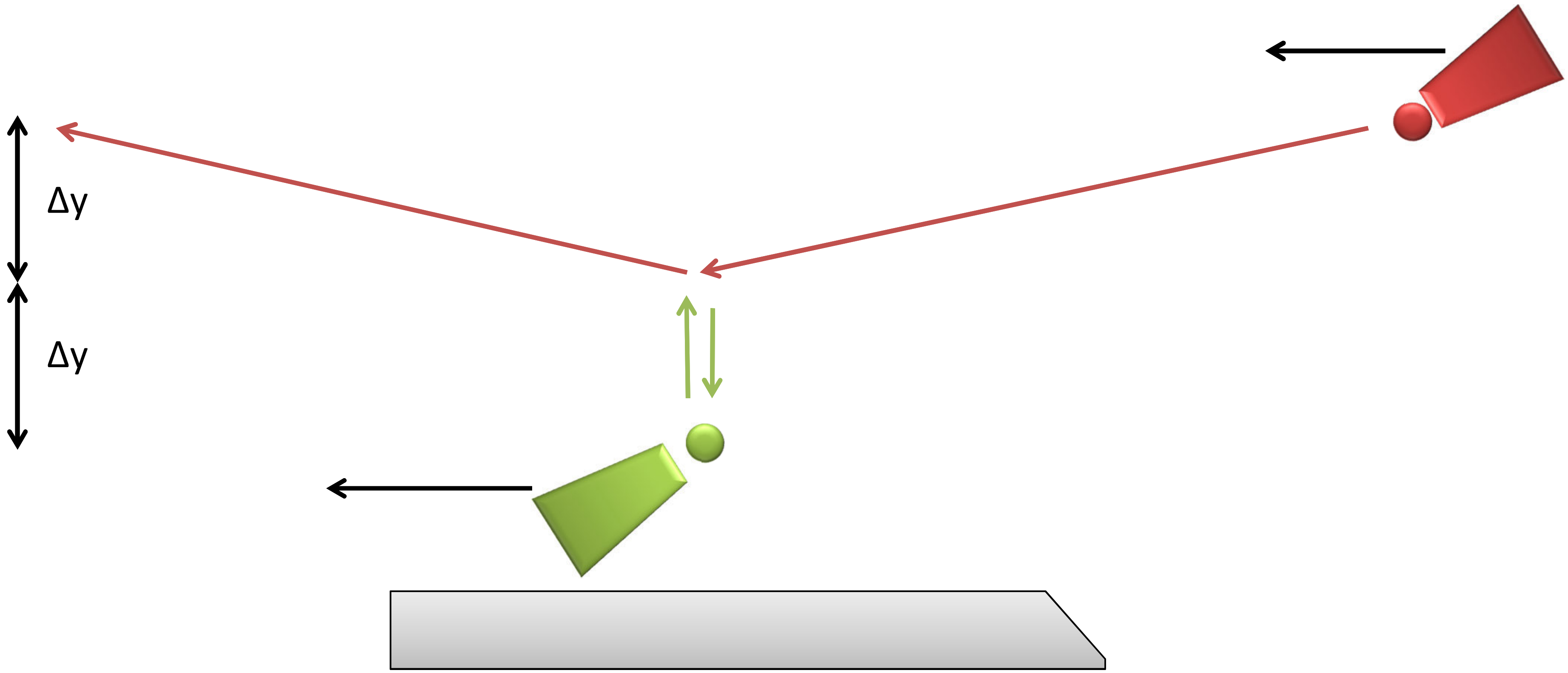
In the new frame, we can say that magnitude of M Δy/Δt:

A) Is greater for the red ball
B) Is greater for the green ball
C) Is the same for both balls



If Δt_{PROP} is the proper time for a ball between when it is fired and when it collides with the other ball, we can say that M ($\Delta y/\Delta t_{PROP}$):

A) Is greater for the red ball
B) Is greater for the green ball
C) Is the same for both balls



If Δt_{PROP} is the proper time for a ball between when it is fired and when it collides with the other ball, we can say that M $(\Delta y/\Delta t_{PROP})$:

A) Is greater for the red ball
B) Is greater for the green ball
C) Is the same for both balls

The proper time does not depend on what frame we are talking about, since it is the actual amount of time that passes on the ball's clock. Since the collision was completely symmetrical between the two balls in the first frame, the proper times must be the same.

Which of the following is NOT true of the relativistic formula for momentum $\vec{p} = \gamma m\vec{v}$?

A) It reduces to the old formula $\vec{p} = m\vec{v}$ for speeds much less than c.

B) For any object, there is no upper limit to the momentum it can have.

C) The relativistic momentum is the same in all frames of reference.

D) The sum of $\vec{p}$ for all objects is the same before and after any collision.

Which of the following is NOT true of the relativistic formula for momentum $\vec{p} = \gamma m\vec{v}$?

A) It reduces to the old formula $\vec{p} = m\vec{v}$ for speeds much less than c.

B) For any object, there is no upper limit to the momentum it can have.

C) **The relativistic momentum is the same in all frames of reference.**

D) The sum of $\vec{p}$ for all objects is the same before and after any collision.

Two objects, each with mass 1kg and speed 3/5c collide as shown in the figure. What can we say about the total energy of the system after the collision?

A) It cannot be determined.
B) It will be c^2 times 2 kg
C) It will be c^2 times 2.5 kg
D) It will be c^2 times 3.24 kg
E) It will be c^2 times 1.6 kg

Extra: If the two objects stick together during the collision, what will be the final speed of this object? What will be its mass?

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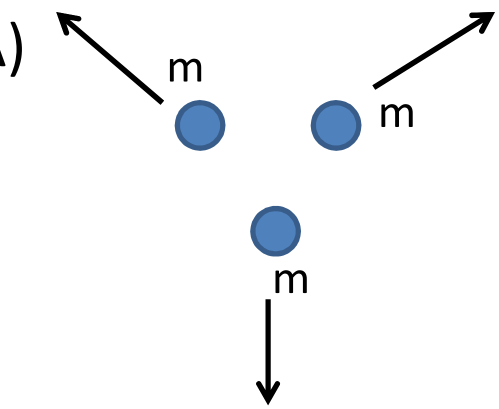
D) It will be c^2 times 3.24 kg
E) It will be c^2 times 1.6 kg

Total energy is conserved. Energy after equals energy before, which is 2 times γ times m times c^2

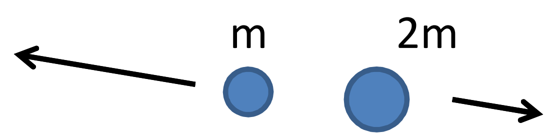
Extra: If the two objects stick together during the collision, what will be the final speed of this object? What will be its mass?

An unstable particle of mass 3m decays into lighter particles. Which of the following represents a possible final state?

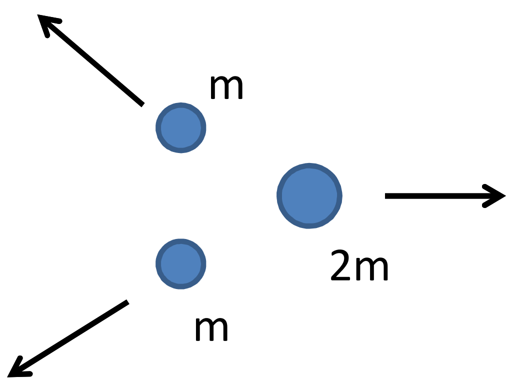
A)



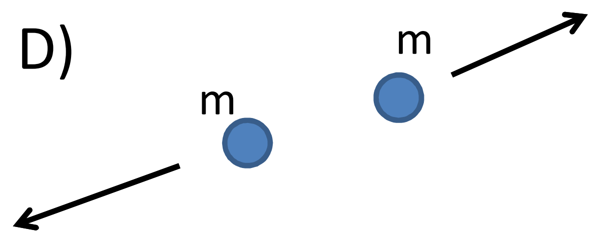
B)



C)

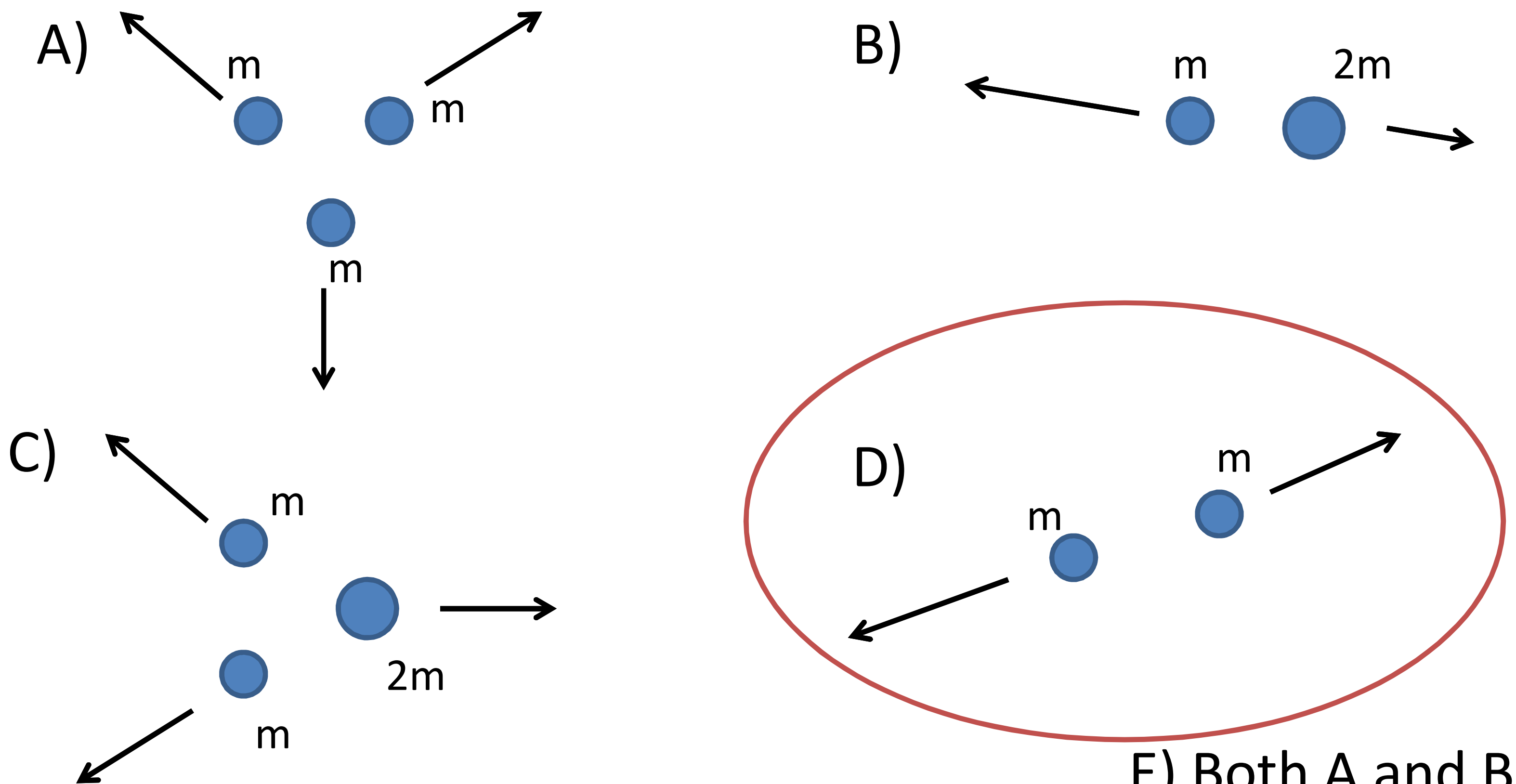


D)



E) Both A and B

An unstable particle of mass 3m decays into lighter particles. Which of the following represents a possible final state?



E) Both A and B

The initial energy is $3mc^2$. The energy of A, B, and C is more than $3mc^2$.

A stationary space salmon has a mass of 20 kg. In the frame of reference of an observer moving at v=3/5c relative to the space salmon, the mass of the salmon is:

A) 16kg
B) 20kg
C) 25kg
D) Cannot be determined

A stationary space salmon has a mass of 20 kg. In the frame of reference of an observer moving at v=3/5c relative to the space salmon, the mass of the salmon is:

A) 16kg
B) 20kg
C) 25kg
D) Cannot be determined

Mass is equal to the energy of an object when it is not moving, divided by c^2. So in the new frame of reference, the kinetic energy and total energy are larger, but the mass is still 20kg.

Two balls of pure gold at rest each contain exactly 10^{23} gold atoms. One ball is at room temperature, while the other ball is at 1000K. Which ball is more massive?

A) The cooler ball
B) The hotter ball
C) They have the same mass

Two balls of pure gold at rest each contain exactly 10^{23} gold atoms. One ball is at room temperature, while the other ball is at 1000K. Which ball is more massive?

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B) The hotter ball
C) They have the same mass

Same atoms, but more kinetic energy, so total energy is greater. Mass is the total energy of an object at rest divided by c^2.

How does the mass of a hydrogen atom compare to the mass of a proton plus the mass of an electron?

A) It is the same: $m_H = m_p + m_e$
B) It is less: $m_H < m_p + m_e$
C) It is greater: $m_H > m_p + m_e$

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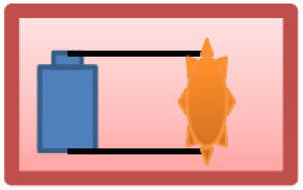
Need to add energy to separate into proton and electron, so energy conservation tells us:

$m_H c^2 + \text{energy} = m_p c^2 + m_e c^2$

This means $m_H < m_p + m_e$

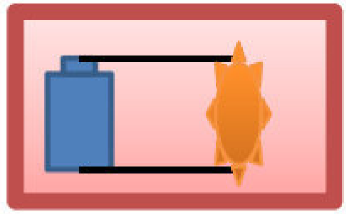


Suppose we build a sealed box which contains a battery connected to a heater which gradually heats the air inside the box. Assuming the box is completely isolated, and that the box neither absorbs nor emits any particles or radiation, what happens to the mass of the box (including its contents) as time passes?

A) The mass increases.

B) The mass decreases.

C) The mass stays the same.



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Mass is the total energy of the object (box and its contents) in its rest frame. For this isolated system total energy is conserved, so the mass stays the same no matter what happens inside the box.