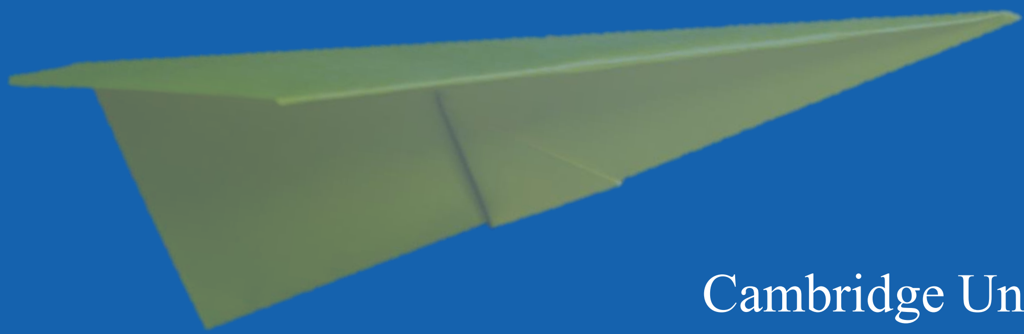
Clicker Questions

Modern Physics

by Gary Felder and Kenny Felder



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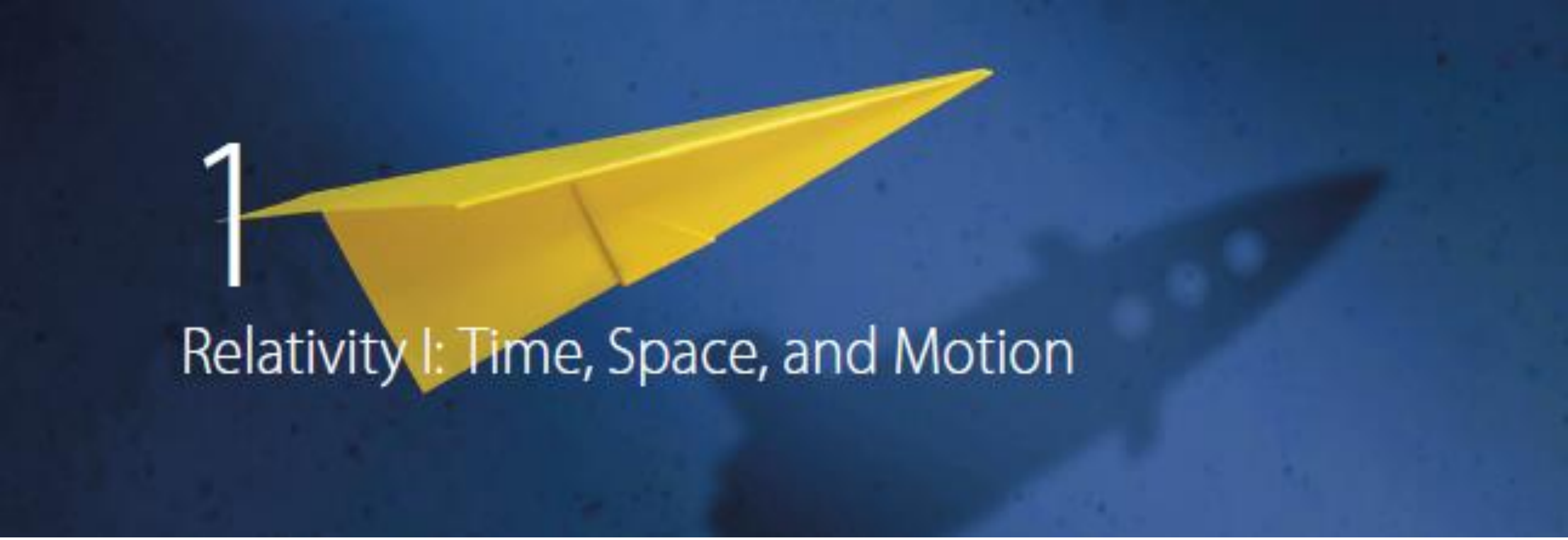
Instructions

- These questions are offered in two formats: a deck of PowerPoint slides, and a PDF file. The two files contain identical contents. There are similar files for each of the 14 chapters in the book, for a total of 28 files.
- Each question is marked as a "Quick Check" or "ConcepTest."
  - Quick Checks are questions that most students should be able to answer correctly if they have done the reading or followed the lecture. You can use them to make sure students are where you think they are before you move on.
  - ConcepTests (a term coined by Eric Mazur) are intended to stimulate debate, so you don't want to prep the class too explicitly before asking them. Ideally you want between 30% and 80% of the class to answer correctly.
- Either way, if a strong majority answers correctly, you can briefly discuss the answer and move on. If many students do not answer correctly, consider having them talk briefly in pairs or small groups and then vote again. You may be surprised at how much a minute of unguided discussion improves the hit rate.
- Each question is shown on two slides: the first shows only the question, and the second adds the correct answer.
- Some of these questions are also included in the book under "Conceptual Questions and ConcepTests," but this file contains additional questions that are not in the book.
- Some of the pages contain multiple questions with the same set of options. These questions are numbered as separate questions on the page.
- Some questions can have multiple answers. (These are all clearly marked with the phrase "Choose all that apply.") If you are using a clicker system that doesn't allow multiple responses, you can ask each part separately as a yes-or-no question.



1 Relativity I: Time, Space, and Motion

1.1 Galilean Relativity

You are inside a train. You cannot look out a window or communicate with the outside world in any way. Which of the following could you detect? (Choose all that apply.)

A. The engineer slams on the brakes.

B. The train is bouncing up and down.

C. The train is moving forward at 200 mph.

D. The train is moving backward at 200 mph.

E. The track is circular rather than straight.

F. The train is moving downhill.

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D. The train is moving backward at 200 mph.

E. The track is circular rather than straight.

F. The train is moving downhill.

Solution: A, B, E, and F

You are running at 4 mph when a football slams into the back of your head. The football is going 20 mph in the same direction you are. How much will the football hurt your head? (Choose one.)

A. It will cause the same injury that it would cause if you were not running.

B. It will cause the same injury that a 16 mph football would cause if you were not running.

C. It will cause the same injury that a 24 mph football would cause if you were not running.

D. None of the above

You are running at 4 mph when a football slams into the back of your head. The football is going 20 mph in the same direction you are. How much will the football hurt your head? (Choose one.)

A. It will cause the same injury that it would cause if you were not running.

B. It will cause the same injury that a 16 mph football would cause if you were not running.

C. It will cause the same injury that a 24 mph football would cause if you were not running.

D. None of the above

Solution: B

An “inertial” reference frame means one that. . . (Choose one.)

A. is massless

B. has mass

C. has momentum

D. has no velocity

E. has no acceleration

An "inertial" reference frame means one that… (Choose one.)

A. is massless

B. has mass

C. has momentum

D. has no velocity

E. has no acceleration

Solution: E

You are standing at rest and Mary is moving by you in the positive y direction. Ben is moving nearby in some way that we haven't specified. Each question below refers to a measurement of Ben taken some time after Mary has passed you, and compares that measurement in your frame (unprimed) with Mary's (primed). For each one say whether A) the unprimed variable is greater, B) the primed variable is greater, C) they are equal, or D) there isn't enough information to tell. *Remember that all the variables refer to Ben, as measured by you (unprimed) and Mary (primed).*

1. x and x'
2. y and y'
3. v_x and v'_x
4. v_y and v'_y
5. a_x and a'_x
6. a_y and a'_y

You are standing at rest and Mary is moving by you in the positive y direction. Ben is moving nearby in some way that we haven't specified. Each question below refers to a measurement of Ben taken some time after Mary has passed you, and compares that measurement in your frame (unprimed) with Mary's (primed). For each one say whether A) the unprimed variable is greater, B) the primed variable is greater, C) they are equal, or D) there isn't enough information to tell. *Remember that all the variables refer to Ben, as measured by you (unprimed) and Mary (primed).*

1. x and x'

   Solution: C (equal)

2. y and y'

   Solution: A ($y > y'$)

3. v_x and v'_x

   Solution: C (equal)

4. v_y and v'_y

   Solution: A ($v_y > v'_y$)

5. a_x and a'_x

   Solution: C (equal)

6. a_y and a'_y

   Solution: C (equal)

A cart has a vertical spring with a ball on top of it. When you push down the spring and release it with the cart at rest, the ball goes straight up and down and falls back into the cart. For each of the scenarios below, will the ball fall A) into the cart, B) behind the cart, or C) in front of the cart?

1. You give the cart a push and release the spring as it is moving at steady velocity along the floor. (Ignore friction.)
2. The same as Part 1, but this time assume the cart does experience significant friction as it slides.

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1. You give the cart a push and release the spring as it is moving at steady velocity along the floor. (Ignore friction.)

   Solution: A (into the cart)

2. The same as Part 1, but this time assume the cart does experience significant friction as it slides.

   Solution: C (in front of the cart)

You are biking at 20 mph when a frisbee moving perpendicular to you at 10 mph slams into the side of your head. How much will the frisbee hurt your head? Explain your answer. (This might involve a bit of math.) (Choose one.)

A. It will cause the same injury that a 10 mph frisbee would cause if you were not riding.

B. It will cause the same injury that a 20 mph frisbee would cause if you were not riding.

C. It will cause the same injury that a 30 mph frisbee would cause if you were not riding.

D. None of the above

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A. It will cause the same injury that a 10 mph frisbee would cause if you were not riding.

B. It will cause the same injury that a 20 mph frisbee would cause if you were not riding.

C. It will cause the same injury that a 30 mph frisbee would cause if you were not riding.

D. None of the above

Solution: D

1.2 Einstein's Postulates and Time Dilation

You are standing on your tiny asteroid as a ship approaches you moving at $c/2$. You send a radio signal (which is a form of light) welcoming them. From your point of view the radio signal is moving from you to them at speed c. From their point of view how fast is it moving? (Choose one.)

A. $c/2$

B. c

C. $3c/2$

D. None of the above

You are standing on your tiny asteroid as a ship approaches you moving at $c/2$. You send a radio signal (which is a form of light) welcoming them. From your point of view the radio signal is moving from you to them at speed c. From their point of view how fast is it moving? (Choose one.)

A. $c/2$

B. c

C. $3c/2$

D. None of the above

Solution: B

Johnny and Rakelle live on opposite sides of the solar system, and they have perfectly synchronized watches. If Johnny flies over to visit Rakelle, what will their watches show when they arrive? (Choose one.)

A. Johnny's watch will be ahead of Rakelle's.

B. Johnny's watch will be behind Rakelle's.

C. They will still be synchronized.

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A. Johnny's watch will be ahead of Rakelle's.

B. Johnny's watch will be behind Rakelle's.

C. They will still be synchronized.

Solution: B

If a clock zooms by you at $c/2$, the clock will look to you like it is going too slowly because... (Choose one.)

A. High speeds affect the mechanisms of clocks.

B. When you look at the clock far away, you are seeing it in the past.

C. Time fundamentally flows differently for different observers.

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A. High speeds affect the mechanisms of clocks.

B. When you look at the clock far away, you are seeing it in the past.

C. Time fundamentally flows differently for different observers.

Solution: C

We believe that time dilation actually occurs because…(Choose all that apply.)

A. Time dilation is one of the starting axioms on which all of Einstein’s theory of relativity is based.

B. Time dilation is an unavoidable result of the invariance of the speed of light.

C. There is direct experimental evidence of time dilation.

We believe that time dilation actually occurs because…(Choose all that apply.)

A. Time dilation is one of the starting axioms on which all of Einstein's theory of relativity is based.

B. Time dilation is an unavoidable result of the invariance of the speed of light.

C. There is direct experimental evidence of time dilation.

Solution: B and C

We discussed a scenario in which a plane passes Mountain A (first event) and then passes Mountain B (second event). Which of the following represents a proper time $\Delta\tau$ between those two events? (Choose one.)

A. The time measured in the plane frame

B. The time measured in the mountain frame

C. Neither of those

D. Both of those

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A. The time measured in the plane frame

B. The time measured in the mountain frame

C. Neither of those

D. Both of those

Solution: A

Galilean relativity postulates that the laws of physics are the same in any non-accelerating reference frame. Einstein's theory of relativity…(Choose one.)

A. Completely rejects this postulate.

B. Accepts but modifies this postulate.

C. Completely accepts this postulate in its original form.

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A. Completely rejects this postulate.

B. Accepts but modifies this postulate.

C. Completely accepts this postulate in its original form.

Solution: C

Does Einstein's theory say that. . . (Choose one.)

A. the *speed* of light is the same for all observers.

B. the *velocity* of light is the same for all observers?

Does Einstein's theory say that. . . (Choose one.)

A. the *speed* of light is the same for all observers.

B. the *velocity* of light is the same for all observers?

Solution: A

A very long train zooms past a station at speed $c/2$. Observers on the train and ground measure the time it takes for the train to pass the station. (Choose one.)

A. The time elapsed on the train clocks, as the train passes the station, is *longer* than the time elapsed on the station clock.

B. The time elapsed on the train clocks, as the train passes the station, is *shorter* than the time elapsed on the station clock.

C. The two times are the same.

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B. The time elapsed on the train clocks, as the train passes the station, is *shorter* than the time elapsed on the station clock.

C. The two times are the same.

Solution: A

The solution to the famous "paradox of the twin" hinges on the time period when Emma reverses direction—thus accelerating—to come home. Now suppose that Asher stays home (as before) but Emma never slows down or speeds up; instead she travels at constant speed in a big circle, ending back at home anyway. What do they find when Emma returns home? (Choose one.)

A. Emma is younger than Asher (just as she was in the original twin paradox).

B. Asher is younger than Emma.

C. They disagree about which one is younger.

D. They are the same age.

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B. Asher is younger than Emma.

C. They disagree about which one is younger.

D. They are the same age.

Solution: A

You are inside a spaceship in which you feel no acceleration. You sleep for your usual eight hours.

1. Is there any inertial reference frame in which your night's sleep lasted longer than eight hours?
2. Is there any inertial reference frame *other than the one you are in* in which your night's sleep lasted exactly eight hours?
3. Is there any inertial reference frame in which your night's sleep lasted less than eight hours?

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1. Is there any inertial reference frame in which your night's sleep lasted longer than eight hours?

   Solution: Yes

2. Is there any inertial reference frame *other than the one you are in* in which your night's sleep lasted exactly eight hours?

   Solution: No

3. Is there any inertial reference frame in which your night's sleep lasted less than eight hours?

   Solution: No

A clock sitting at rest on Earth (which we take to be inertial) measures that an hour passes between two events.

1. Can any inertial reference frame measure less than an hour between those two events?
2. Can any accelerating object measure a proper time of less than an hour between those two events? Explain. *Hint:* Think about the twin paradox.

A clock sitting at rest on Earth (which we take to be inertial) measures that an hour passes between two events.

1. Can any inertial reference frame measure less than an hour between those two events?

   Solution: No

2. Can any accelerating object measure a proper time of less than an hour between those two events? Explain. *Hint:* Think about the twin paradox.

   Solution: Yes

A rocket flies by a planet at speed 0.9 c. Isabella is in the rocket and throws a ball forward (in the direction of the rocket's motion) at 20 m/s (relative to the rocket, as measured in the rocket frame). Which of the following describes the speed of the ball as measured in the planet frame? (Choose one.)

A. $v_b < 20\ \text{m/s} + 0.9\ c$

B. $v_b = 20\ \text{m/s} + 0.9\ c$

C. $v_b > 20\ \text{m/s} + 0.9\ c$

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A. $v_b < 20$ m/s + $0.9\ c$

B. $v_b = 20$ m/s + $0.9\ c$

C. $v_b > 20$ m/s + $0.9\ c$

Solution: A

Much of Einstein's original motivation for special relativity came from electromagnetic theory. Consider two parallel wires, each carrying identical current I in the same direction. The moving charges create magnetic fields, and react to each other's magnetic fields, causing the wires to attract each other. (Curl your right-hand fingers and thumb around until you're convinced that's true.) But now consider the same scene from a reference frame that is moving with the current. In that frame the electrons are (on average) not moving, so they exert no net magnetic field. Do the wires still move toward each other?

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Solution: Yes

1.3 Length Contraction and Simultaneity

A ruler has “proper length” 12 inches. If the ruler is moving with respect to you (along the same axis as the ruler’s length), you will measure its length as. . . (Choose one.)

A. less than 12 inches.

B. exactly 12 inches.

C. more than 12 inches.

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A. less than 12 inches.

B. exactly 12 inches.

C. more than 12 inches.

Solution: A

You hold up a 12-inch ruler. A friend of yours zooms by (along the same axis as the ruler's length) holding up a different 12-inch ruler, which briefly overlaps with yours. You measure your friend's ruler to be shorter than 12 inches. Your friend measures *your* ruler to be…(Choose one.)

A. less than 12 inches.

B. exactly 12 inches.

C. more than 12 inches.

You hold up a 12-inch ruler. A friend of yours zooms by (along the same axis as the ruler's length) holding up a different 12-inch ruler, which briefly overlaps with yours. You measure your friend's ruler to be shorter than 12 inches. Your friend measures *your* ruler to be. . . (Choose one.)

A. less than 12 inches.

B. exactly 12 inches.

C. more than 12 inches.

Solution: A

A square in the xz plane is at rest in your reference frame. If it starts moving in the z direction then in your reference frame it will now be. . . (Choose one.)

A. a rectangle, taller than it is wide.

B. still a square, but smaller than its proper dimensions.

C. a rectangle, wider than it is tall.

D. unchanged

A square in the xz plane is at rest in your reference frame. If it starts moving in the z direction then in your reference frame it will now be. . . (Choose one.)

A. a rectangle, taller than it is wide.

B. still a square, but smaller than its proper dimensions.

C. a rectangle, wider than it is tall.

D. unchanged

Solution: C

A square in the xy plane is at rest in your reference frame. If it starts moving in the z direction then in your reference frame it will now be... (Choose one.)

A. a rectangle, taller than it is wide.

B. still a square, but smaller than its proper dimensions.

C. a rectangle, wider than it is tall.

D. unchanged

A square in the xy plane is at rest in your reference frame. If it starts moving in the z direction then in your reference frame it will now be. . . (Choose one.)

A. a rectangle, taller than it is wide.

B. still a square, but smaller than its proper dimensions.

C. a rectangle, wider than it is tall.

D. unchanged

Solution: D

Observers in two different inertial reference frames view two events. Which of the following might the two observers *disagree* about? (Choose all that apply.)

A. The distance between the two events.

B. The time between the two events.

C. Which event happened first.

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A. The distance between the two events.

B. The time between the two events.

C. Which event happened first.

Solution: All three

Each of the parts below will describe two events. For each one specify whether the separation of the two events is A) timelike, B) spacelike, or C) lightlike.

1. A train leaves Chicago. That train reaches New York.
2. An astronaut on a spacewalk sends a radio signal. The space station receives it.
3. You walk into class. Ten minutes later your professor walks in.
4. A highly accurate atomic clock says it is noon in New York. Another one says it is noon in Miami.

Each of the parts below will describe two events. For each one specify whether the separation of the two events is A) timelike, B) spacelike, or C) lightlike.

1. A train leaves Chicago. That train reaches New York.

   Solution: A (timelike)

2. An astronaut on a spacewalk sends a radio signal. The space station receives it.

   Solution: C (lightlike)

3. You walk into class. Ten minutes later your professor walks in.

   Solution: A (timelike)

4. A highly accurate atomic clock says it is noon in New York. Another one says it is noon in Miami.

   Solution: B (spacelike)

A train follows a straight-line route from New York to Los Angeles at near-light speed. (Let's ignore all the reasons why that would be a Very Bad Idea.) The train and the ground each define a reference frame. Label each of the following measurements as A) "both reference frames must agree" or as B) "the two reference frames might disagree."

1. The relative speed of the train and the ground.
2. The amount of time the journey takes.
3. The setting of the New York clock as the train leaves New York.
4. The setting of the train clock as the train leaves New York.
5. The setting of the Los Angeles clock as the train leaves New York.
6. Whether the gap between the two events ("train leaves N.Y." and "train reaches L.A.") is spacelike, timelike, or lightlike.

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1. The relative speed of the train and the ground.

   Solution: A (Agree)

2. The amount of time the journey takes.

   Solution: B (Disagree)

3. The setting of the New York clock as the train leaves New York.

   Solution: A (Agree)

4. The setting of the train clock as the train leaves New York.

   Solution: A (Agree)

5. The setting of the Los Angeles clock as the train leaves New York.

   Solution: B (Disagree)

6. Whether the gap between the two events ("train leaves N.Y." and "train reaches L.A.") is spacelike, timelike, or lightlike.

   Solution: A (Agree)

Suppose a plane is flying at near-light speed past a chain of mountains. First it passes Mountain A, then Mountain B, and so on. The mountains all have synchronized clocks according to the mountain frame. At the moment the plane passes Mountain B that mountain's clock says noon.

1. According to the plane frame, does the Mountain C clock at that same moment show a time A) before, B) after, or C) exactly at noon?
2. According to the plane frame, does the Mountain A clock at that same moment show a time A) before, B) after, or C) exactly at noon?

Suppose a plane is flying at near-light speed past a chain of mountains. First it passes Mountain A, then Mountain B, and so on. The mountains all have synchronized clocks according to the mountain frame. At the moment the plane passes Mountain B that mountain's clock says noon.

1. According to the plane frame, does the Mountain C clock at that same moment show a time A) before, B) after, or C) exactly at noon?

   Solution: B

2. According to the plane frame, does the Mountain A clock at that same moment show a time A) before, B) after, or C) exactly at noon?

   Solution: A

Suppose a chain of equally spaced planes is flying at near-light speed past a mountain. First Plane A passes it, then Plane B, and so on. The planes all have synchronized clocks according to the plane frame. At the moment Plane B passes the mountain that plane's clock says noon.

1. According to the mountain frame, does the Plane C clock at that same moment show a time A) before, B) after, or C) exactly at noon?
2. According to the mountain frame, does the Plane A clock at that same moment show a time A) before, B) after, or C) exactly at noon?

Suppose a chain of equally spaced planes is flying at near-light speed past a mountain. First Plane A passes it, then Plane B, and so on. The planes all have synchronized clocks according to the plane frame. At the moment Plane B passes the mountain that plane's clock says noon.

1. According to the mountain frame, does the Plane C clock at that same moment show a time A) before, B) after, or C) exactly at noon?

   Solution: B

2. According to the mountain frame, does the Plane A clock at that same moment show a time A) before, B) after, or C) exactly at noon?

   Solution: A

One of the most famous apparent paradoxes in relativity involves two farmers trying to fit a long beam into a short barn. For definiteness let's say the beam is twice as long as the barn (when they are both at rest). Farmer Ben has been studying relativity, so he decides that he will carry the beam into the barn moving so fast that in the barn frame the beam will be contracted by a factor of 3, so it will easily fit. He tells his brother Jack to stand at the barn door and slam the door behind him the moment the beam is entirely in the barn. Does the beam end up fitting in the barn?

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Solution: No

1.4 The Lorentz Transformations

The Lorentz transformations, as expressed in the textbook, assume which of the following? (Choose all that apply.)

A. If two events are simultaneous in frame R, then they are also simultaneous in frame R'.

B. If two events occur at the same place in frame R, then they also occur at the same place in frame R'.

C. The two reference frames agree about one particular place and time labeled as $x = x' = 0$, $y = y' = 0$, $z = z' = 0$, and $t = t' = 0$.

D. The x-axis has been chosen to lie in the direction of the relative motion of the two reference frames.

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C. The two reference frames agree about one particular place and time labeled as $x = x' = 0$, $y = y' = 0$, $z = z' = 0$, and $t = t' = 0$.

D. The x-axis has been chosen to lie in the direction of the relative motion of the two reference frames.

Solution: C and D

If frame R$'$ is moving with velocity u in the positive x-direction relative to frame R, then the velocity of frame R relative to R$'$ is…(Choose one.)

A. u

B. $-u$

C. Neither

D. It depends

If frame R' is moving with velocity u in the positive x-direction relative to frame R, then the velocity of frame R relative to R' is. . . (Choose one.)

A. u

B. $-u$

C. Neither

D. It depends

Solution: B

Two events occur at the same place in the inertial reference frame R, and observers in Frame R measure the spacetime interval between the events. Which of the following must be true? (Choose one.)

A. All other inertial reference frames will measure the same value of s between those two events.

B. If the two events occurred at the same place in R then all other inertial frames will measure a larger value of s.

C. If the two events occurred at the same place in R then all other inertial frames will measure a smaller value of s.

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C. If the two events occurred at the same place in R then all other inertial frames will measure a smaller value of s.

Solution: A

James and Cecelia both have watches on their wrists. Under what circumstances will they both agree that their watches are synchronized? (Read all the answers carefully, then choose one.)

A. They can synchronize their watches if they are both in the same reference frame.

B. They can momentarily synchronize their watches if they are in the same place.

C. A and B. That is, they can only synchronize their watches if they are in the same reference frame AND in the same place.

D. A or B. That is, they can synchronize their watches if they are in the same reference frame, OR if they are in the same place for an instant.

James and Cecelia both have watches on their wrists. Under what circumstances will they both agree that their watches are synchronized? (Read all the answers carefully, then choose one.)

A. They can synchronize their watches if they are both in the same reference frame.

B. They can momentarily synchronize their watches if they are in the same place.

C. A and B. That is, they can only synchronize their watches if they are in the same reference frame AND in the same place.

D. A or B. That is, they can synchronize their watches if they are in the same reference frame, OR if they are in the same place for an instant.

Solution: D

1.5 Velocity Transformations and the Doppler Effect

The Lorentz transformation for finding v'_x has two variables in it, v_x and u. Both of them are velocities in the x-direction. What is the relationship between them? (Choose one.)

A. They are the same.

$B.$ v_x is always greater than u.

$C.$ v_x is always less than u.

D. They are completely independent of each other.

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Solution: D

Two observers are moving with respect to each other in the y direction only. Both of them are measuring a third object that is moving independent of them. Which of the following will the two observers always agree on? (Choose all that apply.)

A. The x-position of that object.

B. The y-position of that object.

C. The time that passes between the birth and death of that object.

D. The horizontal (x-direction) velocity of that object.

E. The vertical (y-direction) velocity of that object.

F. The speed of that object.

G. The color of that object.

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Solution: Only A

An object moving toward you is emitting light of wavelength λ. The wavelength you will see is… (Choose one.)

A. less than λ

B. exactly λ

C. greater than λ

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A. less than λ

B. exactly λ

C. greater than λ

Solution: A

We often say that c is "the speed of light" but it should more properly be called "the speed of light *in a vacuum*." Inside matter, light moves slower than c. For example, light moves through water at 0.77 c. Now, suppose a beam of light is traveling through the Atlantic ocean from England to America. An observer, flying over the ocean in a rocket, will measure the speed of that light beam. . . (Choose one.)

A. faster than 0.77 c.

B. slower than 0.77 c.

C. exactly 0.77 c.

D. It depends on whether the rocket is going in the same direction as the light beam, or the opposite.

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C. exactly 0.77 c.

D. It depends on whether the rocket is going in the same direction as the light beam, or the opposite.

Solution: D

You are standing at rest on the ground. Object A is shining a light while moving towards you at half the speed of light. Object B is playing a sound while moving towards you at half the speed of sound. Which one experiences a greater Doppler shift (fractional shift in frequency)?

A. the light

B. the sound?

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A. the light

B. the sound?

Solution: B