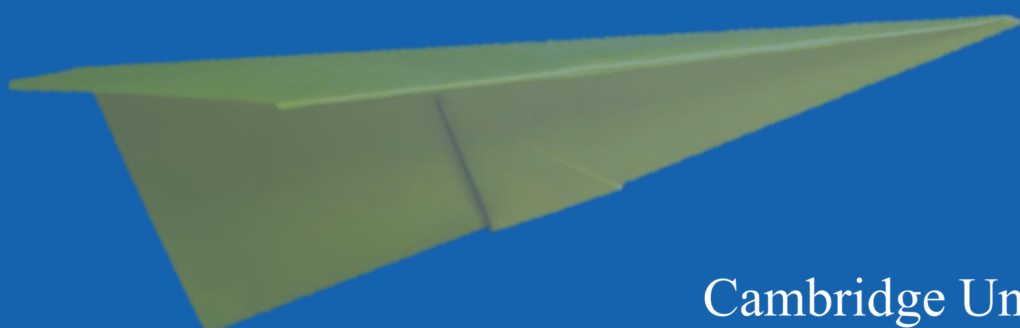
# Clicker Questions

## *Modern Physics*

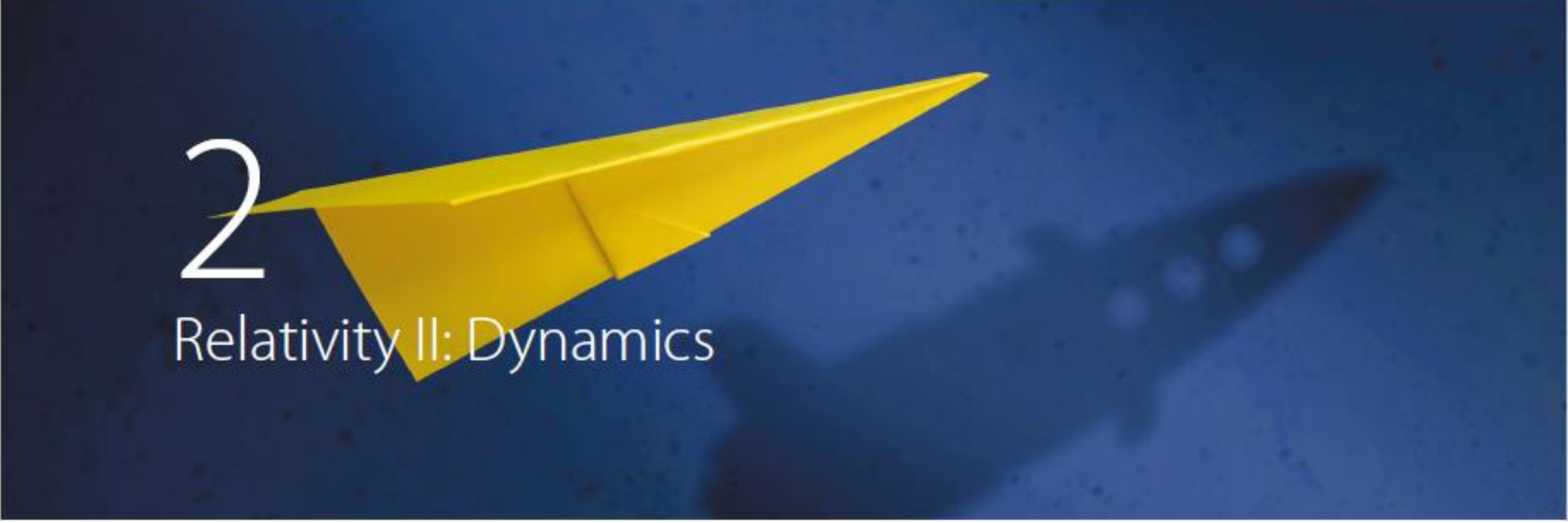
by Gary Felder and Kenny Felder



Cambridge University Press
cambridge.org/core/resources/felder-modernphysics/
felderbooks.com

# 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.



# 2

# Relativity II: Dynamics

## 2.1 Spacetime Diagrams

What slope does the world line of an object have if the object is moving at 0.1 $c$? (Choose one.)

A. 0

B. 0.1

C. 1

D. 10

E. None of the above

What slope does the world line of an object have if the object is moving at 0.1 $c$? (Choose one.)

A. 0

B. 0.1

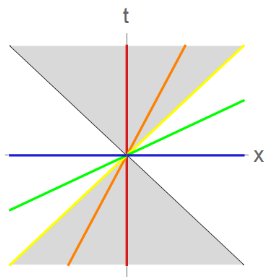
C. 1

D. 10

E. None of the above

**Solution:** D ($-10$ would also have been a valid answer, but we didn't give it as a choice.)

Which of the following represent possible world lines for a person? (Choose all that apply.)




A. Red

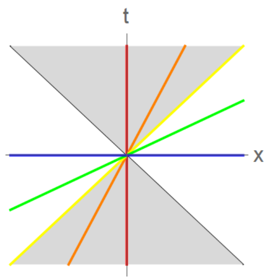
B. Orange

C. Yellow

D. Green

E. Blue

Which of the following represent possible world lines for a person? (Choose all that apply.)




A. Red

B. Orange

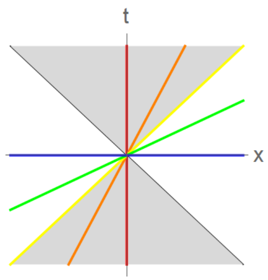
C. Yellow

D. Green

E. Blue

**Solution:** A, B

Which of the following represent possible world lines for a radio message traveling through space? (Choose one.)




A. Red

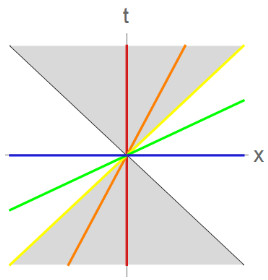
B. Orange

C. Yellow

D. Green

E. Blue

Which of the following represent possible world lines for a radio message traveling through space? (Choose one.)




A. Red

B. Orange

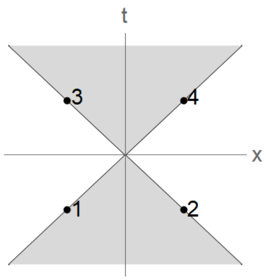
C. Yellow

D. Green

E. Blue

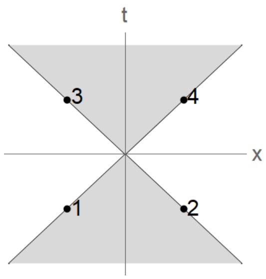
**Solution:** C

For each pair of points given below, is their separation A) spacelike, B) timelike, or C) lightlike?




1. 1 and 2
2. 1 and 3
3. 1 and 4
4. 2 and 3

For each pair of points given below, is their separation A) spacelike, B) timelike, or C) lightlike?




1. 1 and 2

   **Solution:** A

2. 1 and 3

   **Solution:** B

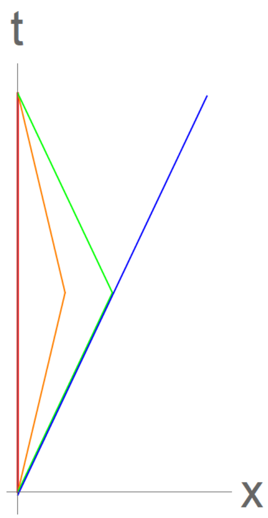
3. 1 and 4

   **Solution:** C

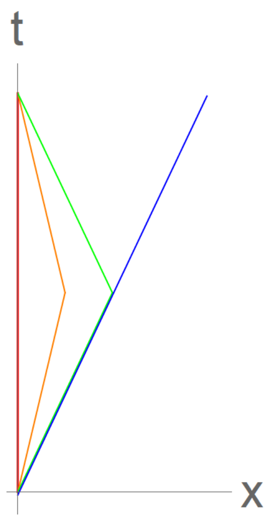
4. 2 and 3

   **Solution:** C

Rank all of the world lines in the spacetime diagram below (red, orange, green, blue) from shortest to longest proper time. (It's possible that some may be equal.)



Rank all of the world lines in the spacetime diagram below (red, orange, green, blue) from shortest to longest proper time. (It's possible that some may be equal.)




**Solution:** RED, ORANGE, GREEN=BLUE

## 2.2 Momentum and Energy

Why can't we just use $p = mv$ and $K = (1/2)mv^2$ in relativity? (Choose the best answer.)

A. They can't be derived from Einstein's postulates.

B. They don't have the right units.

C. They couldn't be conserved in all inertial reference frames.

D. There's nothing wrong with them except that experiments show that they aren't conserved at high speeds.

Why can't we just use $p = mv$ and $K = (1/2)mv^2$ in relativity? (Choose the best answer.)

A. They can't be derived from Einstein's postulates.

B. They don't have the right units.

C. They couldn't be conserved in all inertial reference frames.

D. There's nothing wrong with them except that experiments show that they aren't conserved at high speeds.

**Solution:** C

To determine the outcome of an elastic collision in classical mechanics, you set the initial momentum and energy equal to the final momentum and energy and then solve. In relativity. . . (Choose one.)

A. The process is exactly the same.

B. The overall process is the same, but the formulas for momentum and energy are different.

C. The process itself is different.

To determine the outcome of an elastic collision in classical mechanics, you set the initial momentum and energy equal to the final momentum and energy and then solve. In relativity. . . (Choose one.)

A. The process is exactly the same.

B. The overall process is the same, but the formulas for momentum and energy are different.

C. The process itself is different.

**Solution:** B

You are sitting in a car with a spring on your lap. The spring is at its natural (or relaxed) length. Which of the following change the mass of the spring? (Choose all that apply.)

A. You turn on the car's air conditioning so that the air, and eventually the spring, get colder.

B. You put rubber bands around the spring, forcing it to compress. (Count only the mass of the spring, not of the rubber bands.)

C. You start driving so that the car, and you, and the spring, are all now going 60 mph along a completely flat road.

D. You drive to the top of a hill.

You are sitting in a car with a spring on your lap. The spring is at its natural (or relaxed) length. Which of the following change the mass of the spring? (Choose all that apply.)

A. You turn on the car's air conditioning so that the air, and eventually the spring, get colder.

B. You put rubber bands around the spring, forcing it to compress. (Count only the mass of the spring, not of the rubber bands.)

C. You start driving so that the car, and you, and the spring, are all now going 60 mph along a completely flat road.

D. You drive to the top of a hill.

**Solution:** A and B

1. Does a photon (particle of light) have mass?
2. Does a photon have energy?

1. Does a photon (particle of light) have mass?

   **Solution:** no

2. Does a photon have energy?

   **Solution:** yes

When a photon (particle of light) passes through matter its interactions with particles cause it to slow down below $c$, the speed of light in a vacuum. As it passes through matter, is a photon still massless?

When a photon (particle of light) passes through matter its interactions with particles cause it to slow down below $c$, the speed of light in a vacuum. As it passes through matter, is a photon still massless?

**Solution:** No

Two objects are floating in space orbiting each other. You fly up in your rocket and pull them farther apart, and then leave. (Assume you leave them each with the same velocities they had before you arrived.) Does the mass of the two-object system …

A. decrease?

B. increase?

C. stay the same?

Two objects are floating in space orbiting each other. You fly up in your rocket and pull them farther apart, and then leave. (Assume you leave them each with the same velocities they had before you arrived.) Does the mass of the two-object system …

A. decrease?

B. increase?

C. stay the same?

**Solution:** B (increases)

Four protons deep within the sun fuse together to form a helium nucleus, emitting radiation in the process. *Note:* You do not have to Google any trivia about protons, or helium nuclei, to answer this question. The fact that they fuse tells you everything you need.

1. What effect does fusing have on the potential energy of the four-particle system? (Choose one and explain.)

   A. The potential energy increases.

   B. The potential energy stays the same.

   C. The potential energy decreases.

2. How does the mass of the resulting helium nucleus compare to the sum of the masses of the four protons before the fusion? (Choose one and explain)

   A. The helium nucleus has more mass than the four protons combined.

   B. The helium nucleus has the same mass as the four protons combined.

   C. The helium nucleus has less mass than the four protons combined.

Four protons deep within the sun fuse together to form a helium nucleus, emitting radiation in the process. *Note:* You do not have to Google any trivia about protons, or helium nuclei, to answer this question. The fact that they fuse tells you everything you need.

1. What effect does fusing have on the potential energy of the four-particle system? (Choose one and explain.)

   A. The potential energy increases.

   B. The potential energy stays the same.

   C. The potential energy decreases.

   **Solution:** C

2. How does the mass of the resulting helium nucleus compare to the sum of the masses of the four protons before the fusion? (Choose one and explain)

   A. The helium nucleus has more mass than the four protons combined.

   B. The helium nucleus has the same mass as the four protons combined.

   C. The helium nucleus has less mass than the four protons combined.

   **Solution:** C

Which of the following equations are valid for a massive particle? (Choose all that apply.)

A. $p = \gamma m v$

B. $E = \gamma m c^2$

C. $E^2 = p^2 c^2 + m^2 c^4$

D. $E = pc$

Which of the following equations are valid for a massive particle? (Choose all that apply.)

A. $p = \gamma m v$

B. $E = \gamma m c^2$

C. $E^2 = p^2c^2 + m^2c^4$

D. $E = pc$

**Solution:** A, B, and C

If you apply the equation $p = \gamma m v$ to a photon (a particle of light)... (Choose one.)

A. It tells you correctly how to find the momentum of a photon.

B. It tells you the momentum of a photon, but its answer is not valid.

C. It gives you $0/0$, which doesn't really tell you anything.

If you apply the equation $p = \gamma m v$ to a photon (a particle of light)... (Choose one.)

A. It tells you correctly how to find the momentum of a photon.

B. It tells you the momentum of a photon, but its answer is not valid.

C. It gives you $0/0$, which doesn't really tell you anything.

**Solution:** C

## 2.3 Mass and Energy (and the Speed of Light Squared)

Choose True or False for each of the following.

1. A 1 kg object and a 3 kg object between them must have 4 kg of mass.
2. A 1 J object and a 3 J object between them must have 4 J of energy.
3. If one inertial observer measures that a system has 10 kg of mass then all inertial observers must get the same result.
4. If one inertial observer measures that a system has 10 J of energy then all inertial observers must get the same result.
5. If an isolated system starts a process with 10 J of energy then it must end the process with that same amount.
6. If an isolated system starts a process with 10 kg of mass then it must end the process with that same amount.

Choose True or False for each of the following.

1. A 1 kg object and a 3 kg object between them must have 4 kg of mass.

   **Solution:** F

2. A 1 J object and a 3 J object between them must have 4 J of energy.

   **Solution:** T

3. If one inertial observer measures that a system has 10 kg of mass then all inertial observers must get the same result.

   **Solution:** T

4. If one inertial observer measures that a system has 10 J of energy then all inertial observers must get the same result.

   **Solution:** F

5. If an isolated system starts a process with 10 J of energy then it must end the process with that same amount.

   **Solution:** T

6. If an isolated system starts a process with 10 kg of mass then it must end the process with that same amount.

   **Solution:** T

True or False? If I know an object's energy and momentum I can find its total mass.

True or False? If I know an object's energy and momentum I can find its total mass.

**Solution:** T

A rocket flies past you. You and the captain both measure things about the rocket. Which of the following will you *agree* about? (Check all that apply.)

A. The rocket's mass.

B. The rocket's momentum.

C. The rocket's kinetic energy.

D. The rocket's total energy.

A rocket flies past you. You and the captain both measure things about the rocket. Which of the following will you *agree* about? (Check all that apply.)

A. The rocket's mass.

B. The rocket's momentum.

C. The rocket's kinetic energy.

D. The rocket's total energy.

**Solution:** Only A

For each of the following pairs say whether A) A is higher, B) B is higher, or C) the two are equal.

1. A is the mass of a particle at rest. B is the mass of that same particle moving at $c/2$.
2. A is the energy of a particle at rest. B is the energy of that same particle moving at $c/2$.
3. A is the total system mass of two particles before they collide. B is the total system mass after they collide and stick together. (Assume the system is isolated.)

For each of the following pairs say whether A) A is higher, B) B is higher, or C) the two are equal.

1. A is the mass of a particle at rest. B is the mass of that same particle moving at $c/2$.

   **Solution:** C

2. A is the energy of a particle at rest. B is the energy of that same particle moving at $c/2$.

   **Solution:** B is higher

3. A is the total system mass of two particles before they collide. B is the total system mass after they collide and stick together. (Assume the system is isolated.)

   **Solution:** C

P1 and P2 are fundamental particles of mass $m$ and L is a photon.

1. Can the system of P1 and P2 have a mass greater than $2m$?
2. Can the system of P1 and P2 have a mass less than $2m$?
3. Can the system of P1 and L have a mass other than $m$?

P1 and P2 are fundamental particles of mass $m$ and L is a photon.

1. Can the system of P1 and P2 have a mass greater than $2m$?

   **Solution:** Yes, if P1 and P2 are moving relative to each other.

2. Can the system of P1 and P2 have a mass less than $2m$?

   **Solution:** Yes, if they have a negative potential energy. For example, a helium nucleus has a smaller mass than the sum of its four components.

3. Can the system of P1 and L have a mass other than $m$?

   **Solution:** Yes. The photon has momentum in any reference frame. So the rest frame of the system is one in which P1 has an equal and opposite momentum, and in that frame, the total kinetic energy of the system is certainly not zero.

A photon strikes an object and gets absorbed.

1. Does the object's mass increase?
2. Does the total mass of the system (object plus photon) increase?

A photon strikes an object and gets absorbed.

1. Does the object's mass increase?

   **Solution:** Yes. Any increase in energy implies an increase in mass.

2. Does the total mass of the system (object plus photon) increase?

   **Solution:** No, that's a conserved quantity.

A photon of energy $E_{ph}$ is absorbed by an atom of mass $m_0$ at rest. Is the final mass of the atom …

A. $m_0$?

B. Greater than $m_0$ but less than $m_0 + E_{ph}/c^2$?

C. $m_0 + E_{ph}/c^2$?

D. Greater than $m_0 + E_{ph}/c^2$?

A photon of energy $E_{ph}$ is absorbed by an atom of mass $m_0$ at rest. Is the final mass of the atom …

A. $m_0$?

B. Greater than $m_0$ but less than $m_0 + E_{ph}/c^2$?

C. $m_0 + E_{ph}/c^2$?

D. Greater than $m_0 + E_{ph}/c^2$?

**Solution:** B

## 2.4 Four-Vectors

A scalar describing an object is ... (Choose one.)

A. greatest in the reference frame in which the object is at rest

B. smallest in the reference frame in which the object is at rest

C. equal in all inertial reference frames

A scalar describing an object is . . . (Choose one.)

A. greatest in the reference frame in which the object is at rest

B. smallest in the reference frame in which the object is at rest

C. equal in all inertial reference frames

**Solution:** C

Which of the following are scalars? (Choose all that apply.)

A. An object's mass

B. An object's energy

C. An object's height

D. An object's color (frequency of light you receive when looking at it)

Which of the following are scalars? (Choose all that apply.)

A. An object's mass

B. An object's energy

C. An object's height

D. An object's color (frequency of light you receive when looking at it)

**Solution:** A only

Which of the following are guaranteed to be true of a four-vector? (Choose all that apply.)

A. Its components are the same in all reference frames.

B. Its components transform according to the Lorentz transformations.

C. If you multiply it by a scalar you get another four-vector.

D. There is always some reference frame in which its magnitude is zero.

Which of the following are guaranteed to be true of a four-vector? (Choose all that apply.)

A. Its components are the same in all reference frames.

B. Its components transform according to the Lorentz transformations.

C. If you multiply it by a scalar you get another four-vector.

D. There is always some reference frame in which its magnitude is zero.

**Solution:** B, C

Suppose $\mathbf{V_A}$ and $\mathbf{V_B}$ are four-vectors and $S$ is a scalar. Which of the following is a four-vector? (Choose all that apply.)

**A.** $\mathbf{V_A} + \mathbf{V_B}$

*B.* $S\mathbf{V_A}$

*C.* $V_{Bt}\mathbf{V_A}$

*D.* $d\mathbf{V_A}/dt$

Suppose $\mathbf{V_A}$ and $\mathbf{V_B}$ are four-vectors and $S$ is a scalar. Which of the following is a four-vector? (Choose all that apply.)

**A.** $\mathbf{V_A} + \mathbf{V_B}$

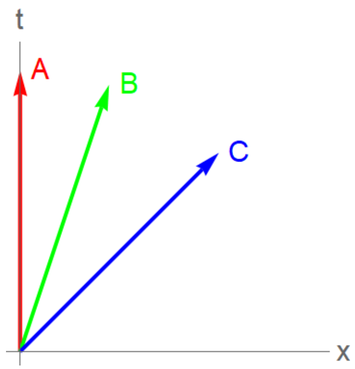
$B.$ $S\mathbf{V_A}$

$C.$ $V_{Bt}\mathbf{V_A}$

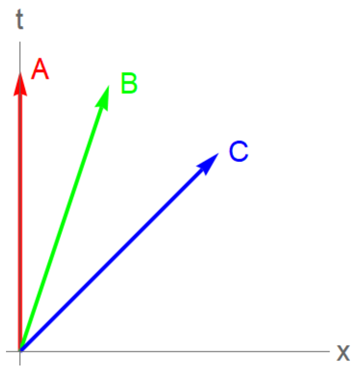
$D.$ $d\mathbf{V_A}/dt$

**Solution:** A, B

Rank the magnitudes of the four-vectors in the image below from largest to smallest. (They all have the same length on the diagram, and their magnitudes are not all equal.) Explain how you know.



Rank the magnitudes of the four-vectors in the image below from largest to smallest. (They all have the same length on the diagram, and their magnitudes are not all equal.) Explain how you know.




**Solution:** A, B, C

Because magnitude is $\sqrt{V_t^2 - V_x^2}$ the time components adds and the space components subtract from the magnitude. The lightlike four-vector C has zero magnitude, and the closer you tilt towards the vertical the larger it gets. (For spacelike four-vectors the magnitude would be imaginary.)

What does it tell you about a four-vector, drawn on a spacetime diagram, if its magnitude is imaginary? (Choose one.)

A. The vector points downward—that is, in the direction of negative time.

B. The vector has an angle below 45°, pointing in a spacelike direction.

C. The vector has an angle above 45°, pointing in a timelike direction.

D. This is mathematically impossible.

What does it tell you about a four-vector, drawn on a spacetime diagram, if its magnitude is imaginary? (Choose one.)

A. The vector points downward—that is, in the direction of negative time.

B. The vector has an angle below 45°, pointing in a spacelike direction.

C. The vector has an angle above 45°, pointing in a timelike direction.

D. This is mathematically impossible.

**Solution:** B. It means the spatial component is bigger than $c$ times the time component, so it points in a spacelike direction.

Would $d\mathbf{P}/dm$ be a four-vector or not? Explain briefly how you know.

Would $d\mathbf{P}/dm$ be a four-vector or not? Explain briefly how you know.

**Solution:** Yes

This is really a partial derivative in which the particle's velocity is being held constant while its mass is increased. How would that affect the four-momentum? If you think of it as a comparison between two different particles with identical velocities and different masses, then you can see that each one has a four-momentum, so the difference $\mathbf{dP}$ is also a four-vector. Since their masses are scalar everyone will agree on the difference $\Delta m$. So $\mathbf{dP}/dm$ is a four-vector divided by a scalar, and therefore a four-vector.

There's also a much simpler answer that doesn't really have as much to do with the properties of four-vectors. The only $m$ dependence in $\mathbf{P}$ is a constant multiplied in front of everything, so $d\mathbf{P}/dm = d\mathbf{R}/d\tau$, which we know is a four-vector.

## 2.5 More about the Michelson-Morley

The Michelson-Morley experiment was designed to measure. . . (Choose one.)

A. The way light travels at different speeds in different directions.

B. The way time intervals differ in different reference frames.

C. The way a beam of light carries momentum and energy.

D. The way the energy of a beam of light depends on its frequency (or wavelength).

The Michelson-Morley experiment was designed to measure. . . (Choose one.)

A. The way light travels at different speeds in different directions.

B. The way time intervals differ in different reference frames.

C. The way a beam of light carries momentum and energy.

D. The way the energy of a beam of light depends on its frequency (or wavelength).

**Solution:** A

The Michelson interferometer measured the difference in two light beam's speeds by measuring… (Choose one.)

A. Which one got to the eyepiece first.

B. Which one conveyed more momentum to the eyepiece.

C. Whether they arrived at the eyepiece out of phase.

The Michelson interferometer measured the difference in two light beam's speeds by measuring. . . (Choose one.)

A. Which one got to the eyepiece first.

B. Which one conveyed more momentum to the eyepiece.

C. Whether they arrived at the eyepiece out of phase.

**Solution:** C

Michelson and Morley rotated their apparatus because. . . (Choose one.)

A. They expected the speed of light to be different when their apparatus was in motion.

B. The rotational motion damped out vibrations.

C. They expected to see different interference patterns in different orientations.

D. They couldn't know the direction of Earth's rotation accurately enough.

Michelson and Morley rotated their apparatus because. . . (Choose one.)

A. They expected the speed of light to be different when their apparatus was in motion.

B. The rotational motion damped out vibrations.

C. They expected to see different interference patterns in different orientations.

D. They couldn't know the direction of Earth's rotation accurately enough.

**Solution:** C

Why did the Michelson-Morley experiment have to be repeated six months later? (Choose the best answer.)

A. Good experiments should always be repeated to guard against error.

B. Six months later the Earth would be pointing a different way, effectively rotating the apparatus.

C. They wanted to account for possible changes in the aether over time.

D. They wanted to account for possible motion of the solar system through space.

E. Michelson needed more grant funding.

Why did the Michelson-Morley experiment have to be repeated six months later? (Choose the best answer.)

A. Good experiments should always be repeated to guard against error.

B. Six months later the Earth would be pointing a different way, effectively rotating the apparatus.

C. They wanted to account for possible changes in the aether over time.

D. They wanted to account for possible motion of the solar system through space.

E. Michelson needed more grant funding.

**Solution:** D