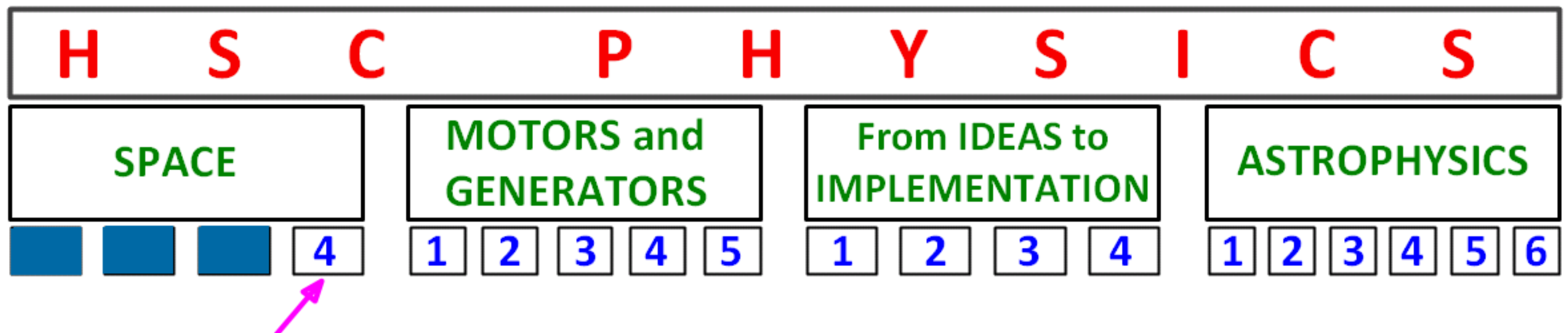


SPACE

1st Quarter; Module 1

PERIOD 26

Length Contraction, Relativity of Simultaneity



Space 4

Current and emerging understanding about time and space has been dependent upon earlier models of the transmission of light

Students learn to:

- outline the features of the aether model for the transmission of light
- describe and evaluate the Michelson-Morley attempt to measure the relative velocity of the Earth through the aether
- discuss the role of the Michelson-Morley experiments in making determinations about competing theories
- outline the nature of inertial frames of reference
- discuss the principle of relativity
- describe the significance of Einstein's assumption of the constancy of the speed of light
- identify that if c is constant then space and time become relative
- discuss the concept that length standards are defined in terms of time in contrast to the original metre standard
- explain qualitatively and quantitatively the consequence of special relativity in relation to:
 - the relativity of simultaneity
 - the equivalence between mass and energy
 - length contraction
 - time dilation
 - mass dilation
- discuss the implications of mass increase, time dilation and length contraction for space travel

Space 4

Current and emerging understanding about time and space has been dependent upon earlier models of the transmission of light

Students:

- gather and process information to interpret the results of the Michelson-Morley experiment
- perform an investigation to help distinguish between non-inertial and inertial frames of reference
- analyse and interpret some of Einstein's thought experiments involving mirrors and trains and discuss the relationship between thought and reality
- analyse information to discuss the relationship between theory and the evidence supporting it, using Einstein's predictions based on relativity that were made many years before evidence was available to support it
- solve problems and analyse information using:

$$E = mc^2$$

$$l_v = l_0 \sqrt{1 - \frac{v^2}{c^2}}$$

$$t_v = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$m_v = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

STEPS FOR RELATIVITY PROBLEMS

1. Read and Understand the question
2. Identify the two IFRs
3. Decide what is being measured [What is the incident?]
4. Decide which IFR the incident belongs to. Label the two IFRs as "proper (rest) [t_o]" and "travelling [t_v]"
5. Check if the relative velocity of IFRs is provided.
6. Pick the appropriate formula and solve for unknown.

LENGTH CONTRACTION

> another result of 'constancy of speed of light'

$$\gamma = \sqrt{1 - \left(\frac{v}{c}\right)^2}$$

↓
Lorentz factor.

$$l_v = l_0 \sqrt{1 - \frac{v^2}{c^2}}$$

$$\Rightarrow l_0 > l_v$$

l_0 = rest length, measured on the rest frame

l_v = the measurement of the rest length from a frame moving relative to rest frame.

v : relative velocity b/w frames.

Length contraction is the shortening of an object in the direction of its motion as observed from a reference frame in relative motion.

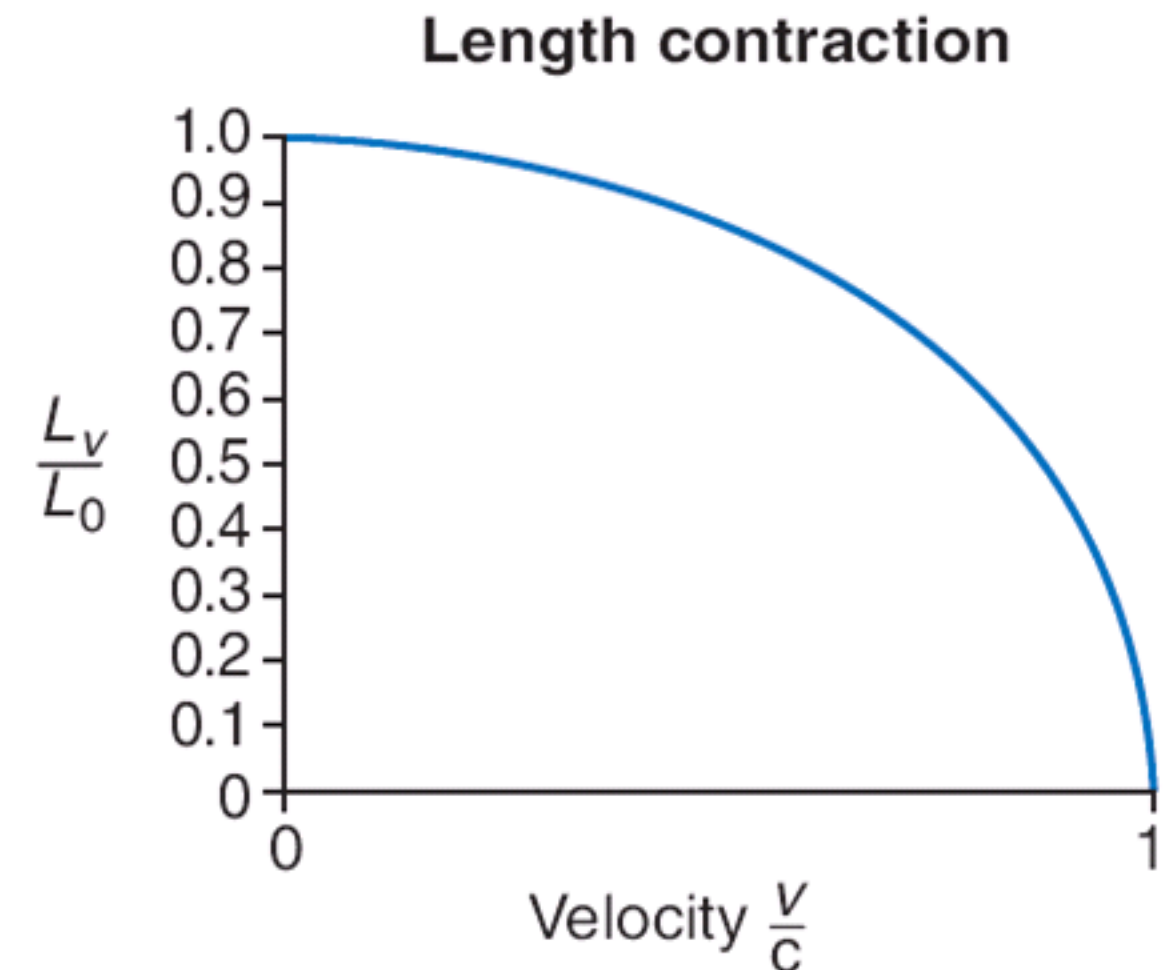
Length contraction can be generally stated as follows: the length of an object measured within its rest frame is called its proper length, L_0 , or rest length. Measurements of this length, L_v , made from any other inertial reference frame in relative motion parallel to that length, are always less.

$$L_v < L_0$$

It can be most simply stated as:

Moving objects shorten in the direction of their motion.

Notice that as velocity approaches the speed of light, the observed length approaches zero.

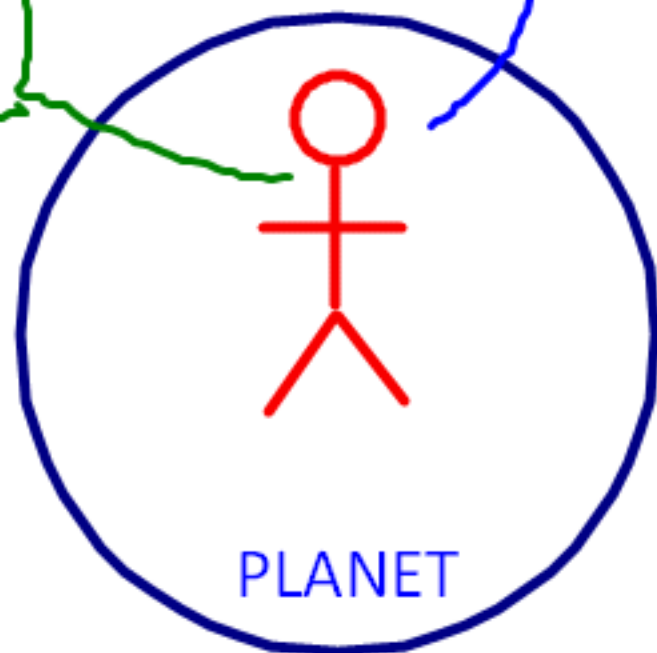


If this were a spaceship blasting past a planet at near light speed, the inhabitants of the planet would see a very short spaceship of nearly zero length, but the space travellers would notice no change at all to the length of their ship. They would, instead, briefly observe a wafer-thin planet in their windows, since from their inertial frame of reference it is the planet in rapid motion, not themselves.

$$L_v = L_0 \gamma \quad \gamma = \frac{t_0}{\tau} \quad \gamma = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

earth is
12000 km
in diameter

L_0

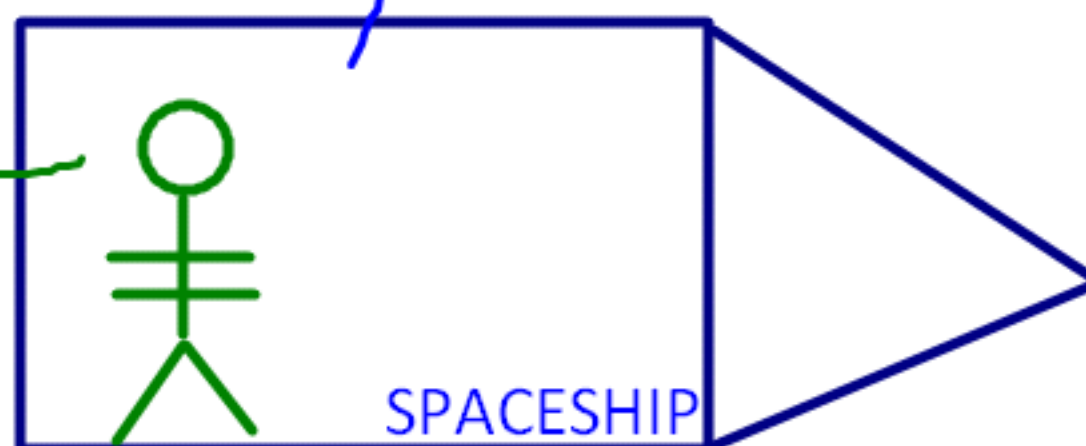


no it is
only 60m

L_v

no it is
only
8000 km

\hookrightarrow



my ship is 100m


L_0



Exercise 1: A length-contracted train

When stationary, the carriages on the state's new VVFT (very, very fast train) are each 20 m long. How long would each carriage appear to a person standing on a station platform as this express train speeds through at half the speed of light?





A diagram showing a person standing on a platform, looking at a train carriage. The person is represented by a stick figure. The train carriage is shown as a rectangle. The person's line of sight is indicated by two lines converging from the person's eyes to the front and back of the carriage. The carriage is labeled L_v in red.

$$L_v = L_0 \sqrt{1 - \left(\frac{v}{c}\right)^2}$$
$$= 20 \times \sqrt{1 - \left(\frac{0.5c}{c}\right)^2}$$
$$= 20 \times \sqrt{0.75} = 17.32 \text{ m}$$

STEPS FOR RELATIVITY PROBLEMS

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5. Check if the relative velocity of IFRs is provided.
6. Pick the appropriate formula and solve for unknown.

Exercise 2: A length-contracted person

An occupant of the VVFT looks out of a window and catches a quick glimpse of the person standing on the platform. If the thickness (from chest to back) of that person measured on the platform is 30 cm, what is the thickness observed from the train?



$$L_v = 30 \times \sqrt{1 - \left(\frac{0.5c}{c}\right)^2}$$

$$L_v = 26 \text{ cm}$$

L_v

STEPS FOR RELATIVITY PROBLEMS

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FORMULA SO FAR

$$t_v = \frac{t_0}{\gamma}$$

$$L_v = L_0 \cdot \gamma$$

$$\gamma = \sqrt{1 - \left(\frac{v}{c}\right)^2}$$

$$\gamma < 1$$

for non-relativistic
speeds $\gamma = 1$

$$t_0 = t_v$$

$$L_0 = L_v$$

$$\left(= \sqrt{1 - \frac{v^2}{c^2}} \right)$$

$$v = 0.94c$$

Exercise 3: UFOs in your backyard.

You see a flying saucer passing by Earth at $0.8c$. You measure its length to be 45 metres. What will you measure its length if it lands in your backyard.

2 frames \rightarrow 1: earth
2: saucer \rightarrow rest frame
because what we are measuring is in the saucer.

$$L_v = 45$$
$$v = 0.8c$$

$$L_0 = \frac{L_v}{\sqrt{1 - \left(\frac{0.8c}{c}\right)^2}} = 75\text{m}$$

what I measure if it lands on my backyard

or the length (rest/proper length) measured by Zogo in saucer.

STEPS FOR RELATIVITY PROBLEMS

1. Read and Understand the question
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2007 HSC QUESTION

- 2 A spaceship sitting on its launch pad is measured to have a length L . This spaceship passes an outer planet at a speed of $0.95c$.

Which observations of the length of the spaceship are correct?

	<i>Observer on the spaceship</i>	<i>Observer on the planet</i>
(A)	No change	Shorter than L
(B)	No change	Greater than L
(C)	Shorter than L	No change
(D)	Greater than L	No change

RELATIVITY OF SIMULTANEITY

> another result of 'constancy of speed of light'

Einstein contended that if an observer sees two events to be simultaneous then any other observer, in relative motion to the first, generally will not judge them to be simultaneous.

In other words, **simultaneous events in one frame of reference are not necessarily observed to be simultaneous in a different frame of reference.**

This is known as the **relativity of simultaneity.**

RELATIVITY OF SIMULTANEITY

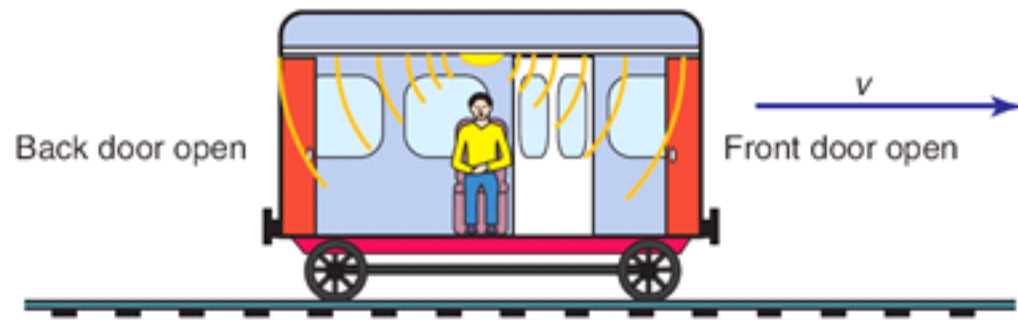
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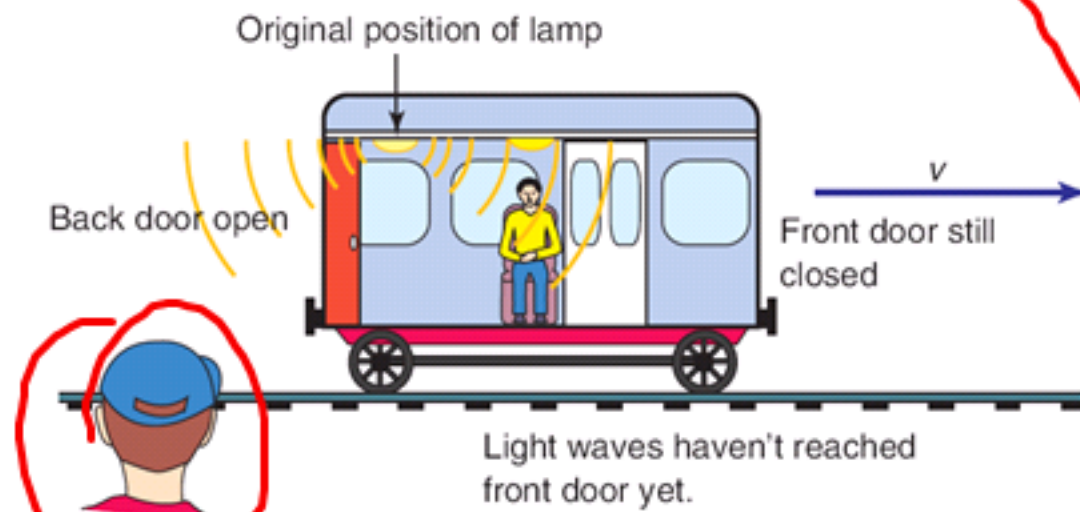
...

(a) As seen by train traveller



he sees
both doors
open simultaneously

(b) As seen by stationary observer



she

she sees back
door open first,
then front door.

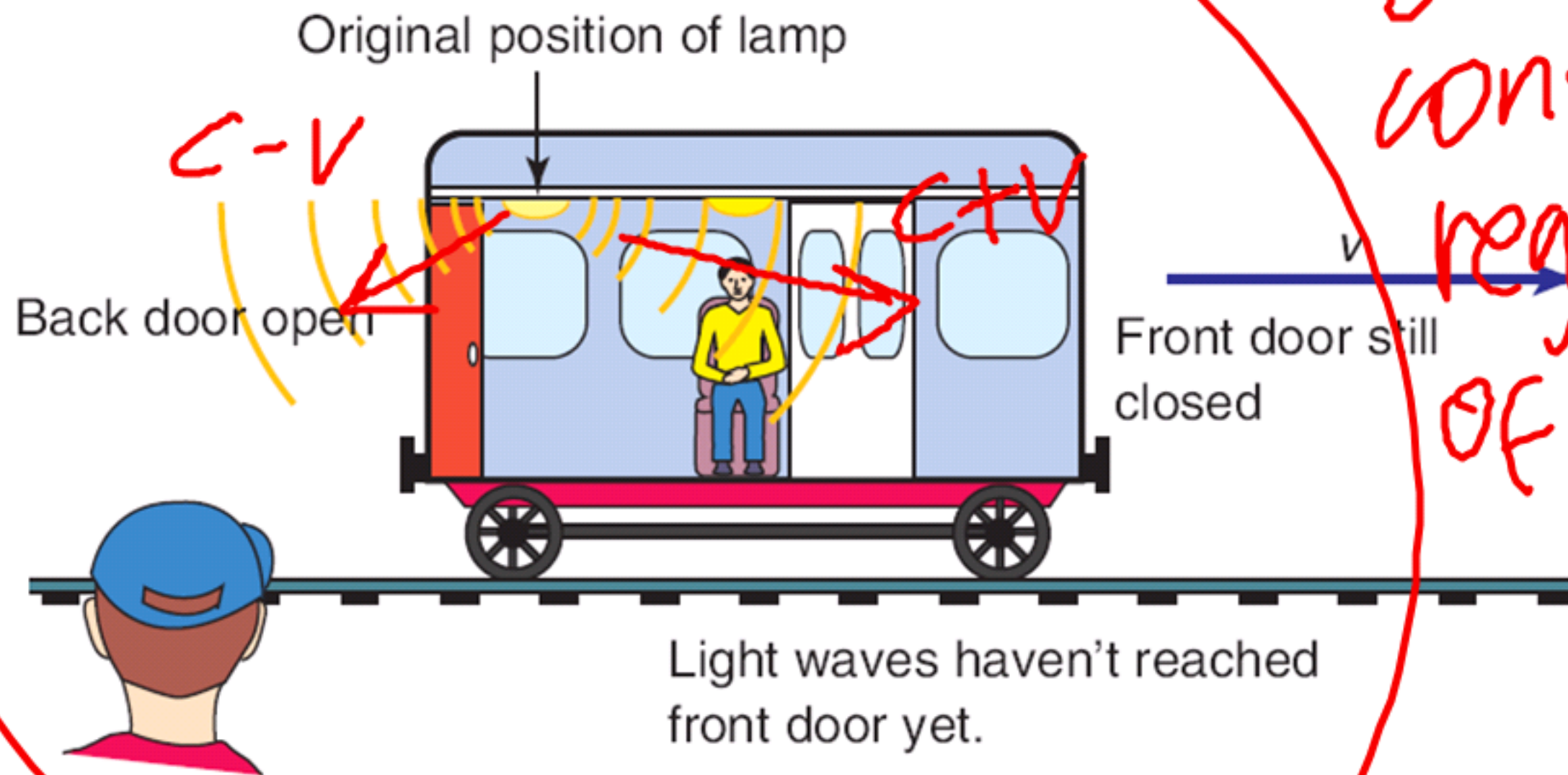
simultaneity
is

relative

"due to the
fact that
speed of light
is constant."

WHAT WOULD HAPPEN IF WE TREAT LIGHT LIKE A NORMAL WAVE OR BALL AND
ADD/SUBTRACT SPEED OF TRAIN TO FIND ITS NEW SPEED?

(b) As seen by stationary observer



this is
not happening
" " " " is
constant
regardless
of IFE.

DEFINITION OF "METRE"

- ✦ The metre as a unit of length was first defined in 1793 when the French government decreed it to be 1×10^{-7} times the length of the Earth's quadrant passing through Paris.
- ✦ When it was discovered that the quadrant survey was incorrect, the metre was redefined as the distance between two marks on a bar.
- ✦ In 1875 the Systeme Internationale (SI) of units was set up so that the definition became more formal: a metre was the distance between two lines scribed on a single bar of platinum–iridium alloy.
- ✦ There is always a need for the accuracy of a unit of measure to keep pace with improvements in technology and science, so the metre has since been redefined twice.

CURRENT DEFINITION OF METRE

- ✦ The current definition of the metre uses the constancy of the speed of light in a vacuum (299 792 458 m/s) and the accuracy of the definition of one second (9 129 631 770 oscillations of the ^{133}Cs atom), to achieve a definition that is both highly accurate and consistent with the idea of space–time.
- ✦ One metre is now defined as the length of the path travelled by light in a vacuum during the time interval of $1/299\,792\,458$ of a second.
- ✦ The term 'light-year' is a similar distance unit, being the length of the path travelled by light in a time interval of one year. One light-year is approximately equal to $9.467\,28 \times 10^{12}$ km.

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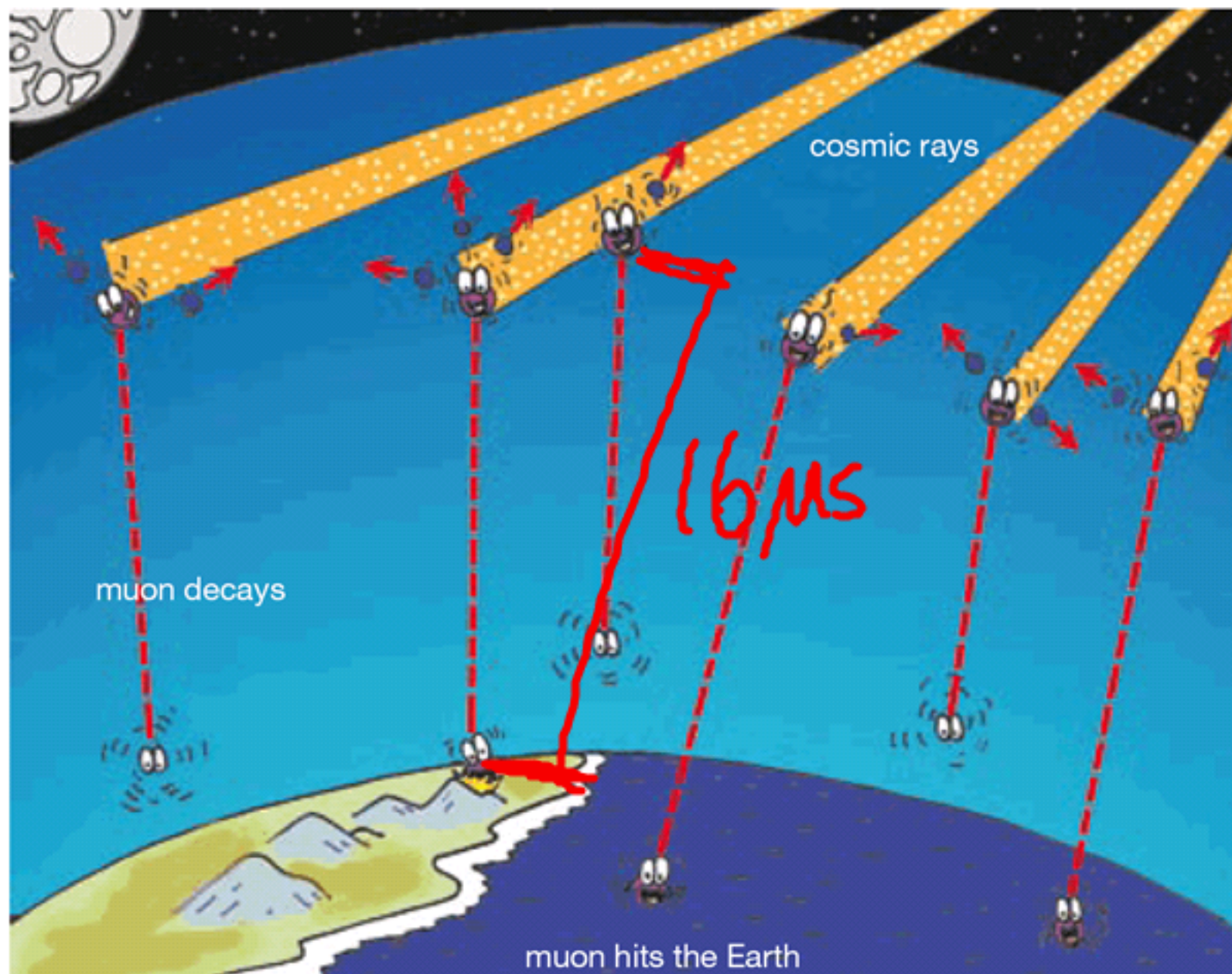
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- ✦ ...
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Proofs of Time Dilation

1. Comparison of atomic clocks that have been flown over long journeys with clocks that have remained stationary for the same period. The travelling clock was found to be lagging slightly behind the the one stayed stationery when they are brought together again. These experiments are possible only because of the extreme accuracy of atomic clocks built over the last few decades, even though Einstein predicted this effect about 100 years ago.

Proofs of Time Dilation

2. Further supporting evidence has been found in the **abundance of mesons striking the ground** after having been created in the upper atmosphere by incoming cosmic rays. What is surprising is that the mesons have a velocity of about $0.996c$ and, at that speed, should take approximately 16 microseconds to travel through the atmosphere. However, when measured in a laboratory, mesons have an average lifetime of approximately 2.2 microseconds. This anomaly can be explained by the fact that 2.2 microseconds represents their proper lifetime, as measured in their rest frame, whereas 16 microseconds is a dilated lifetime due to their relativistic speed.



$$v = 0.996c$$

rest time

$$t_0 = 2.2 \mu s$$
$$t_v = 16 \mu s$$

P25 SOLUTIONS

6.4 Time and space

1 D **2** B, C **3** D **4** **a** 1 m **b** 0.44 m **5** **a** 1 m **b** 1 m

6 **a** $0.866c$ **b** No, $0.968c$ **7** A, C **8** A, B

9 It would represent something being in many places at the same time.

10 It is very close, even up to 10% of c . It breaks down beyond about 25% of c .

11 $\gamma = 1 + 3.6 \times 10^{-10} = 1.000\,000\,000\,36$.

P26 H/W

Multiple-choice questions

- Newton's second law of motion states that the acceleration of a body is proportional to the force applied. In which way does this law strongly support the principle of relativity?
 - Because a force produces an acceleration, it results in a certain velocity. This velocity is quite independent of the frame of reference.
 - Because a certain force produces a certain velocity which is independent of the frame of reference.
 - Because a force produces an acceleration, it causes a change in velocity. The actual change of velocity is dependent on the frame of reference.
 - Because a force produces an acceleration, it causes a change in velocity. The actual velocity does not matter and so the law is quite independent of the frame of reference.
- Galileo tried to measure the speed of light by having an assistant uncover a lamp on a hill about 2 km away when he saw the light from Galileo's lamp. Which of the following is a reasonable estimate of the minimum value for the speed of light which Galileo could have measured using this technique?
 - 40 m s^{-1}
 - $4 \times 10^4 \text{ m s}^{-1}$
 - $4 \times 10^6 \text{ m s}^{-1}$
 - $3 \times 10^8 \text{ m s}^{-1}$
- Why was Maxwell so convinced that light was an electromagnetic wave?
 - His equations showed that electromagnetic waves would travel at the same speed as light.
 - His equations showed that electromagnetic waves would affect the path of light.
 - He did many experiments and found that the speed of electromagnetic waves was the same as that of light.
 - He did many experiments and found that light was bent by strong magnetic fields.
- In 1905 Einstein put forward two postulates. Which two of the following best summarise them?
 - All observers will find the speed of light to be the same.
 - In the absence of a force, motion continues with constant velocity.
 - There is no way to detect an absolute zero of velocity.
 - Absolute velocity can only be measured relative to the aether.
- Was Einstein's first postulate inconsistent with the physics of the time?
 - No, it had already been stated by Galileo.
 - No, it was simply an extension of Galileo's principle of relativity to include electromagnetism as well.

- Yes, it went against Newton's laws.
 - Yes, it was a completely new principle which had not been thought of before Einstein.
- Which one of the following best represents the basis of Einstein's considerations, which eventually led to the theory of special relativity?
 - The results of numerous experiments to determine the speed of light.
 - The work of Isaac Newton and Michael Faraday.
 - His consideration of the consequences of accepting the implications of Maxwell's equations.
 - His own experiments in electromagnetism.
 - Which of the following is closest to Einstein's first postulate?
 - Light always travels at $3 \times 10^8 \text{ m s}^{-1}$.
 - There is no way to tell how fast you are going unless you can see what's around you.
 - Velocities can only be measured relative to something else.
 - Absolute velocity is that measured with respect to the Sun.
 - Which one or more of the following statements (which are all true in classical physics) was particularly inconsistent with Einstein's second postulate (that the speed of light is the same for all observers)?
 - A net force on an object produces an acceleration.
 - There is no frame of reference in which there is an absolute zero of velocity.
 - The principle of relativity said that the speed of light should depend on the speed of the observer.
 - The principle of relativity said that the speed of light should depend on the speed of the light source.
 - You are travelling from Earth towards Alpha Proxima. You notice that you are getting closer to another spaceship which remains directly in line with Alpha Proxima. Which one or more of the following could be true? This other ship:
 - could be travelling towards Earth
 - could be travelling towards Alpha Proxima more slowly than you
 - could be stationary between Earth and Alpha Proxima
 - must be heading towards Earth.
 - You are in interstellar space and know that your velocity relative to Earth is $4 \times 10^6 \text{ m s}^{-1}$ away from it. You then notice another spacecraft with a velocity, towards you, of $4 \times 10^5 \text{ m s}^{-1}$. Which one or more of the following best describes the velocity of the other craft?
 - Away from Earth at $3.6 \times 10^6 \text{ m s}^{-1}$
 - Towards Earth at $3.6 \times 10^6 \text{ m s}^{-1}$
 - Away from Earth at $4.4 \times 10^6 \text{ m s}^{-1}$
 - Towards Earth at $4.4 \times 10^6 \text{ m s}^{-1}$

HOMEWORK

- ✦ Homework is an integral part of your "Learning Curve", take it seriously!
- ✦ Target minimum 1 hour of Physics everyday
- ✦ Divide your physics home study in three segments;
 - ✓ Revision (past)
 - ✓ Homework (present)
 - ✓ Tomorrow (future)
- ✦ Homework is due next period, unless otherwise stated
- ✦ If you cannot do all, at least do a few from each piece

*Apart from **reading the relevant pages from the textbook and solving the rest of the questions in this booklet**
your homework is:*

- ✓ Study CSU Space 4 notes
- ✓ New questions in this booklet
- ✓ Relevant pages in Multiple Choice Dot Points Book (DPB). Bring the book for Monday.
- ✓ Space 4 Past year questions
- ✓ Chapter 5 questions 1-20

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NEXT PERIOD > MASS DILATION