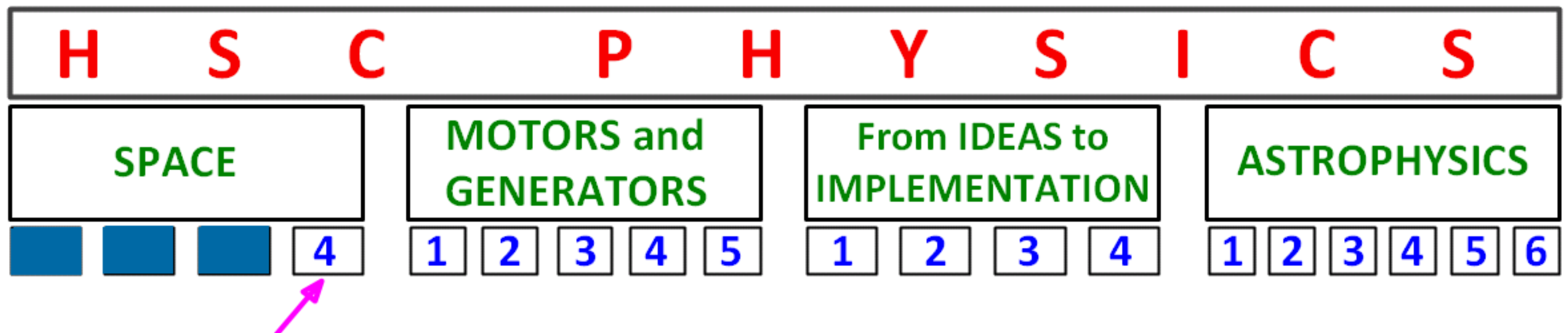


# SPACE

1<sup>st</sup> Quarter; Module 1

## PERIOD 25

Time Dilation, Relativity of Simultaneity, Length Contraction



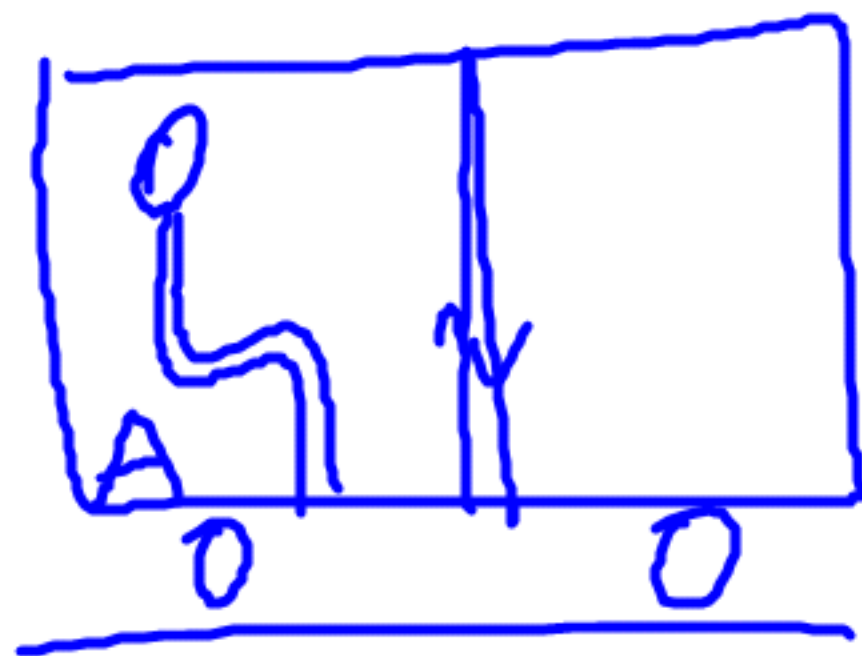
## STEPS FOR RELATIVITY PROBLEMS

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.

## Time Dilation Formula

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

$$t_v > t_0$$



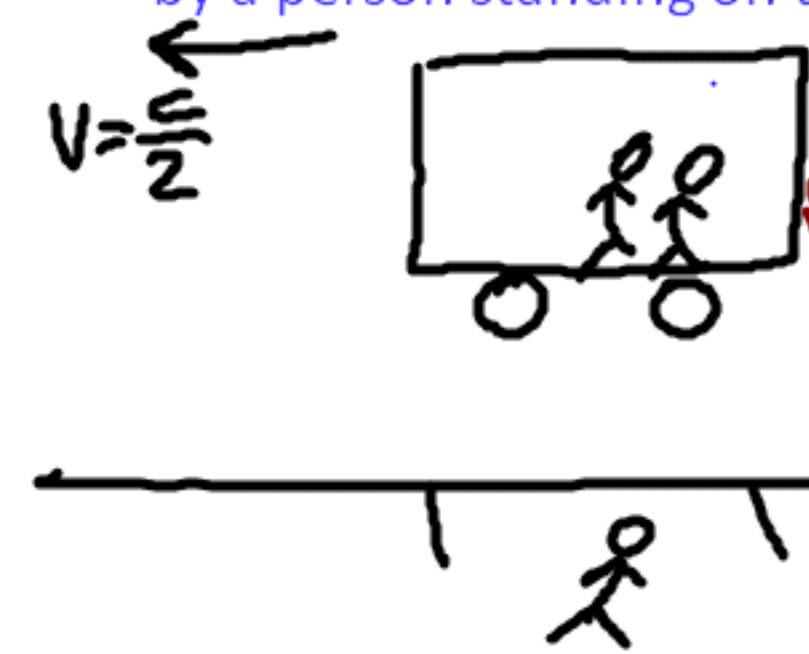
$t_0$  = the time recorded by an observer in the rest frame (in the frame where the incident is taking place) = Proper time

$t_v$  = the time recorded for the same incident by an observer travelling relative to rest frame

$v$  = relative velocity w/v the frames.

### Example 1: A time-dilated sneeze

A train traveller sneezes just as his train passes through a station. The sneeze takes precisely 1.000 s as measured by another person seated next to the sneezer. If the train is travelling at half the speed of light, how long does the sneeze take as seen by a person standing on the platform of the station?



1<sup>st</sup> IFR: train & people inside

2<sup>nd</sup> IFR: the platform & earth

incident = the length of sneeze?

is taking place in the train.

$$t_0 = 1\text{ s}$$

$$v = \frac{c}{2}$$

$$t_v = \frac{t_0}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = \frac{1}{\sqrt{1 - \left(\frac{c/2}{c}\right)^2}} = \frac{1}{\sqrt{1 - 0.25}}$$

$$> \frac{1}{\sqrt{0.75}} = 1.15\text{ s}$$

$$t_v > t_0 \quad \checkmark$$

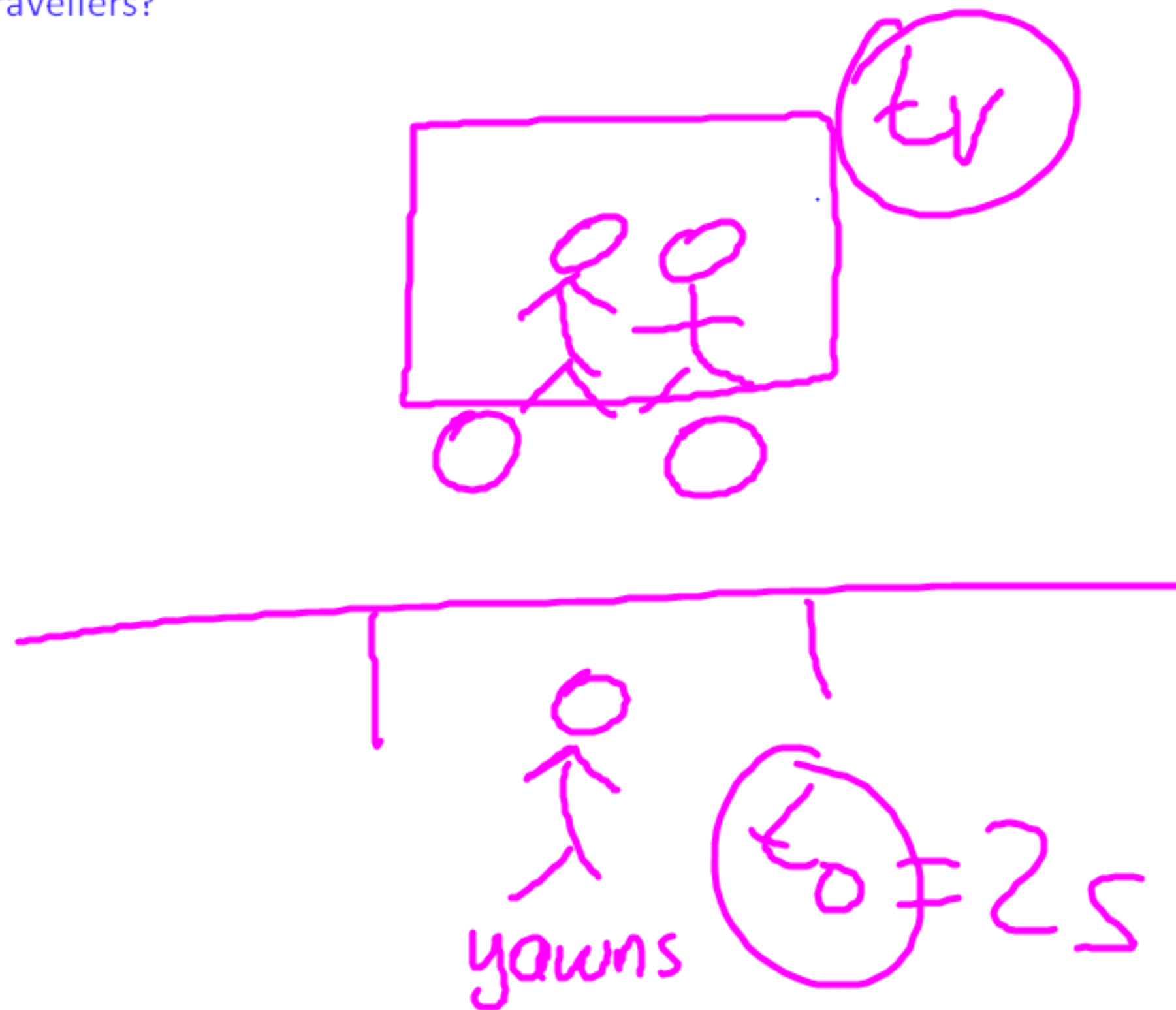
### STEPS FOR RELATIVITY PROBLEMS

1. Read and Understand the question
2. Identify the two IFRs
3. Label the two IFRs as "proper (rest) [ $t_0$ ]" and "travelling [ $t_v$ ]"
4. Check if the relative velocity of IFRs is provided
5. Identify which IFR the given data belongs to
6. Pick the appropriate formula and solve for unknown



### Example 2: A time-dilated yawn

Continuing the last problem, if the person standing on the platform yawned just as the train was passing through, and this yawn lasted 2.000 s as measured by the yawner, what would be the duration of the yawn as measured by the train travellers?



$$t_v = 2.3s$$

### STEPS FOR RELATIVITY PROBLEMS

1. Read and Understand the question
2. Identify the two IFRs
3. Label the two IFRs as "proper (rest) [ $t_0$ ]" and "travelling [ $t_v$ ]"
4. Check if the relative velocity of IFRs is provided
5. Identify which IFR the given data belongs to
6. Pick the appropriate formula and solve for unknown

## Worked example 6.3A

Imagine that one of a pair of twins takes off on a long space journey to Vega, 25 light-years away, at a speed, relative to Earth, of 99.5% of  $c$  ( $\gamma = 10$ ). Once there he decides he doesn't like the Vegans, so turns around and comes straight back at the same speed.

- a** How long, in Earth's frame, does it take for the traveller to reach Vega?
- b** As seen by the Earth twin, how long does the trip take the traveller?
- c** How long does it take the traveller in his reference frame?
- d** Assuming a negligible turnaround time, how long did the trip take in the Earth's frame of reference?
- e** How long did the trip take the traveller?

## Solution

- a** At  $0.995c$ , a trip of 25 light-years will take just over 25 years (25.1 years).
- b, c** Time for the traveller will seem to go at one-tenth ( $1/\gamma$ ) the rate of Earth time, so when he gets there, his clocks (or calendar) will say that it took only 2.5 years. This is the time as seen in the traveller's frame from the Earth's frame, as well as in his own frame.
- d** In the Earth's frame the trip took  $2 \times 25.1 = 50.2$  years (plus turnaround time).
- e** The traveller perceived that it took just 5 years (plus turnaround). So he returns to find his twin sister has aged over 50 years while he has only aged 5 years!

## 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

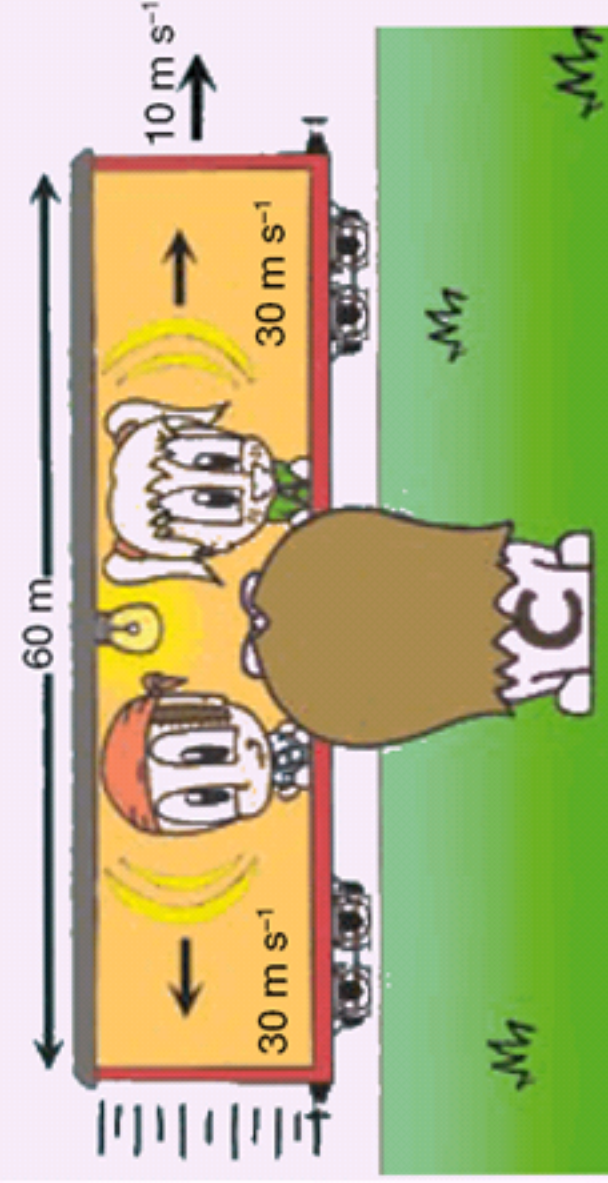
2. Further supporting evidence has been found in the **abundance of mesons striking the ground** after having been created in the upper atmosphere by incoming cosmic rays. What is surprising is that the mesons have a velocity of about  $0.996c$  and, at that speed, should take approximately 16 microseconds 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.



## 6.3 questions

Time is not what it seems

The following information applies to questions 1–7. The train carriage in the diagram is equipped with the famous flashing light in the centre. Anna and Ben, in the train, time the flashes as they are emitted, reflect off the end walls and return to Anna and Ben. Chloe is doing the same from the platform. (Chloe corrects her times for any look-back effects.) To make the numbers manageable we will slow light down to just  $30 \text{ m s}^{-1}$ . The train is moving at  $10 \text{ m s}^{-1}$  and is  $60 \text{ m}$  long.



**1** According to Anna and Ben, how long does the light take to travel to the ends of the carriage and back to them?

In questions 2–6 consider the situation from Chloe's point of view.

**2** The flash that travels to the back of the carriage will meet the wall early because the train is moving towards it.

**a** Chloe sees light travelling at  $30 \text{ m s}^{-1}$  in her frame, but at what speed *relative to the train* does she see the backward-directed flash moving?

**b** How long will it take this flash to reach the back wall?

**c** Use similar reasoning to find the time for the forward flash to reach the front wall.

**3 a** Continue the reasoning in Question 2 in order to find:

**i** the time, as seen by Chloe, for the flashes to return to Anna and Ben

**ii** the total time for the round trips for the forward and backward flashes.

**b** How does this time compare with the time Anna and Ben measured for the same events?

**4** Which events in these questions occurred simultaneously for both sets of observers and which were not simultaneous?

**5** Had Anna and Ben been throwing balls or sending sound pulses, how would your answers to questions 1–4 have been different? Why would this have been the case?

**6** In Question 2 we saw that Chloe 'saw' the light travelling at  $40 \text{ m s}^{-1}$  relative to the train. This is faster than the assumed speed of light ( $30 \text{ m s}^{-1}$ ). Does this contravene Einstein's second postulate? Explain.

**7** Throughout these questions we have made an assumption which seems perfectly reasonable, but which Einstein would say we have to question. Can you think what that assumption might be?

**8** Anna's Gedanken light clock has a height of  $1 \text{ m}$  between the mirrors, and relative to Chloe her spaceship is travelling at  $90\%$  of the speed of light ( $c = 3.0 \times 10^8 \text{ m s}^{-1}$ ). One tick is the time for light to go from one mirror to the other.

**a** How far does the light flash travel in Anna's frame of reference in one tick,  $t_A$ ?

**b** So what is the tick time,  $t_A$ , for the clock in Anna's frame?

Now we know that, because the light takes a zig-zag path in her frame, Chloe sees the clock ticking at a slower rate,  $t_C$ . (Note also that in one tick Chloe sees the ship travel a distance  $0.9ct_C$ .)

**c** In terms of  $c$  and  $t_C$  what is the length of the zig path that the flash travels in one tick in Chloe's frame?

**d** Because the height of the light clock is  $1 \text{ m}$  we can now find (with some help from Pythagoras) the value of  $t_C$ . What is the tick time of the clock in Chloe's frame?

**e** What is the ratio of Chloe's tick to Anna's tick.

How does that compare to the value of  $\gamma$  as found in Table 6.1?

**9** If we repeat Question 8 but have Anna's ship travelling at  $0.1c$ , which answers would be different, and what would they be?

**10** If Anna saw Ben fly by at  $0.5c$ , how long, in her frame, would it take Ben's clock to tick 1 second?

**11** Briefly explain why Einstein said that a clock at the Earth's equator should run slightly slower than one at the Earth's poles. Why do we not find this to be a problem?



# **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
- ✓ 10 questions in this booklet
- ✓ Relevant pages in Multiple Choice Dot Points Book (DPB)
- ✓ New Dot Points booklet (pages 24-27)
- ✓ Chapter 4 all questions
- ✓ 10 questions of P22
- ✓ 20 questions of P21
- ✓ 12 questions of P19
- ✓ 12 questions of P18
- ✓ 8 questions of P17
- ✓ Experiment 5 Report
- ✓ Chapter 3 all questions

**NEXT PERIOD > LENGTH CONTRACTION**