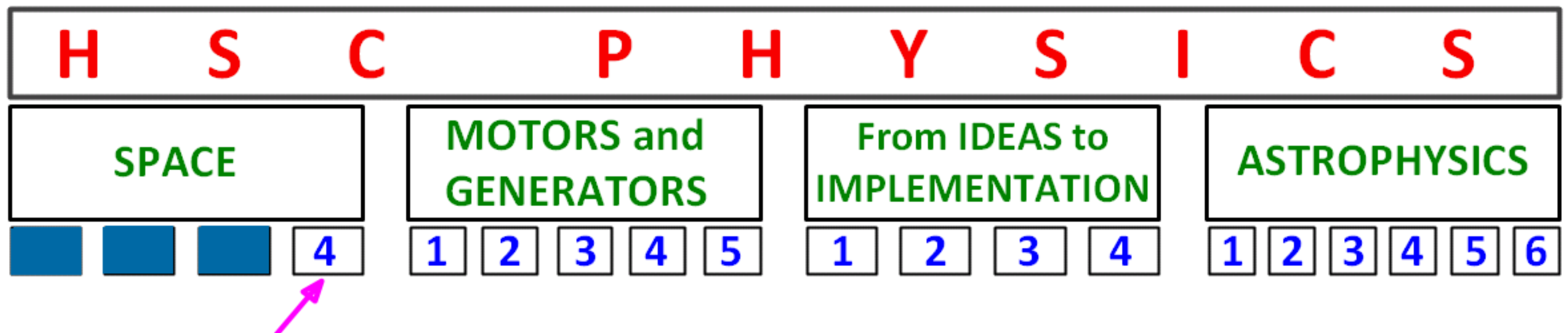


# SPACE

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

## PERIOD 29 - last

Space Travel, Theories may Change



## 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:

$$E = mc^2$$

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

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

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



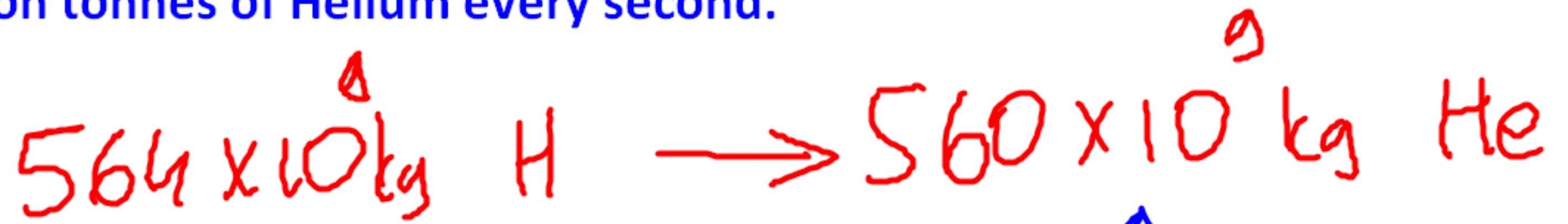
# EINSTEIN'S THEORY OF SPECIAL RELATIVITY:

- ★ The laws of physics are the same in all frames of reference; that is, the principle of relativity always holds
- ★ The speed of light is independent of the motion of the observer; that is, everyone always observes the same speed of light regardless of their motion

## RESULTS OF 'CONSTANCY OF SPEED OF LIGHT'

- ✓ Time Dilation
- ✓ Length Contractions
- ✓ Relativity of simultaneity
- ✓ Mass dilation
- ✓ Mass - Energy Equivalence

Find the power rating of our SUN, if 564 million tonnes of Hydrogen turns into 560 million tonnes of Helium every second.



$P = \frac{E}{t}$

we only get  $\frac{4}{2} \times 10^9$  of it

$4 \times 10^9 \text{ kg}$  of mass is converted into energy

$$E = \frac{4 \times 10^9 \times (3 \times 10^8)^2}{1}$$

$$= 3.6 \times 10^{26} \text{ J}$$

$$P = \frac{3.6 \times 10^{26} \text{ J}}{1 \text{ s}} = 3.6 \times 10^{26} \text{ Watts}$$

# SPACE TRAVEL

Designers of a new kind of spacecraft called a light sail make the remarkable claim that these craft could journey to Proxima Centauri (the distance to Proxima Centauri is approximately four light-years, or  $3.8 \times 10^{13}$  km), our closest neighbouring star and shortest interstellar journey, at a speed of  $0.6c$  or 60% of the speed of light ( $6.5 \times 10^8$  km/h). This is far<sup>3</sup> in excess of current achievable velocities. Assuming it to be true, how long would such a journey take?

2 frames  $\rightarrow$  1. earth  
2. light sail

$$t = \frac{d}{v}$$

$$t = \frac{3.8 \times 10^{13} \text{ km}}{6.5 \times 10^8 \text{ km/h}} = 5.8 \times 10^5 = 58500 \text{ h}$$
$$\approx 2435 \text{ days}$$
$$\approx 6.7 \text{ years}$$

$$t = \frac{4 \text{ ly}}{0.6c} = 6.7 \text{ years}$$

$$t_v = 6.7$$

how long for the astronaut?  $t_0 = ?$

$$t_v = t_0 / \gamma \Rightarrow t_0 = t_v \times \sqrt{1 - \left(\frac{0.6c}{c}\right)^2}$$

$$L_0 = 4 \text{ ly}$$
$$L_v = 3.2 \text{ ly}$$

$$t_0 = 5.4 \text{ years}$$

$$t = \frac{L_v}{v} = \frac{3.2 \text{ ly}}{0.6} = 5.4 \text{ years}$$

## 3 Golden Steps in Relativity Problems

- 1 - Identify the (inertial) Frame of References; there must be two
- 2 - (Once you identify the frame of references) decide which one is Rest frame ( $t_0$ ,  $L_0$ ,  $m_0$ ) and which one is Travelling frame ( $t_v$ ,  $L_v$ ,  $m_v$ )  
Ask yourself "What am I measuring/recording?" and "from where?"
- 3 - Choose the appropriate formula and solve it for unknown

$$t_v = 6.7$$

how long for the astronaut?

$$t_0 = ?$$

$$t_v = t_0 / \gamma \Rightarrow t_0 = t_v \times \sqrt{1 - \left(\frac{0.6c}{c}\right)^2}$$

$$L_0 = 4 \text{ ly}$$

$$L_v = 3.2 \text{ ly}$$

$$t = \frac{L_v}{v} = \frac{3.2 \text{ ly}}{0.6} = 5.4 \text{ years}$$

$$t_0 = 5.4 \text{ years}$$



in 2023

## TWO INERTIAL FRAME OF REFERENCES

in 2009

### 1. Earth-Proxima Centauri



$$t_v = \frac{4 \text{ ly}}{0.6c} = 6.7 \text{ years}$$

$$\frac{4 \text{ ly}}{6.7 \text{ y}} = v$$

### 2. Ligth Sail



$$L_v = L_0 \times \sqrt{1 - \left(\frac{0.6c}{c}\right)^2} = 3.2 \text{ ly}$$

$$t_0 = \frac{t_v}{\sqrt{1 - \left(\frac{0.6c}{c}\right)^2}} = 5.4 \text{ years}$$

$$= \frac{3.2 \text{ ly}}{5.4 \text{ y}} = v = 0.6c$$



A COMPARISON OF RELATIVISTIC EFFECTS

SPACECRAFT	SPEED (km h <sup>-1</sup> )	RATIO $\frac{v}{c}$	TIME PASSED ON SPACECRAFT IN ONE EARTH DAY			CONTRACTED LENGTHS AS % OF ORIGINAL
			HOURS	MINUTES	SECONDS	
Space shuttle	28 000	0.000 026	23	59	59.999 972	99.999 999 97
Fast space probe	100 000	0.000 093	23	59	59.999 630	99.999 999 6
Light sail	108 000 000	0.1	23	52	46.92	99.499
Starship <i>Intastella</i>	972 000 000	0.9	10	27	40.89	43.59
Starship <i>Galactica</i>	1 079 892 000	0.999 9	0	20	21.85	1.4
EVO-10	260	$2.4 \times 10^7$				
Dream-X	0.60c					
	5 km/h					
	0.9999999c					
	1c					
	2c					

# 2009 HSC QUESTION

## Question 18 (4 marks)

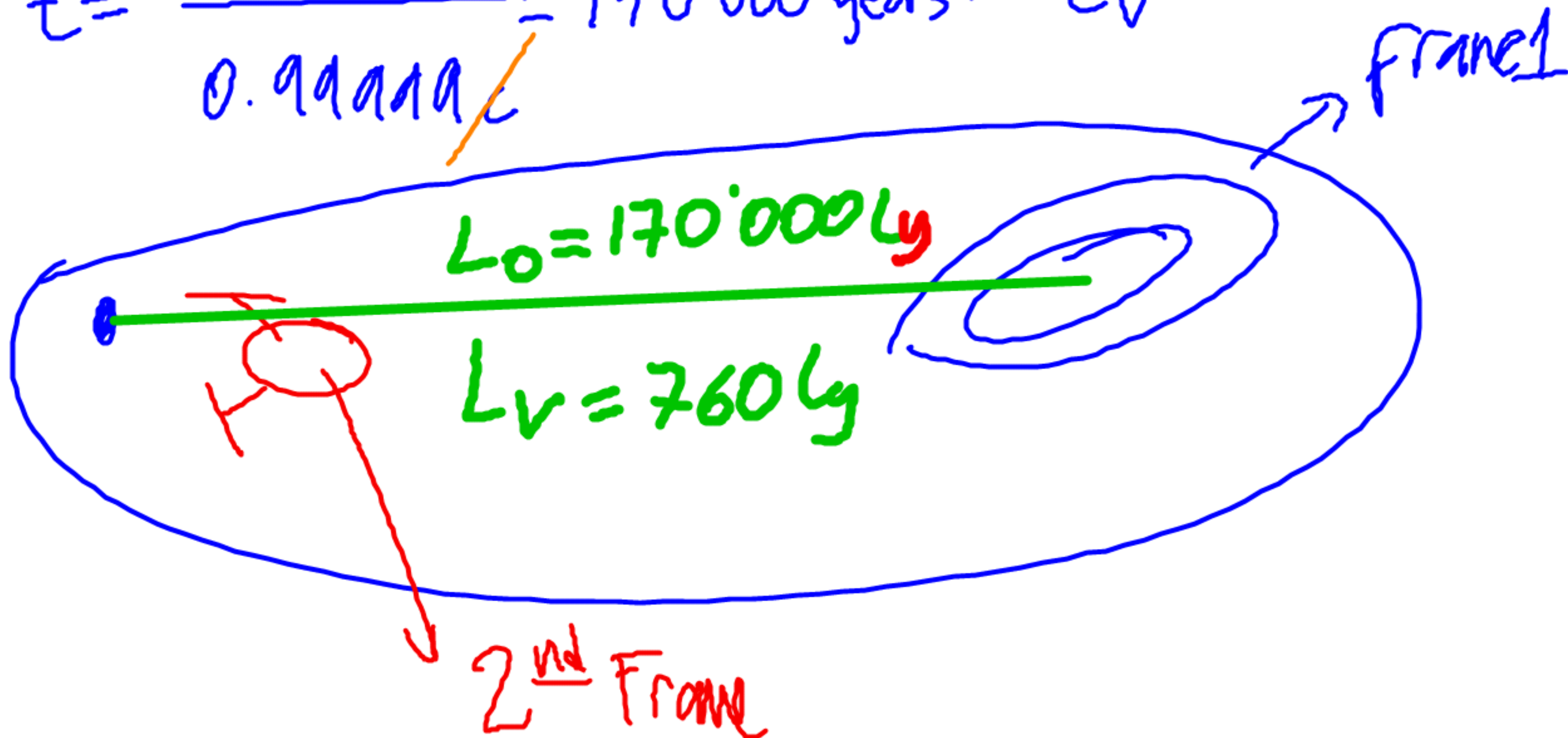
The nearest galaxy to ours is the Large Magellanic Cloud (LMC), with its centre located  $1.70 \times 10^5$  light years from Earth. Assume you are in a spacecraft travelling at a speed of  $0.99999c$  towards the LMC.

(a) In your own reference frame, what is the distance between Earth and LMC?

$$L_v = L_0 \times \sqrt{1 - v^2/c^2} = 1.7 \times 10^5 \times \sqrt{1 - (0.99999)^2} = 760 \text{ Ly}$$

$$t = \frac{760 \text{ Ly}}{0.99999c} \approx 760 \text{ y}$$

$$t = \frac{1.7 \times 10^5 \text{ Ly}}{0.99999c} = 170\,000 \text{ years} = t_v$$



## 2009 HSC QUESTION

### Question 18 (4 marks)

The nearest galaxy to ours is the Large Magellanic Cloud (LMC), with its centre located  $1.70 \times 10^5$  light years from Earth. Assume you are in a spacecraft travelling at a speed of  $0.99999c$  towards the LMC.

(a) In your own reference frame, how long will it take you to travel from Earth to the LMC?

$L_0 = 170\,000\text{ ly}$  is the distance b/w earth & LMC  
measured from earth (rest length)

$L_v = 760\text{ ly}$  the measurement of rest length from  
spacecraft

$t_0 = 170\,000\text{ y}$  is the time for the spacecraft to reach  
LMC measured from the earth.

$t_v = 760\text{ y}$  is the rest time, measured in spacecraft.



discuss the role of the Michelson-Morley experiments in making determinations about competing theories

## SCIENTIFIC MODEL

✦ From theory come predictions that can be tested.

✦ Experiments are performed to test the predictions.

✦ from the results of the experiments, judgements can be made regarding the validity of the theory.

→ null

→ what is wrong?

The Michelson-Morley experiments were performed to test the prediction, based on the aether model, that an aether wind should exist.

discuss the role of the Michelson-Morley experiments in making determinations about competing theories

## SCIENTIFIC MODEL

✦ ...

✦ ...

✦ ...

The Michelson-Morley experiments were performed ...

discuss the role of the Michelson-Morley experiments in making determinations about competing theories

- ✦ The Michelson-Morley experiments were performed in 1887 and had null results, despite satisfying all requirements regarding sensitivity. **This did not, however, disprove the theory.**
- ✦ **Various modifications** of the aether theory were offered over the following years. Each modified theory resulted in **new predictions** to be tested. **Each test failed.**
- ✦ Almost twenty years after the Michelson-Morley experiments, Einstein proposed **the theory of relativity**, in which the **aether model was not needed.**
- ✦ The theory of relativity produced its **own set of predictions**, not all of which were testable at that time. As technology has improved, **the predictions have been tested and found to be correct.**
- ✦ The choice for scientists was as follows: **continue to follow a theory** for which no predictions proved true (aether) OR **follow an alternative theory** for which prediction do prove true (relativity).



discuss the role of the Michelson-Morley experiments in making determinations about competing theories

- ✦ The Michelson-Morley experiments were performed in 1887 and ...

- ✦ ...

- ✦ Almost twenty years after the Michelson-Morley experiments, ...

- ✦ The theory of relativity produced its ...

- ✦ The choice for scientists was as follows: ...

## P26, P27, P28 SOLUTIONS

### Chapter review

**1** D   **2** B   **3** A   **4** A & C   **5** B   **6** C   **7** C   **8** C & D  
**9** A, B, C   **10** A & C   **11** B   **12** C   **13** D   **14** C   **15**  
B   **16** A

**17** A, well established by Einstein's time, B, basis of all modern physics, C, important, D, did none

**18** A, true, B, false, C, true, D, false.

**19** Aristotle's ideas agreed with everyday observation. In space, we see constant velocity

**20** Light had a constant speed. In conflict with Galilean relativity

**21 a** Light travelled with a fixed velocity relative to the aether.   **b** Could not measure the speed directly accurately enough.   **c** No difference in the speed of light. **22 a** 128 min   **b** 139 min   **c** 150 min.

**23** M-M looking for similar result. Equivalent to the pilot finding the wind has no effect on the plane's motion!

**24** No difference between (i) and (iii); in (ii) object will tilt.

**25** Space and time are interdependent.

**26** Normal for you, slow for Mars.   **27 a** 5.6 years  
**b** 2.4 years   **c** Apparent distance travelled much less than 5 l.y.

**28 a** About 1.4 mm   **b** No

**29 a** This is  $\gamma$  with  $v/c = 0.995$    **b** No

**c** About 25.1 years   **d** 2.51 years   **e** No   **f** No time

**30 a** 1.7 mm   **b** No!   **c** Electrons have much greater mass

**31 a** No, went with energy.   **b**  $9 \times 10^7$  GJ.

**c** About 70 days.   **d** One-third of a gram

**32 a**  $4.2 \times 10^{-12}$  J   **b**  $9.2 \times 10^{37}$  every second

**c** 370 billion tonnes   **d** Mass associated with energy radiated into space

# 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:*

- ✓ Personal Notes - at least 5 pages every day
- ✓ New booklet
- ✓ Chapter 5 all questions
- ✓ 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

**NEXT PERIOD > TASK 1 10% - STUDY THE BLUE PRACTICAL BOOKLET**