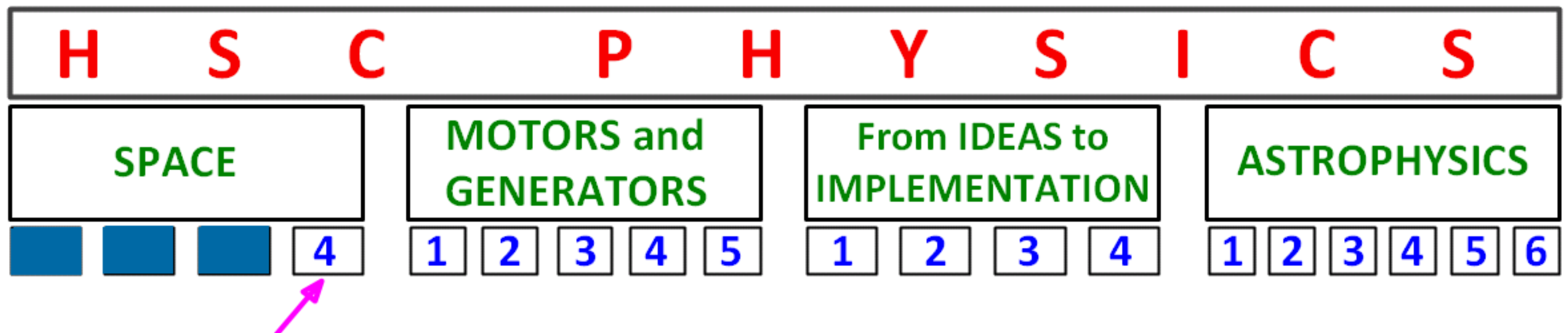


SPACE

1st Quarter; Module 1

PERIOD 21

Aether and Michelson&Morley's Experiment



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:

$$E = mc^2$$

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

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

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

Why did we need "aether" in the first place

anyway!

* they believed light travels as a wave.

* all waves they knew needed a medium to travel (water waves in water, waves in string, sound in air)

* So, light travels in space, there is no air/water in space, but ~~it~~ it needs a medium!

* Aether is the medium for light to travel.

THE AETHER MODEL

Having concluded that light moves as a waveform, nineteenth-century physicists turned to other wave motions in order to better understand light. There were many others known, including sound waves, water waves, and earthquake waves. All of these waveforms need a medium through which to travel, and so it was believed that light waves would also require a medium. Nobody could find such a medium but belief in its existence was so strong that it was given a name, the ‘luminiferous **aether**’, and its properties were identified. The aether:

- filled all of space, had low density and was perfectly transparent
- permeated all matter and yet was completely permeable to material objects
- had great elasticity to support and propagate the light waves.

This list of properties may seem odd to us now and the whole concept of the aether may seem strange in hindsight, but bear in mind that nineteenth-century physicists were trying to understand a phenomenon completely unknown to them. It is not unlike the situation facing modern cosmologists in trying to understand why the universe seems to have much more matter than can be observed, and why the expansion of the universe seems to be accelerating. Some explanations of these modern-day puzzles attribute some similarly unusual properties to otherwise ‘ordinary’ space.

The search for the aether was to occupy physicists for several decades before it was finally accepted that (a) the aether does not actually exist, and (b) electromagnetic waves (including light) are unique in that they do not require a **medium** of any sort in order to move.

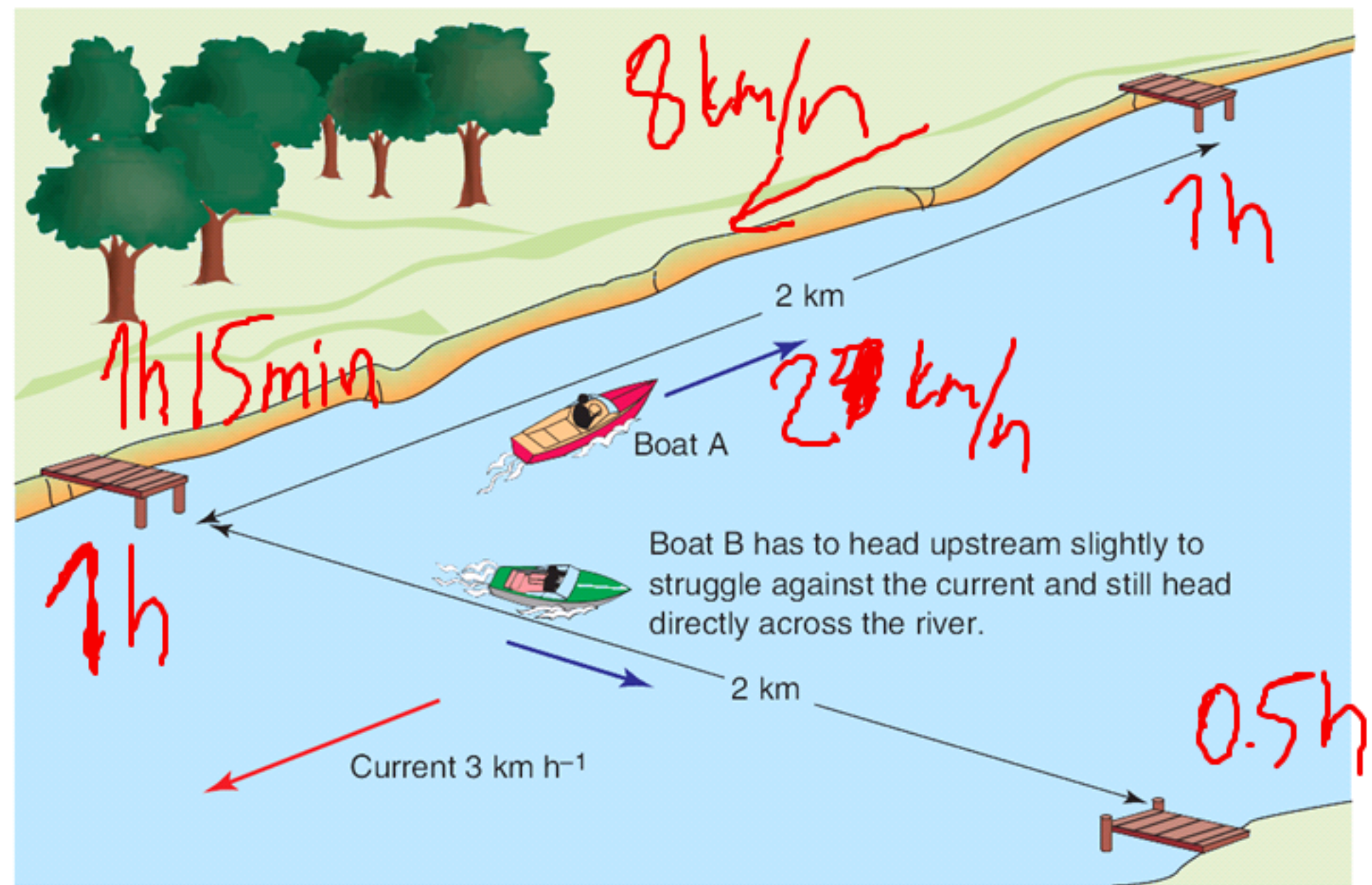
The **aether** was the proposed medium for light and other electromagnetic waves, before it was realised that these waveforms do not need a medium in order to travel.

THE AETHER MODEL



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ANALOGY TO BETTER UNDERSTAND THE "MM EXPERIMENT"



(a) The situation for boat A heading along the river

→ Journey out (against current)

Boat speed = 5 km h^{-1} through the water
= 2 km h^{-1} as seen from the river bank

$$\therefore \text{time taken} = \frac{\text{distance}}{\text{speed}} = \frac{2 \text{ km}}{2 \text{ km h}^{-1}} = 1 \text{ h}$$

← Current 3 km h^{-1}

← Return journey (with current)

Boat speed = 5 km h^{-1} through the water
= 8 km h^{-1} as seen from the river bank

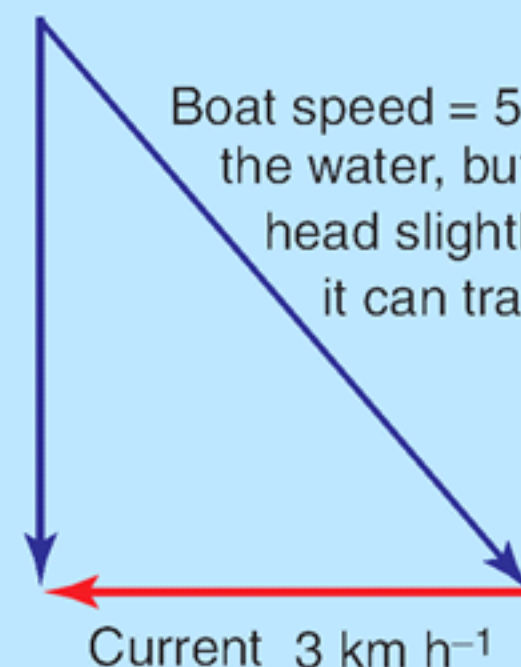
$$\therefore \text{time taken} = \frac{\text{distance}}{\text{speed}} = \frac{2 \text{ km}}{8 \text{ km h}^{-1}} = 0.25 \text{ h} = 15 \text{ min}$$

Hence, total time taken = 1 h 15 min

(b) The situation for boat B heading across the river

From Pythagoras' theorem,
boat speed = $\sqrt{5^2 - 3^2}$
= 4 km h^{-1}
as seen from the river bank

Boat speed = 5 km h^{-1} through the water, but this boat must head slightly upstream so that it can travel directly across.



$$\therefore \text{time taken} = \frac{\text{distance}}{\text{speed}} = \frac{2 \text{ km}}{4 \text{ km h}^{-1}} = 0.5 \text{ h each way}$$

Hence, total time taken = 1 h and this boat wins!

River - still

B



A



River - water flow

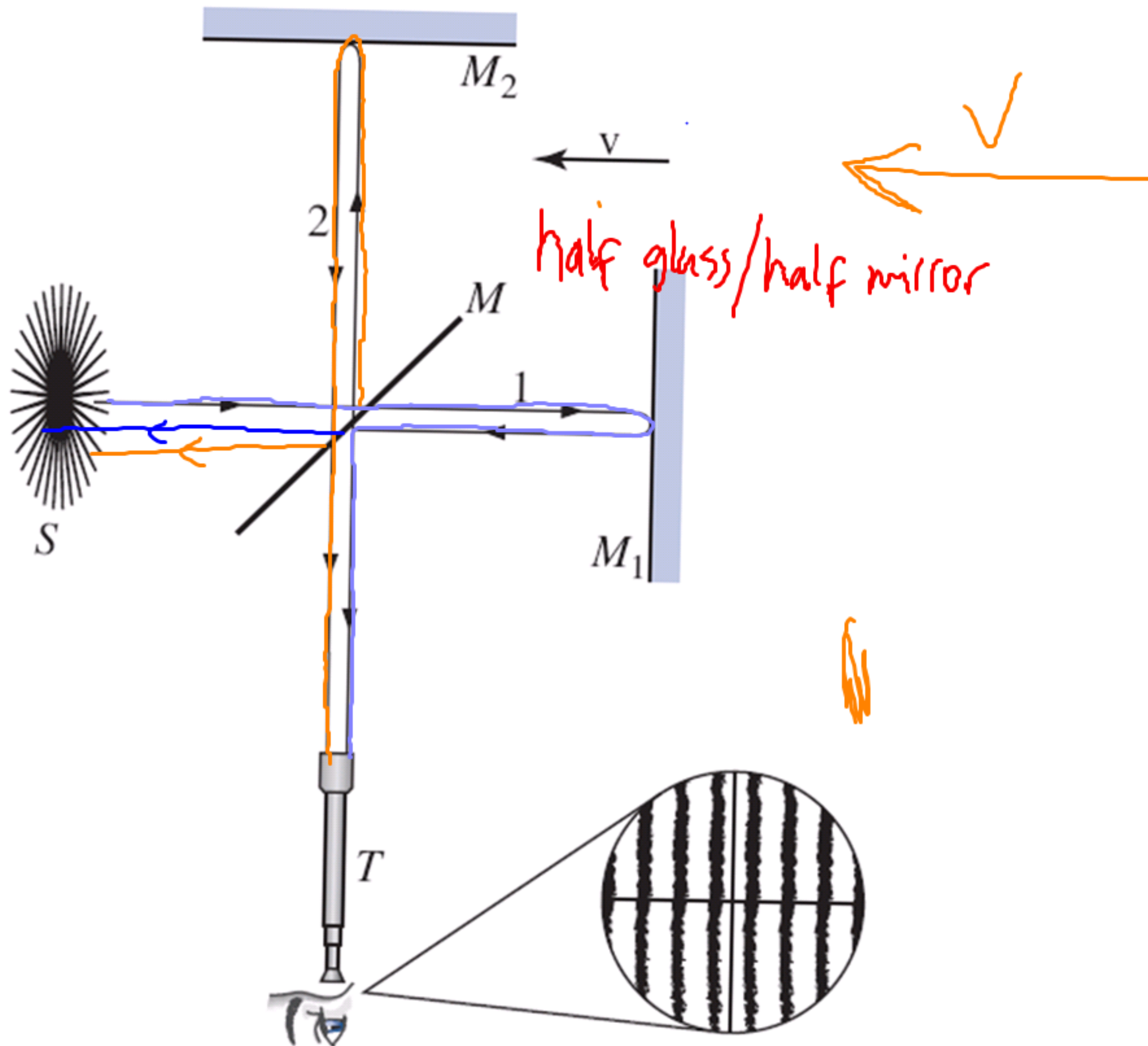
B



A

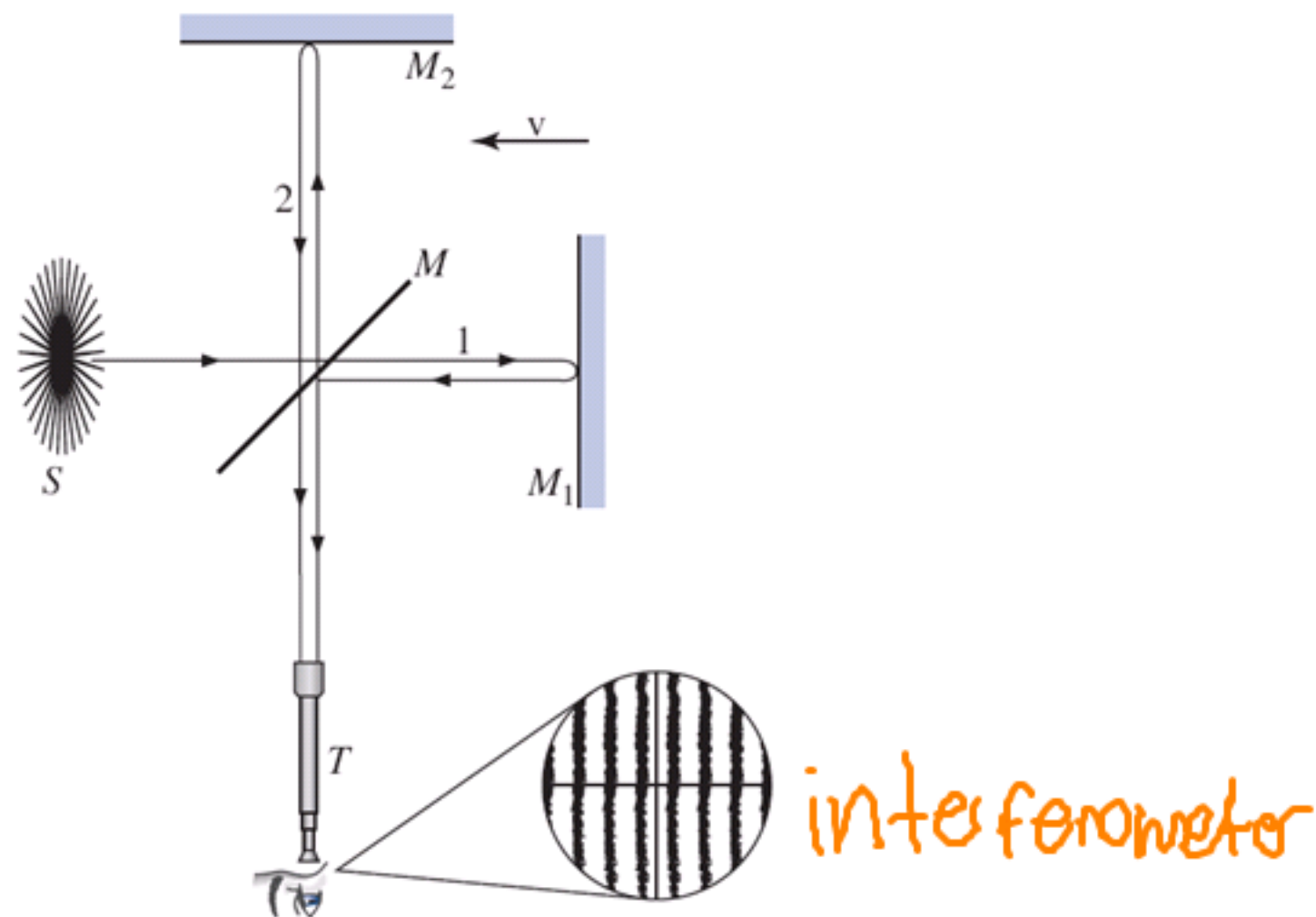
Michelson-Morley experiment

Aim: to measure the speed of Earth through aether



This is essentially what Michelson and Morley did — they raced two light rays over two courses, one into the supposed aether wind and one across it, then swung the apparatus through 90 degrees to interpose the rays. They were looking for a difference between the rays as they finished their race, from which they could calculate the value of the aether wind. Figure 5.4 shows their apparatus, while figure 5.5 uses a simplified diagram to show how it worked.

Figure 5.5 A simplified diagram showing the light rays' paths in the Michelson–Morley experiment. A light ray from the source is split into two by the half-silvered mirror. Ray A heads into the aether wind then reflects against mirror M_1 and returns. Ray B heads across the aether wind before reflecting back. Both rays finish their journey at the telescope, where they are compared.



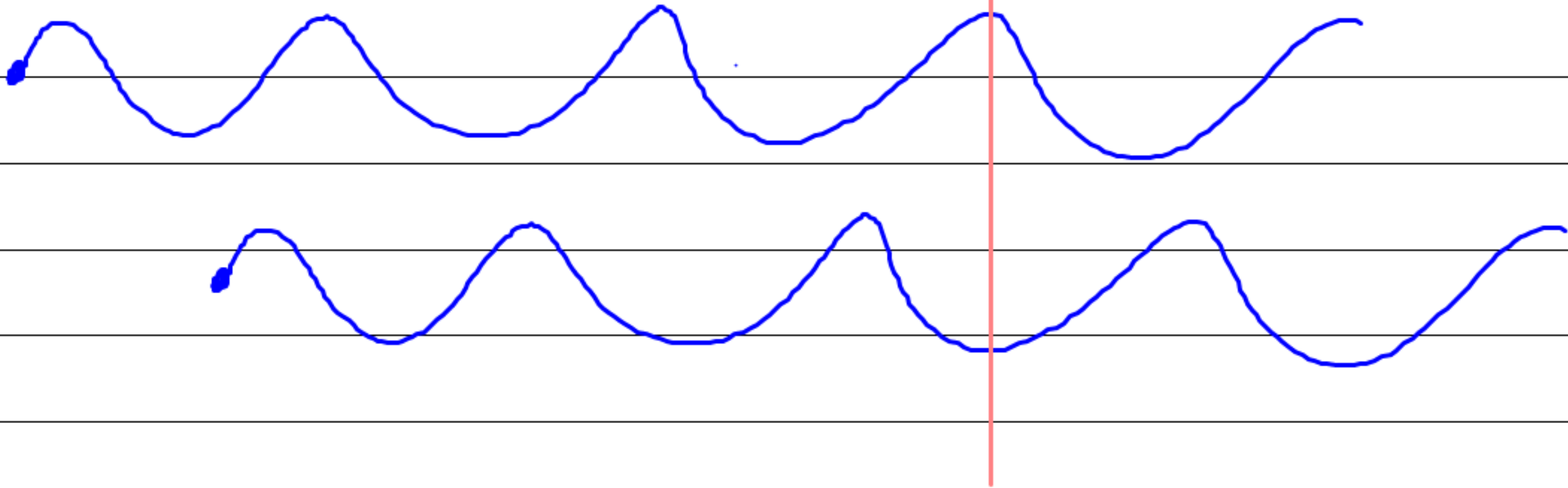
The method of comparing the light rays involves a very sensitive effect called ‘interference’, and hence this apparatus is referred to as an ‘interferometer’. Essentially, when looking into the telescope a pattern of light and dark bands will be seen, as shown in figure 5.5. If the aether wind exists, so that one light ray is indeed faster than the other, then when the apparatus is rotated, so that the rays are interposed, the interference pattern should be seen to shift. However, no such shift was observed.

The experiment was repeated many times by Michelson and Morley, at different times of the day and year, but no evidence of an aether wind was ever found. The scientific community was not quick to abandon the aether model, however, and adapted the theory to keep it alive. One suggestion was that a large object such as a planet could drag the aether along with it. Another was that objects contract in the direction of the aether wind. However, none of these modifications survived close scrutiny. Further, the Michelson–Morley experiment has been repeated many times since 1887 by different groups with more and more sensitive equipment, and no evidence of an aether has ever been found. Yet belief in the necessity of the aether was so strong that physicists found it difficult to let go of the idea until, in 1905, Albert Einstein showed that the aether was not necessary at all.

Micholson-Morley experiment

Aim: to measure the speed of Earth through aether

A



Micholson-Morley experiment

Aim: to measure the speed of Earth through aether

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SOLUTIONS OF PERIOD 19 QUESTIONS

A1.
D is correct. The gravitational field strength at this altitude is less than 9.8 N kg^{-1} , so a satellite will orbit with an acceleration of less than 9.8 m s^{-2} .

A2.
Since the gravitational force of attraction between the Earth and the satellite is always perpendicular to the satellite's velocity, the speed of the satellite remains constant and therefore there is no change in its kinetic energy during its circular orbit.

A3.
The net force acting on the satellite during its orbit = mg
 $= (1.5 \times 10^3 \text{ kg})(0.22 \text{ N kg}^{-1}) = 3.3 \times 10^2 \text{ N}$

A4.
The centripetal force is produced by the gravitational force of attraction between the Earth and the satellite.

A5.
a $a = F/m = GM/R^2$
 $= (6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2})(1.02 \times 10^{26} \text{ kg})/(3.55 \times 10^8 \text{ m})^2$
 $= 5.40 \times 10^{-2} \text{ m s}^{-2}$
b $a = v^2/R$

then $5.4 \times 10^{-2} \text{ m s}^{-2}$
 $v^2/(3.55 \times 10^8 \text{ m})$
and $v = 4.38 \text{ km s}^{-1}$
c $T = 2\pi R/v$
 $= 2\pi(3.55 \times 10^8 \text{ m})/(4.378 \times 10^3 \text{ m s}^{-1})$
 $= 5.095 \times 10^5 \text{ s} = 5.90 \text{ days}$

A6.
a $v = 2\pi R/T$
 $= 2\pi(1.22 \times 10^9 \text{ m})/(1.38 \times 10^6 \text{ s}) = 5.55 \text{ km s}^{-1}$
b $a = v^2/R$
 $= (5.55 \times 10^3 \text{ m s}^{-1})^2/(1.22 \times 10^9 \text{ m}) = 2.52 \times 10^{-2} \text{ m s}^{-2}$

A7.
$$F = \frac{GMm}{R^2} = \frac{4\pi^2 Rm}{T^2}$$

Transposing to make M the subject gives:
$$M = \frac{4\pi^2 R^3}{GT^2} = 5.64 \times 10^{26} \text{ kg}$$

A8.
a $F = GMm/R^2$
 $= m4\pi^2 R/T^2$
then $R^3 = GMT^2/4\pi^2$
 $= (6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2})(4.87 \times 10^{24} \text{ kg})(2.10 \times 10^7 \text{ s})^2/4\pi^2$
and $R = 1.54 \times 10^9 \text{ m}$
b $v = 2\pi R/T$
 $= 2\pi(1.54 \times 10^9 \text{ m})/(2.10 \times 10^7 \text{ s})$
 $= 4.61 \times 10^2 \text{ m s}^{-1}$

c $a = v^2/r$
 $= (4.61 \times 10^2 \text{ m s}^{-1})^2/(1.54 \times 10^9 \text{ m})$
 $= 1.38 \times 10^{-4} \text{ m s}^{-2}$

A9.
a $\frac{v_A}{v_H} = \frac{\frac{2\pi R_A}{T_A}}{\frac{2\pi R_H}{T_H}} = \frac{T_H R_A}{T_A R_H} = 1.66$
b $\frac{a_A}{a_H} = \frac{\frac{GM}{R_A^2}}{\frac{GM}{R_H^2}} = \frac{R_H^2}{R_A^2} = 7.58$

A10.
 $g_A/g_B = R_0^2/(6.4 \times 10^6 \text{ m})^2 = 1.2$
and $R_0 = 7.0 \times 10^6 \text{ m}$

A11.
The centre of the circular orbit of a satellite must be the centre of the Earth.

A12.
a $g = GM/R^2$
 $= (6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2})(7.0 \times 10^{20} \text{ kg})/(385 \times 10^3 \text{ m})^2 = 0.31 \text{ N kg}^{-1}$
b $F = GMm/R^2 = mv^2/R$
then $v = (GM/R)^{1/2}$
 $= (6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2})(7.0 \times 10^{20} \text{ kg})/(395 \times 10^3 \text{ m})^{1/2} = 3.4 \times 10^2 \text{ m s}^{-1}$

PERIOD 21 HOMEWORK DUE MONDAY 16 NOV

Skip questions 10, 14, 15, 16, 17

In the following questions, assume that the universal constant of gravitation, $G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$; gravitational field strength on surface of the Earth, $g = 9.80 \text{ N kg}^{-1}$.

1 The gravitational force of attraction between Saturn and Dione, a satellite of Saturn, is equal to $2.79 \times 10^{20} \text{ N}$. Calculate the orbital radius of Dione. Data: mass of Dione = $1.05 \times 10^{21} \text{ kg}$, mass of Saturn = $5.69 \times 10^{26} \text{ kg}$.

2 A person standing on the surface of the Earth experiences a gravitational force of 900 N. What gravitational force will this person experience at a height of 2 Earth radii above the Earth's surface?

- A** 900 N
- B** 450 N
- C** zero
- D** 100 N

3 During a space mission, an astronaut of mass 80 kg initially accelerates at 30 m s^{-2} upwards, then travels in a stable circular orbit at an altitude where the gravitational field strength is 8.2 N kg^{-1} .

a What is the apparent weight of the astronaut during lift-off?

- A** zero
- B** 780 N
- C** 2400 N
- D** 3200 N

b During the lift-off phase, the astronaut will feel:

- A** lighter than usual
- B** heavier than usual
- C** the same as usual.

c The weight of the astronaut during the lift-off phase is:

- A** lower than usual
- B** greater than usual
- C** the same as usual.

d During the orbit phase, the apparent weight of the astronaut is:

- A** zero
- B** 780 N
- C** 2400 N
- D** 660 N

e During the orbit phase, the weight of the astronaut is:

- A** zero
- B** 780 N
- C** 2400 N
- D** 660 N

4 Two stars of masses M and m are in orbit around each other. As shown in the following diagram, they are a distance R apart.



A spacecraft located at point X experiences zero net gravitational force from these stars. Calculate the value of the ratio M/m .

5 Neptune has a planetary radius of $2.48 \times 10^7 \text{ m}$ and a mass of $1.02 \times 10^{26} \text{ kg}$.

a Calculate the gravitational field strength on the surface of Neptune.

b A 250 kg lump of ice is falling directly towards Neptune. What is its acceleration as it nears the surface of Neptune? Ignore any drag effects.

- A** 9.8 m s^{-2}
- B** zero
- C** 11 m s^{-2}
- D** 1.6 m s^{-2}

6 Given that the mass of the Earth is $5.98 \times 10^{24} \text{ kg}$ and the mean distance from the Earth to the Moon is $3.84 \times 10^8 \text{ m}$, calculate the orbital period of the Moon. Express your answer in days.

7 One of Jupiter's moons, Leda, has an orbital radius of $1.10 \times 10^{10} \text{ m}$. The mass of Jupiter is equal to $1.90 \times 10^{27} \text{ kg}$. Calculate:

- a** the orbital speed of Leda
- b** the orbital acceleration of Leda
- c** the orbital period of Leda (in days).

8 a Which of the following best explains what is meant by a satellite being in a geosynchronous orbit?

- A** It is orbiting the Earth.
- B** It is orbiting the Moon and remains above the same location.
- C** It is orbiting the Earth and remains above the same location.
- D** It is orbiting the Earth and returns to the same location every 24 hours.

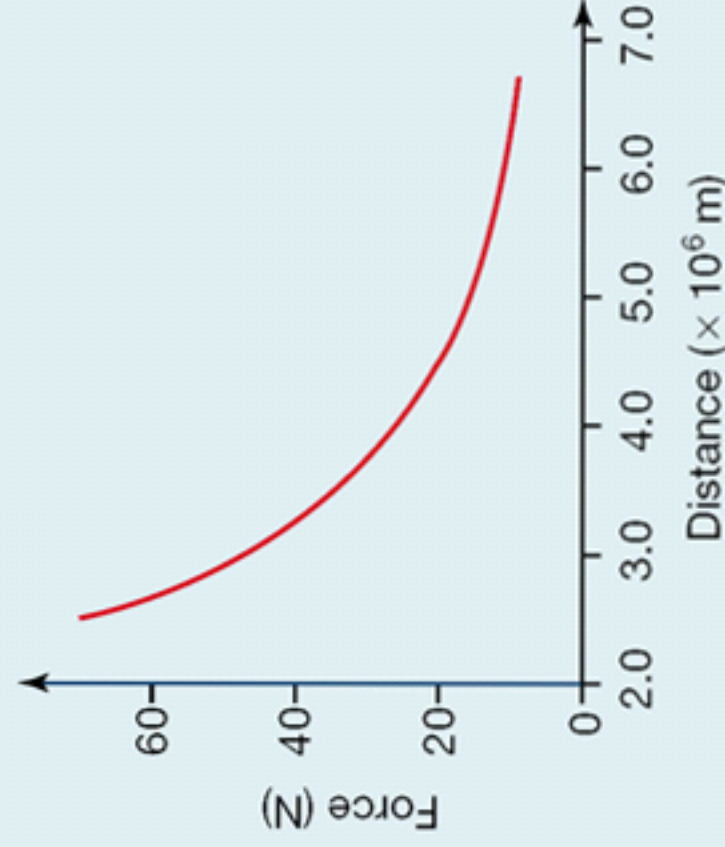
b What is the purpose of such an orbit?

c Assuming that the length of a day on Earth is exactly 24 hours, calculate the radius of orbit of a geostationary satellite (mass of Earth = $6.0 \times 10^{24} \text{ kg}$).

9 The planet Mercury has a mass of $3.30 \times 10^{23} \text{ kg}$. Its period of rotation about its axis is equal to $5.07 \times 10^6 \text{ s}$. For a satellite to be in a synchronous orbit around Mercury, calculate:

- a** the orbital radius of the satellite
- b** its orbital speed
- c** its orbital acceleration.

- 10** The following graph shows the force on a 20 kg rock as a function of its distance from the centre of the planet Mercury. The radius of Mercury is 2.4×10^6 m.



A 20 kg rock is speeding towards Mercury. When the rock is 3.0×10^6 m from the centre of the planet, its speed is estimated at 1.0 km s^{-1} . Using the graph, estimate:

- the increase in kinetic energy of the rock as it moves to a point that is just 2.5×10^6 m from the centre of Mercury
- the kinetic energy of the rock at this closer point
- the speed of the rock at this point
- the gravitational field strength at 2.5×10^6 m from the centre of Mercury.

- 11** Two satellites S_1 and S_2 are in circular orbits around the Earth. Their respective orbital radii are R and $2R$. The mass of S_1 is twice that of S_2 . Calculate the value of the following ratios and use the following answer key: **A** 1, **B** $\sqrt{2}$, **C** $1/\sqrt{8}$, **D** 4.

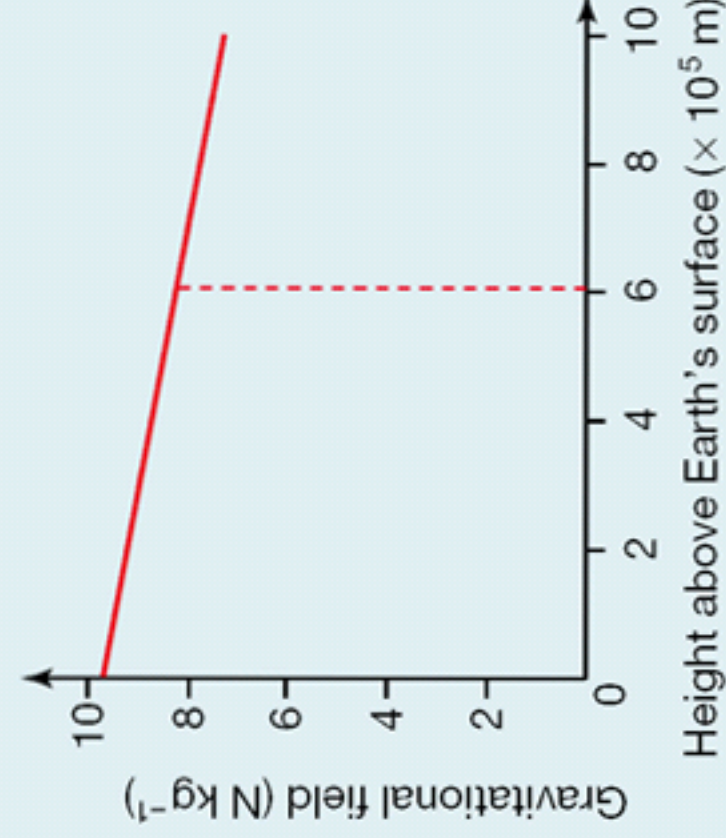
- orbital period of S_1 /orbital period of S_2
- orbital speed of S_1 /orbital speed of S_2
- acceleration of S_1 /acceleration of S_2 .

- 12** Earth is in orbit around the Sun. The Earth has an orbital radius of 1.5×10^{11} m and an orbital period of 1 year. Use this information to calculate the mass of the Sun.

The following information relates to questions 13–17.

The diagram shows the gravitational field and distance near the Earth.

A wayward satellite of mass 1000 kg is drifting towards the Earth.



- 13** What is the gravitational field strength at an altitude of 300 km?
- 14** Which of the following units is associated with the area under this graph?
- J
 - m s^{-2}
 - J s
 - J kg^{-1}
- 15** Which one of the following quantities is represented by the shaded area on the graph? (Ignore air resistance.)
- The kinetic energy per kilogram of the satellite at an altitude of 600 km
 - The loss in gravitational potential energy of the satellite
 - The loss in gravitational potential energy per kilogram of the satellite as it falls to the Earth's surface
 - The increase in gravitational potential energy of the satellite as it falls to the Earth's surface
- 16** How much kinetic energy does the satellite gain as it travels from an altitude of 600 km to 200 km altitude?
- 17** In reality, would the satellite gain the amount of kinetic energy that you have calculated in Question 16? Explain.
- The following information relates to questions 18–20.

Charon is the largest of Pluto's moons. It orbits Pluto with a period of 6.4 days and an orbital radius of 19 600 km. Nix, another of Pluto's moons was discovered using the Hubble Space Telescope in 2005. Nix has an orbital radius of 49 000 km—about double that of Charon.

- 18** Which of the following statements is correct?
- The gravitational force between Nix and Pluto is greater than the force between Charon and Pluto.
 - The gravitational force between Nix and Pluto is less than the force between Charon and Pluto.
 - The gravitational force between Nix and Pluto is equal to the force between Charon and Pluto.
 - The gravitational forces cannot be compared with the information given.

- 19** Use Kepler's third law to determine the orbital period of Nix [in days].

- 20** Use the data relating to Charon to calculate the mass of Pluto.

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

NEXT PERIOD > INERTIAL FRAMES AND PRINCIPLE OF RELATIVITY