13.1 **Measuring the Solar System** Name SA

Past Paper Questions

- Describe and explain the use of radar-type measurements to determine distances within the solar system; how distance is measured and defined in units of time, assuming the relativistic principle of the invariance of the speed of light.
- Describe and explain the measurement of relative velocities by radar observation.
- Make appropriate use of, by sketching and interpreting: logarithmic scales of magnitudes of quantities: distance, size, mass, energy, power, brightness.
- Make calculations and estimates of distances and relative velocities from radar type measurements.

2863 Jan 2002

5 The distance from Earth to a comet can be found by firing a pulse of radio waves at the comet and recording the time for the reflected pulse to return. On one occasion the pulse took 500 s to make the round trip.

(a) Show that the distance from Earth to the comet at the time of measurement was 7.5 x 10^{10} m.

$$s = vt = 3 \times 10^8 \times \frac{500}{2} = 7.5 \times 10^{10} \text{ m}$$

[1]

(b) Describe how this technique could be used to find the speed of a comet which is directly approaching Earth.

* Make a pair of distance measurements at a known time apart.

$$\text{average speed} = \frac{\text{change in distance}}{\text{time taken}}$$

[2]

2863 Jan 2006

1 The nearest star, Proxima Centauri, is at a distance of 4.3 **light years** from Earth.

Calculate the distance to Proxima Centauri in metres.

$c = 3.0 \times 10^8 \text{ m s}^{-1}$

1 year = 3.2×10^7 s

$$s = vt = 3 \times 10^8 \times 4.3 \times 3.2 \times 10^7 =$$

distance = 4.1×10^{16} m [2]

* Or use doppler effect $v = c\Delta\lambda / 2\lambda$

($\Delta\lambda$ is double for reflection from moving object)

2863 June 2006

3 The speed of a comet approaching the Earth can be measured by reflecting radar pulses off the approaching body.

The tables give results from a pair of measurements to determine the speed of a comet directly approaching the Earth. The first measurement took place at 12:00 hours.

time pulse sent			time reflected pulse received		
hours	minutes	seconds	hours	minutes	seconds
12	00	00	12	00	55.0

time pulse sent			time reflected pulse received		
hours	minutes	seconds	hours	minutes	seconds
12	35	00	12	35	54.9

(a) Show that the distance to the comet at 12:00 hours was about 8.3×10^9 m.

$c = 3.00 \times 10^8 \text{ m s}^{-1}$

$$s = vt = 3{\cdot}00 \times 10^8 \times \frac{55{\cdot}0}{2} = 8{\cdot}25 \times 10^9 \text{ m}$$

[2]

(b) Use the data in the tables to calculate the average velocity of approach of the comet during the measurement period.

$$s \text{ at } 12{:}35 = 3{\cdot}00 \times 10^8 \times \frac{54{\cdot}9}{2} = 8{\cdot}235 \times 10^9 \text{ m}$$

$$\Delta s = 8{\cdot}25 \times 10^9 - 8{\cdot}235 \times 10^9 = 1{\cdot}5 \times 10^7 \text{ m}$$

$$v = \Delta s/\Delta t = 1{\cdot}5 \times 10^7 / 35 \times 60 = 7143 \text{ ms}^{-1}$$

average velocity = $7{\cdot}14 \times 10^3$ m s^{-1} [2]

<u>OR</u> $$\left(\frac{55 - 54{\cdot}9}{2} \times 3 \times 10^8\right) \Big/ 35 \times 60$$

2863 June 2010 (also used in 2003)

9 This question is about measuring distances and velocities in the Universe.

Distances and velocities of planets and other objects within the Solar System can be measured by radar pulses from Earth reflected from distant objects.

(a) A radar pulse from Earth was aimed at an asteroid. The time interval between the pulse leaving the transmitter and the detection of the reflected pulse was 42.4 s.

Show that the distance to the asteroid at the time of measurement was about 6.4×10^9 m. State any assumptions you make.

$c = 3.00 \times 10^8 \, \mathrm{m\,s^{-1}}$

$s = vt = 3.00 \times 10^8 \times 42.4/2 = 6.36 \times 10^9$ m

assumptions: c is constant, out & return journeys are of equal time.

[2]

(b) The measurement was repeated 780 s later. The time interval had reduced to 42.2 s.

Calculate the average velocity of approach of the asteroid between the two measurements. Show your method clearly.

New $s = 3.00 \times 10^8 \times 42.2/2 = 6.33 \times 10^9$ m

$v = \Delta s/\Delta t = 0.03 \times 10^9/780 = 38461 \, \mathrm{ms^{-1}}$

average velocity = 3.8×10^4 $\mathrm{m\,s^{-1}}$ **[3]**

(c) This radar-ranging method is impractical for measuring the distance or velocity of a star such as Sirius which lies about 7 light years from Earth.

Suggest **two** reasons why this is so.

Long time delay ~ 14 yrs to make measurement

Returned signal will be too weak to detect.

(radar beam will spread out)

[2]

G494 June 2010

11 This question is about measuring the relative velocity of asteroids.

An asteroid is displaced from its orbit around the Sun and heads towards Earth.

(a) A concerned astronomer uses radar to measure the distance of the asteroid from the Earth. This is the method:

- a short radar pulse is emitted at time 0.00 s
- an echo from the asteroid is detected at 8.00 s.

(i) On the axes of Fig. 11.1, draw two straight lines to show the space-time worldline of the radar pulse.

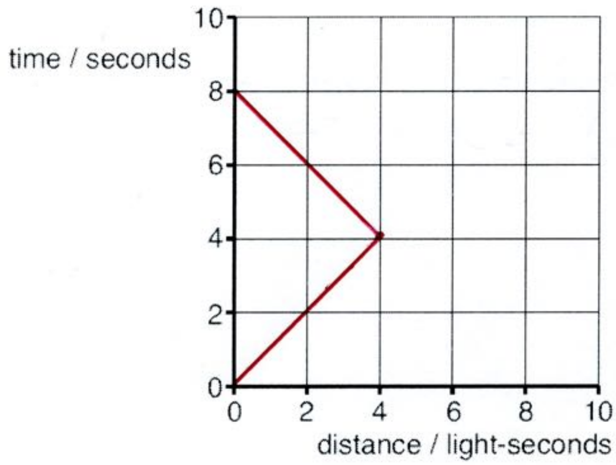

Fig. 11.1

[2]

(ii) Explain why the astronomer can assume that the radar pulse reflects off the asteroid at time 4.00 s.

The speed of light is constant so the time out is equal to the return time.

[2]

(iii) Calculate the distance from the asteroid to the Earth at time 4.00 s.

$c = 3.00 \times 10^8 \, \text{m s}^{-1}$

$s = vt = 3.00 \times 10^8 \times 8.00/2 =$

distance = 1.20×10^9 m **[1]**

(b) The astronomer sends out a second pulse at time 946.33 s, receiving an echo at time 953.67 s.

(i) Explain how the astronomer's data show that the asteroid is getting closer to the Earth.

The trip time is now shorter, 7·34 s

[2]

(ii) Use the data to calculate the component of the velocity of the asteroid towards the Earth.

New distance $= 3{\cdot}00 \times 10^8 \times 7{\cdot}34/2 = 1{\cdot}101 \times 10^9$ m

$v = \Delta s/\Delta t = \dfrac{1{\cdot}20 \times 10^9 - 1{\cdot}10 \times 10^9}{946} = 1{\cdot}06 \times 10^5$ ms^{-1}

component velocity = ...1·06 × 10^5.... ms^{-1} **[2]**

(c) Explain how the astronomer could use the wavelength of a **single** radar echo to confirm the measurement of the asteroid's component of velocity towards the Earth.

Measure change in wavelength of returned pulse.

For reflected wave $v = c\Delta\lambda/2\lambda$

[2]

G494 June 2013

3 The distance of an asteroid from the Earth can be measured by firing a pulse of electromagnetic radiation at the asteroid and measuring how long it takes for the pulse to return to Earth.

One of the following assumptions is needed to calculate the distance.

Put a tick (✓) in the box next to the **one** necessary assumption.

The asteroid is not moving relative to the Earth. ✗	☐
None of the radiation is absorbed by the asteroid. ✗	☐
The outward and returning pulses travel for the same time. ✓	✓
The outward and returning pulses have the same wavelength. ✗	☐

[1]

Practice H557/01

36 **Fig. 36.1** and **Fig. 36.2** show space-time diagrams for radar ranging of two objects. Lines representing the paths of objects through space and time are called worldlines.

The *y*-axes are in μs and the *x*-axes in light μs as shown. We are stationary in our frame of reference, travelling only in time and not in space, therefore represented by a vertical worldline from the origin.

Fig. 36.1 shows an object not moving relative to our frame, with another vertical worldline.
Fig. 36.2 shows an object moving relative to our frame through space and time.
The objects are at the same distance when radar pulses are reflected.

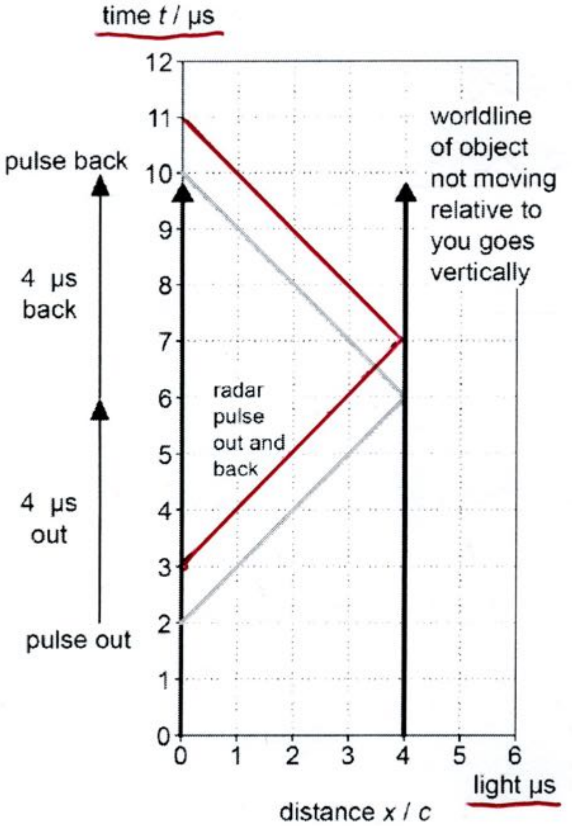

Fig. 36.1

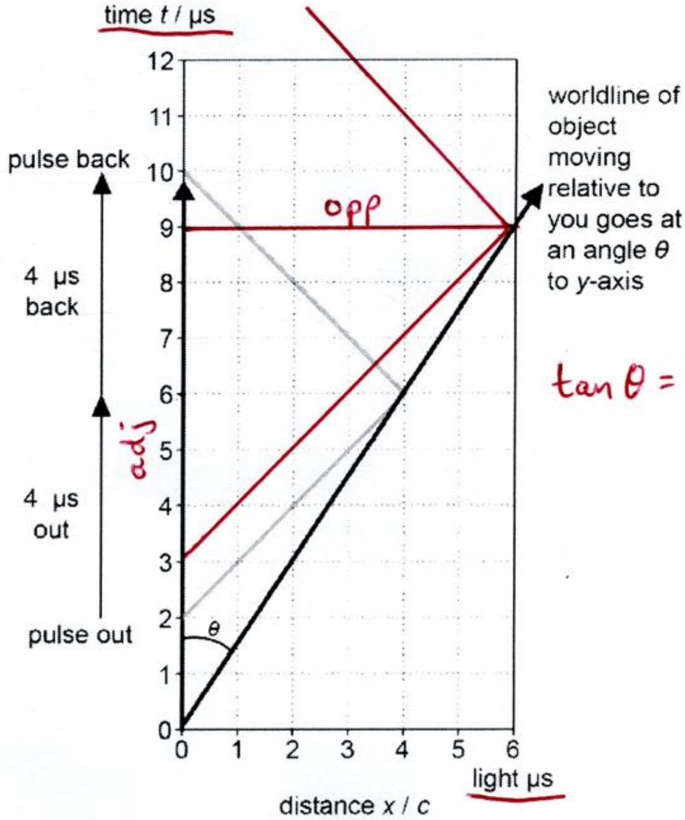

Fig. 36.2

$\tan\theta = \frac{opp}{adj} = v$

(a) Calculate the range of the objects when the radar pulse is reflected.

$s = v\Delta t = 3.00 \times 10^8 \times 4 \times 10^{-6} =$

range = 1200 m **[1]**

(b) (i) State why radar pulses on this diagram travel at 45° across the diagram.

Light (e-m radiation) travels 1 light second per second. Scales are same so 45° **[1]**

(ii) Show that speed of moving object in **Fig. 36.2** is given by tan θ. Calculate this speed.

$$V = \frac{\Delta s}{\Delta t} = \frac{opp}{adj} = \frac{6 \text{ light } \mu s}{9 \ \mu s} = \frac{2}{3}c = \tan\theta$$

[1 light second = $c \times 1$ sec]
dist/c → 1s

speed = 2×10^8 m s^{-1} **[2]**

(c) On **Fig. 36.1** and **Fig. 36.2** draw on the radar pulses emitted at t = 3.0 μs and their reflections. **[2]**

H557/02 June 2017

4 This question is about the New Horizons spacecraft mission to the dwarf planet Pluto.

In July 2015, the Long Range Reconnaissance Imager (LORRI) sent the image shown in Fig. 4.1a.

Fig. 4.1a

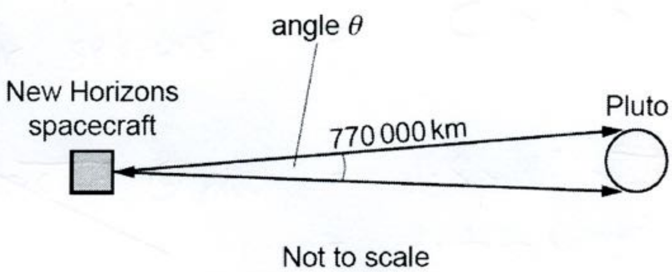

Fig. 4.1b

(a) It takes 4.5 hours for the radio signal from the spacecraft at Pluto to reach the Earth. Calculate the distance of the spacecraft from Earth when the signal was transmitted.

$$s = vt = 3.00 \times 10^8 \times 4.5 \times 3600 = 4.86 \times 10^{12}$$

distance = 4.9×10^{12} m **[2]**

H557/01 June 2017

35 An asteroid is tracked from the Earth by radar pulses.
A pulse places it at a distance of 44.444 light-minutes from Earth.
After 24 hours a second pulse places it 44.204 light-minutes from Earth. $\Delta t = 0.204 \times 60 = 14.4\,s$

$= \Delta T$

(a) Use this data to calculate the average velocity of approach of the asteroid relative to Earth.

$$V = \frac{\Delta s}{\Delta T} = \frac{v\Delta t}{\Delta T} = \frac{3.00\times10^{8}\times 14.4}{24\times3600} =$$

OR Calculate two distances and....

relative velocity = 5.0×10^{4} m s^{-1} **[2]**

(b) The path of the asteroid is shown in **Fig. 36.1**. After 24 hours the angular shift in position of the asteroid relative to Earth is 1.8 mrad.

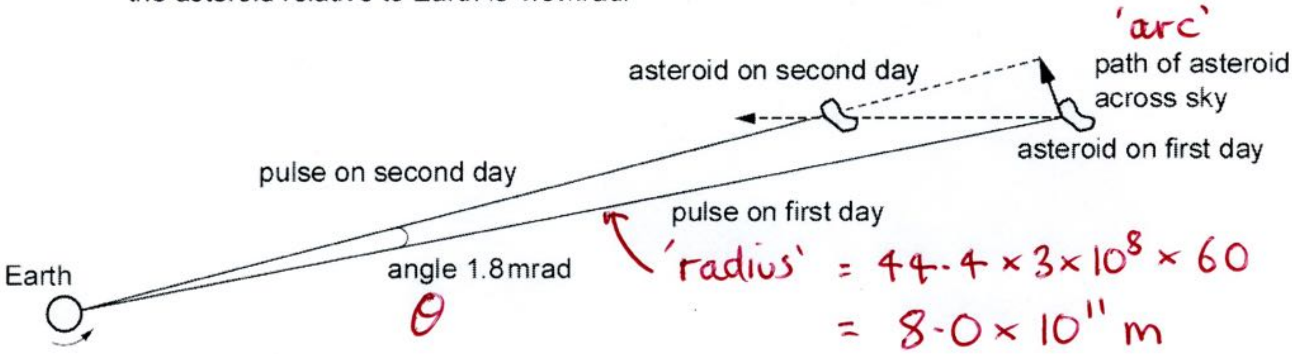

Fig. 36.1 (not to scale)

Estimate the velocity component of the asteroid perpendicular to its direction from Earth.
Make your method clear.

$$\theta = \frac{arc}{rad} \quad \therefore \quad arc = \theta\, rad = 1.8\times10^{-3}\times 8\times10^{11}$$
$$= 1.44\times10^{9}\,m$$

$$V = \frac{\Delta s}{\Delta t} = 1.44\times10^{9}/24\times3600 =$$

perpendicular velocity = 1.67×10^{4} m s^{-1} **[3]**