5 Fig. 5.1 shows two microwave transmitters **A** and **B** 0.20 m apart. The transmitters emit microwaves of frequency 10 GHz, of equal amplitude and in phase. A microwave detector is placed at **O** a distance of 4.0 m from **AB**.

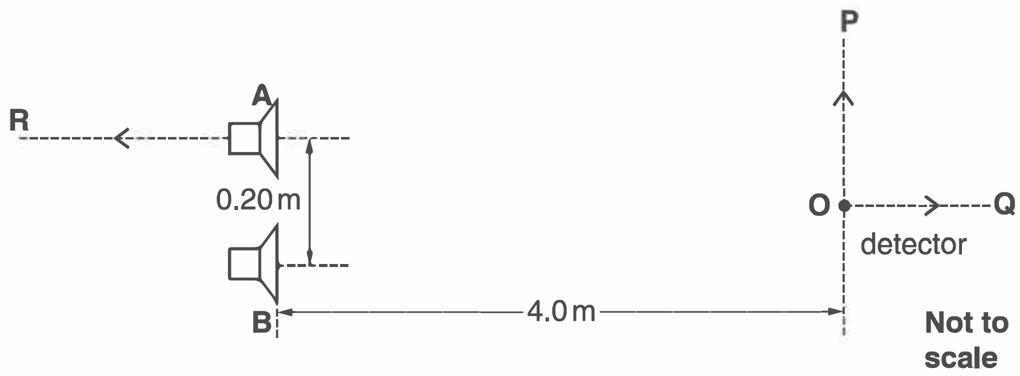

Fig. 5.1

(a) Interference of the waves from the two transmitters is detected only when the transmitters are coherent. Explain the meaning of

(i) *interference*

....

....

.... **[2]**

(ii) *coherent.*

....

.... **[1]**

(b) The length of the detector aerial is half a wavelength. Calculate the length of the aerial.

Show your working.

aerial length = ... m **[2]**

(c) **(i)** **1** Explain why the amplitude of the detected signal changes when the detector is moved in the direction **OP**.

....

....

....

.... **[2]**

2 Calculate the distance between adjacent **maximum** and **minimum** signals.

distance = ... m **[2]**

(ii) Explain why the amplitude of the detected signal changes when the detector is moved in the direction **OQ**.

....

....

....

.... **[2]**

(iii) Explain why the amplitude of the detected signal decreases to a minimum before increasing again as transmitter **A** is moved a small distance in the direction **AR** with the detector fixed at **O**. Calculate the distance **A** is moved to cause this minimum signal at **O**.

....

....

....

....

....

....

distance = ... m **[2]**

(d) State, with a reason, the effect on the intensity of the signal detected at **O** when each of the following changes is made.

(i) The amplitude of the waves emitted from **A** and **B** is doubled.

....

....

.... **[2]**

(ii) The detector **O** is rotated 90° about the axis through **OQ**.

....

....

....

....

.... **[3]**

8* The upper surface of a solar cell is represented in Fig. 8.1.

Use ideas about superposition of waves to explain why a transparent layer of silicon monoxide about 100 nm thick reduces the amount of reflection of light of wavelength 613 nm and increases the efficiency of the solar cell (lines 29 – 30 in the Article). **[6]**

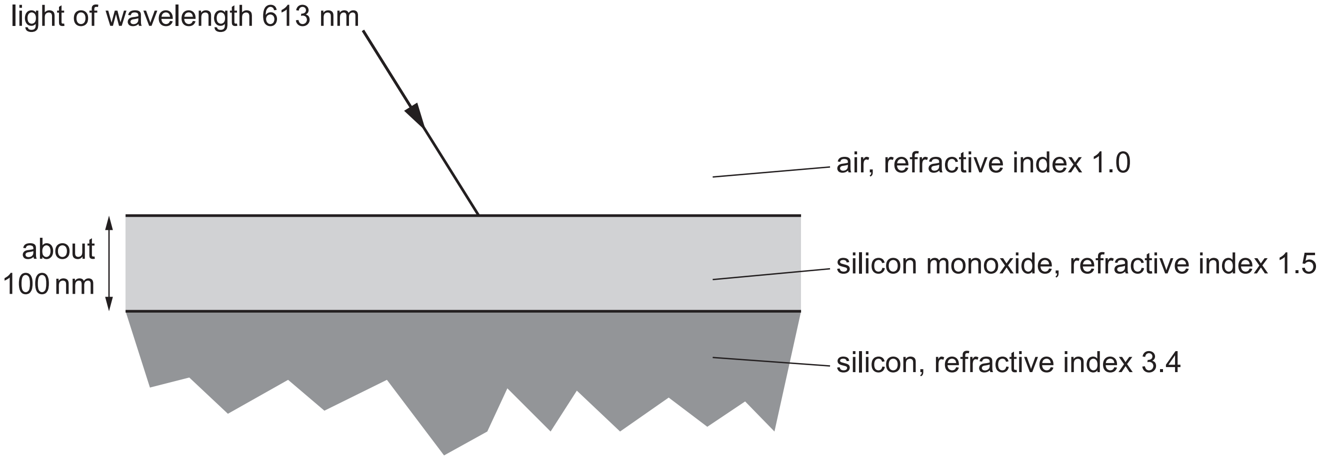

Fig. 8.1

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Flying on sunshine

Having left the Earth nearly five years earlier, the space probe Juno entered orbit around Jupiter on July 4, 2016. A little over three weeks later, on July 26, the aeroplane Solar Impulse 2 landed in Abu Dhabi having flown around the world in a number of stages. Juno and Solar Impulse 2, both record-breakers, share a common power source – the Sun.

Juno has travelled further from the Sun than any previous solar-powered probe and Solar Impulse 2 is the first solar-powered aeroplane to circle the globe. These achievements show that there is much more to solar cells than simply units for recharging batteries to power calculators or LED garden lights. Banks of solar cells are increasingly seen on the roofs of houses, factories and schools and missions such as Juno and Solar Impulse 2 help push forward the technology of solar power, improving its efficiency and making sunshine an increasingly attractive source of energy.

Photovoltaic cells

When light of sufficiently high frequency strikes a metal surface, photoelectrons are released. This is the photoelectric effect, explained by Einstein in 1905. In modern terminology, a photon transfers its energy to an individual electron which, if the energy of the photon is great enough, will escape the surface of the metal.

Photovoltaic cells (or solar cells) also rely on the transfer of energy from a photon to an electron. In this case, photons strike electrons within a semiconductor arrangement known as a p-n junction, a p-type semiconductor joined to an n-type semiconductor. The details of the physics of the junction are beyond the scope of this article.

If photons striking the cell have sufficient energy, electrons will be promoted into the ‘n’ region. This sets up an e.m.f. which can drive a current through a load. If the wavelength of light falling on the semiconductor is too long there will be no e.m.f. generated.

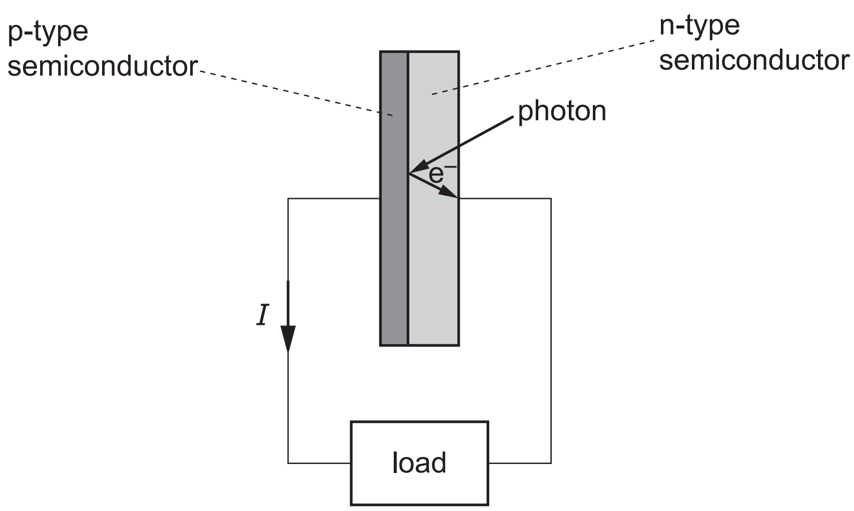


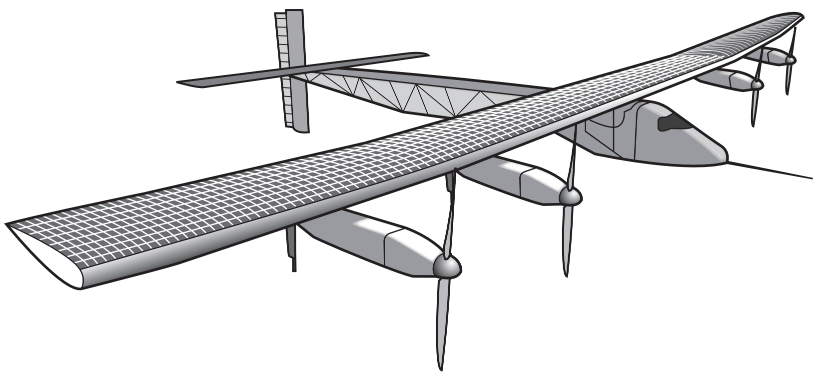
Fig. 1

Diagrammatic representation of the principle of the p-n junction photovoltaic cell.

The photovoltaic cell is a slice of p-n material. Its upper surface (the top of the n-type layer) has a grid of wires to collect the electrons which pass through the load and then back to the p-type layer. The upper surface can also be given a non-reflective coating to increase the efficiency of the cell. An individual cell can produce an e.m.f. of about 0.5 V. Combining a number of cells in series increases the e.m.f. of the system. Typically, a number of cells are combined in a module which produces an e.m.f. of 12 V. Such modules can be combined to produce e.m.f.s and currents suitable for a range of applications. In nearly all cases, the cells are used to recharge batteries to provide a constant source of power independent of light levels.

Solar Impulse 2

A solar-powered aircraft needs to be light and have a large surface area of wing for gliding and to provide a surface for the solar cells.



Solar Impulse 2 Data

Number of solar cells: 17 000

Total area of solar cells: 270 m^2

Mass of batteries: 630 kg

Energy storage in batteries: $9.4 \times 10^5\ J\,kg^{-1}$

Total mass of plane: 2300 kg

Efficiency of solar cells: 23%

Wingspan: 72 m

Fig. 2 Solar Impulse 2

The skin of the wings is supported by an internal frame made from carbon fibre which is low-density, stiff and strong. The plane does not fly at a constant height; during daylight, when there is sufficient light to power the motors and recharge the batteries, it rises to a height of 8500 m. At night it glides down to a height of about 1500 m over a period of 4 hours. After this, the motors are powered by the batteries until the cycle repeats the next day.

Juno

The Atlas V rocket that launched Juno did not give the spacecraft sufficient energy to climb the gravitational potential well from Earth to Jupiter. To gain more energy, after orbiting the Sun for two years, Juno swung past the Earth, picked up kinetic energy from the planet and headed out for Jupiter.

This is a process known as a gravitational slingshot. Simplifying the situation greatly, imagine the situation shown in Fig. 3, where V_S is the velocity of the spacecraft relative to the Sun and V_E is the velocity of the Earth relative to the Sun.

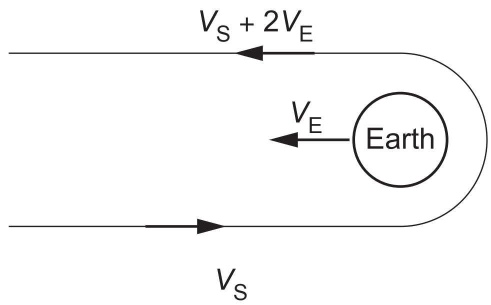
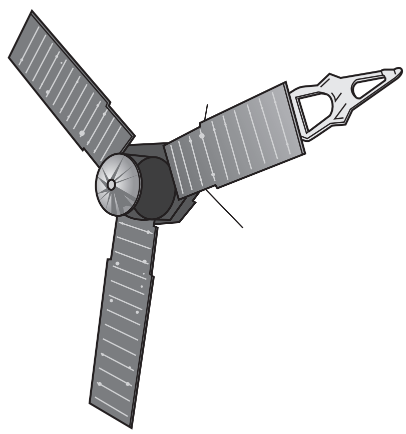


Fig. 3 Velocities of approach and recession of spacecraft to Earth, relative to the Sun.

From the point of view of an observer on the Earth, the spacecraft approaches at velocity $V_S + V_E$. The spacecraft swings past the Earth and leaves at the same speed relative to the Earth that it approached. But relative to the Sun things look rather different; its initial velocity is V_S and when the spacecraft is travelling away with a velocity $V_S + V_E$ relative to the Earth it will be travelling relative to the Sun at velocity $(V_S + V_E) + V_E = V_S + 2V_E$.

Of course, spacecraft do not make head-on approaches to planets in this manner but this simplification shows the basic principle. When Juno performed the slingshot manoeuvre with the Earth, it increased its speed from $3.5 \times 10^4\,\text{m s}^{-1}$ to $4.2 \times 10^4\,\text{m s}^{-1}$.



Juno Data
number of solar cells: 19 000
total area of solar cells: $60\,\text{m}^2$
mass of spacecraft: 3600 kg

Fig. 4 Juno's three solar-cell arrays.

The intensity of solar radiation follows an inverse-square relationship with distance from the Sun. Jupiter is 5.2 astronomical units (AU) from the Sun; in other words, 5.2 times further from the Sun than the Earth is. The solar panels on Juno need to be as large and efficient as practicable. Powered only by the Sun, Juno will orbit Jupiter while sending valuable scientific data back to Earth. It is expected to make about 50 orbits of the planet until its instruments and solar cells are too damaged by radiation to be of further use and the spacecraft will be directed to fall towards Jupiter, burning up in the atmosphere of the giant planet.

Juno and Solar Impulse 2 show that solar cells have a bright future – even in the darker reaches of the Solar System.

END OF ADVANCE NOTICE ARTICLE

38 A student performs Young's double slit experiment as shown in **Fig. 38.1**.

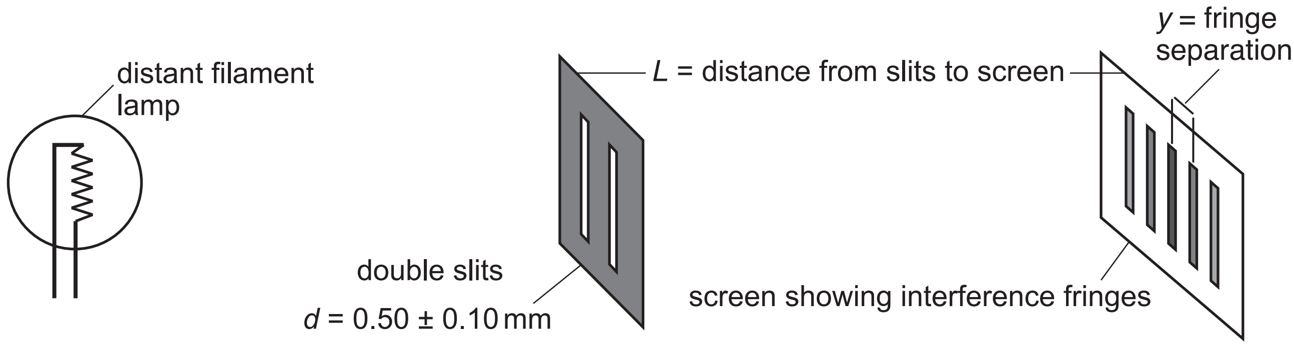


Fig. 38.1

The student investigates how the fringe spacing y varies with the distance L from slits to screen.
The student measures the slit separation d = 0.5 ± 0.1 mm.
Fig. 38.2 shows the data obtained with uncertainties.

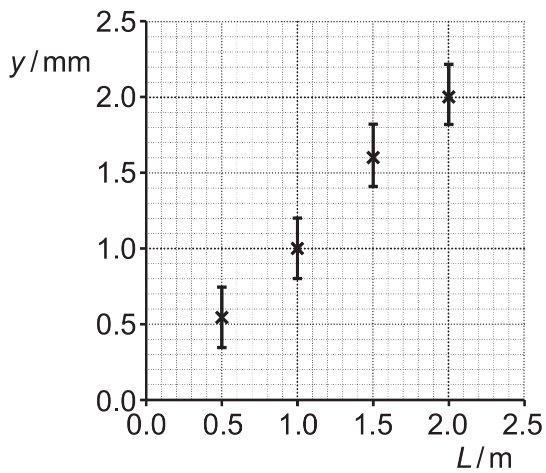


Fig. 38.2

(a) Suggest a reason why only uncertainties in the fringe spacing are shown on the graph.

....

.... **[1]**

(b) Draw a line of best fit on the graph and measure its gradient with an uncertainty estimate.

gradient = ... ± .... **[3]**

(c) Use the gradient to estimate an average wavelength for the light together with an uncertainty estimate. Make your method clear.

wavelength = ... ± .... m **[3]**

(d) State **one** way in which you could refine or develop this practical design or procedure to reduce uncertainty.

....

.... **[1]**

4 **(a)** Fig. 4.1 shows a section of a uniform string under tension at one instant of time. A progressive wave of wavelength 80 cm is moving along the string from left to right. At the instant shown, the displacement of the string is zero at the point opposite the zero mark on the scale beneath the string.

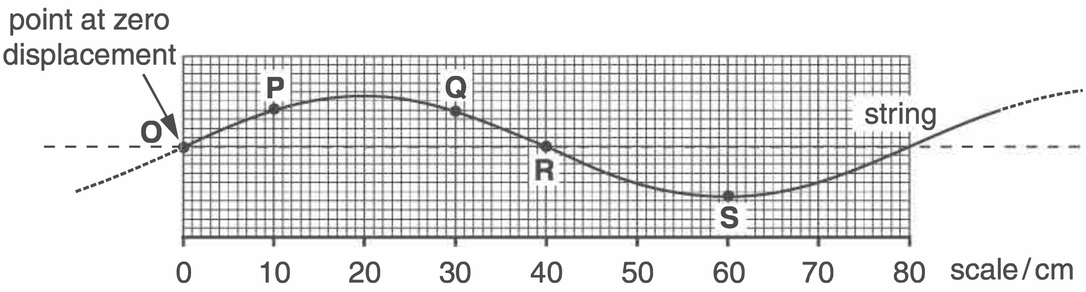


Fig. 4.1

Four points **P**, **Q**, **R** and **S** at 10, 30, 40 and 60 cm respectively, are marked on the string. The oscillatory motion of each point can be described in terms of amplitude, frequency and phase difference from **O**.

(i) State the meaning of each of the terms

1 *amplitude*

....

....

2 *frequency*

....

....

3 *phase difference*.

....

.... **[3]**

(ii) Describe using these three terms how the motion of points **P**, **Q**, **R** and **S**

1 is similar,

....

....

2 is different.

....

.... **[2]**

(b) Fig. 4.2 shows the same section of string now held under tension between a clamp and a pulley, 80 cm apart. A mechanical oscillator is attached to the string close to the clamped end. The frequency of the mechanical oscillator is varied until the stationary wave shown is set up between the clamp and the pulley. The same four points as in Fig. 4.1 are marked on the string.

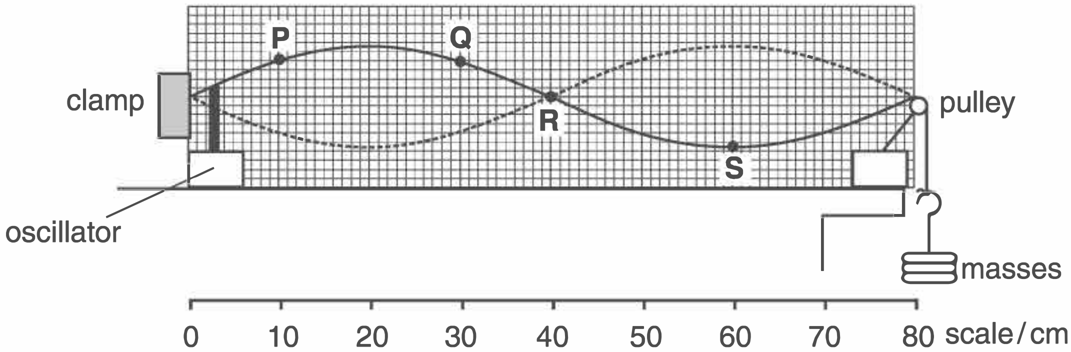


Fig. 4.2

(i) Describe how a stationary wave is different from a progressive wave.

....

....

....

....

.... **[2]**

(ii) Explain how the stationary wave is formed on this string.

....

....

....

....

....

.... **[3]**

(iii) Describe, using the terms amplitude, frequency and phase difference, how the motions of the points **P**, **Q** and **S**

1 are similar,

....

....

2 are different.

....

.... **[3]**

(iv) In Fig. 4.2 the frequency of oscillation is 30 Hz. State, with a reason, the lowest frequency of oscillation of the string at which the motions of all of the points **P**, **Q**, **R** and **S** are

1 in phase,

....

....

2 all at rest.

....

.... **[4]**