8 Microwaves are a form of electromagnetic waves which has wavelengths ranging from one meter to one millimetre with frequencies between 300 MHz and 300 GHz. Microwaves are very widely used in today's world. They are used for point-to-point communication links, wireless networks, satellite and spacecraft communication, cancer treatment, collision avoidance systems, garage door openers and keyless entry systems, and for cooking food in microwave ovens.

Microwaves are divided into sub-bands based on their wavelengths. Some bands of microwaves and their applications are shown in Fig. 8.1.

<table>
<tr><th>Band</th><th>Wavelength range</th><th>Applications</th></tr>
<tr><td>L</td><td>15 cm to 30 cm</td><td>Used in navigations, GSM mobile phones, and in military applications</td></tr>
<tr><td>S</td><td>7.5 cm to 15 cm</td><td>Used in navigation beacons, optical communications, microwave ovens and wireless networks</td></tr>
<tr><td>C</td><td>2.0 cm to 7.5 cm</td><td>Used in long-distance radio telecommunications as they can penetrate clouds, dust, smoke, snow, and rain</td></tr>
<tr><td>X</td><td rowspan="4">25 mm to 6.0 mm</td><td rowspan="4">Used in satellite communications, broadband communications, radars, space communications, and amateur radio signals</td></tr>
<tr><td>Ku</td></tr>
<tr><td>K</td></tr>
<tr><td>Ka</td></tr>
</table>

Fig. 8.1

Some properties of microwaves are listed below.

- Microwave transmission is affected by wave effects such as reflection, refraction, diffraction and interference.
- When microwaves interact with materials, some of the energy can be absorbed or transmitted while a portion of it can be reflected. The microwave energy absorbed by the material is converted to heat.
- Metal surfaces are considered reflectors of microwaves while most of the microwave energy can pass through glass and plastics. Rubber-based materials are considered good absorbers of microwaves.
- Microwaves follow the law of reflection, which states that the angle of incidence equals to the angle of reflection, where both angles are measured between the beam and the normal of the surface.

There are many different types of experiments which can be used to determine the wavelength of microwaves. One of the ways is described below.

A monochromatic microwave transmitter T and a receiver R are arranged on a straight line marked on the bench. A thin metal sheet M is placed on the marked line perpendicular to the bench, at the mid-point between the R and T.

Fig. 8.2 shows the side and plan views of the arrangement. The circuit connected to T and the ammeter connected to R are only shown in the plan view.

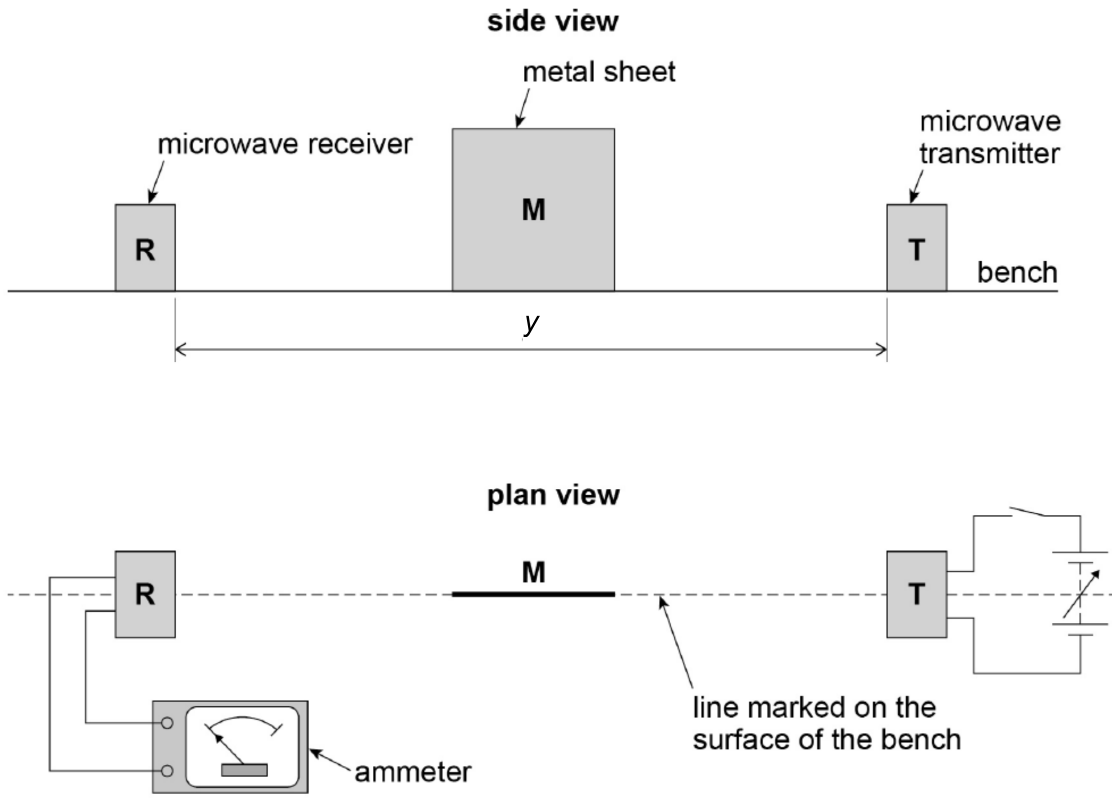

Fig. 8.2

The distance y between T and R is recorded.

T is switched on and the output from T is adjusted so a reading is produced on the ammeter as shown in Fig. 8.3.

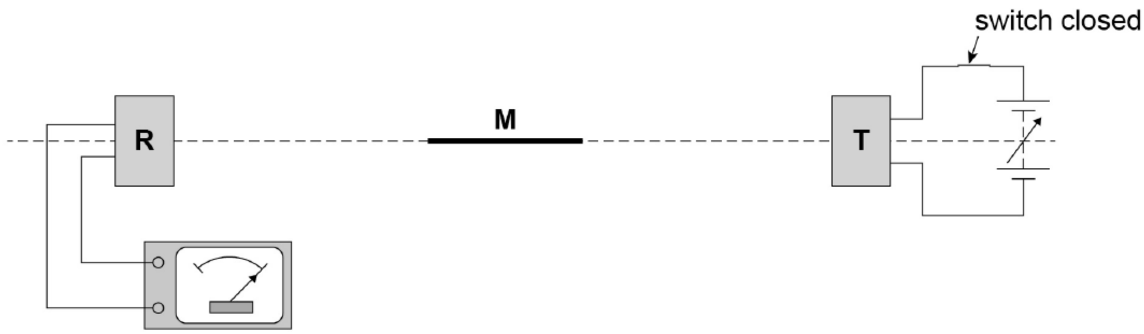

Fig. 8.3

M is kept parallel to the marked line and moved slowly away as shown in Fig. 8.4.

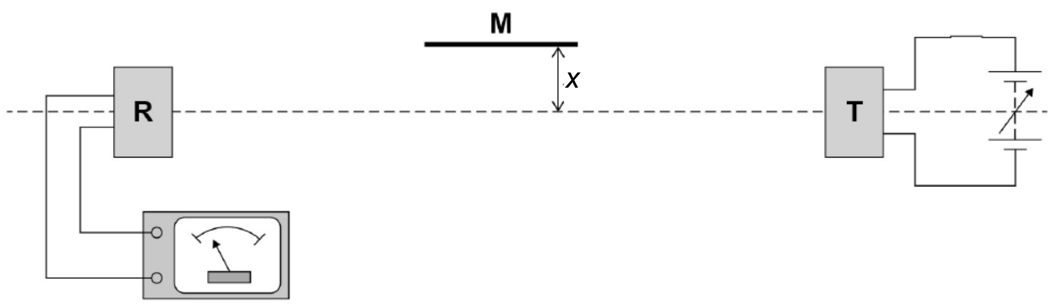

Fig. 8.4

The ammeter reading decreases to a minimum reading **which is not zero**. The ammeter reading depends on the superposition of waves travelling directly to R and other waves that reach R after reflection from M.

The perpendicular distance x between the marked line and M is recorded.

(a) State the phase difference between the sets of waves superposing at R when the ammeter reading is a minimum.

phase difference = ………………….. rad [1]

(b) **(i)** In Fig. 8.4, draw the two paths of the microwaves which results in the ammeter reading due to superposition at the receiver.

[2]

(ii) By considering the principle of superposition, explain why the minimum reading of ammeter is **not zero**.

…………………………………………………………………………………………...

…………………………………………………………………………………………...

…………………………………………………………………………………………………..

…………………………………………………………………………………………………..

…………………………………………………………………………………………………..

…………………………………………………………………………………………………..

………………………………………………………………………………………… [3]

(c) When M is moved further away, the reading increases to a maximum then decreases to a minimum.

At the first minimum position, a student labels the minimum n = 1 and records the value of x.

The next minimum position is labelled n = 2 and the new value of x is recorded. Several positions of maxima and minima are produced.

(i) Describe a procedure that the student could use to make sure that M is parallel to the marked line before measuring each value of x.

……………………………………………………………………………………………...

……………………………………………………………………………………………...

……………………………………………………………………………………………...

………………………………………………………………………………………… [2]

(ii) There is a phase change of π radians upon reflection at the surface M. By considering the path difference of the waves arriving at R, show that the equation

$$n\lambda = \sqrt{4x^2 + y^2} - y$$

holds when the ammeter reading is a minimum, where λ is the wavelength of the microwaves and y is the distance defined in Fig. 8.2.

(d) The variation of $\sqrt{4x^2 + y^2}$ with n is shown in Fig. 8.5.

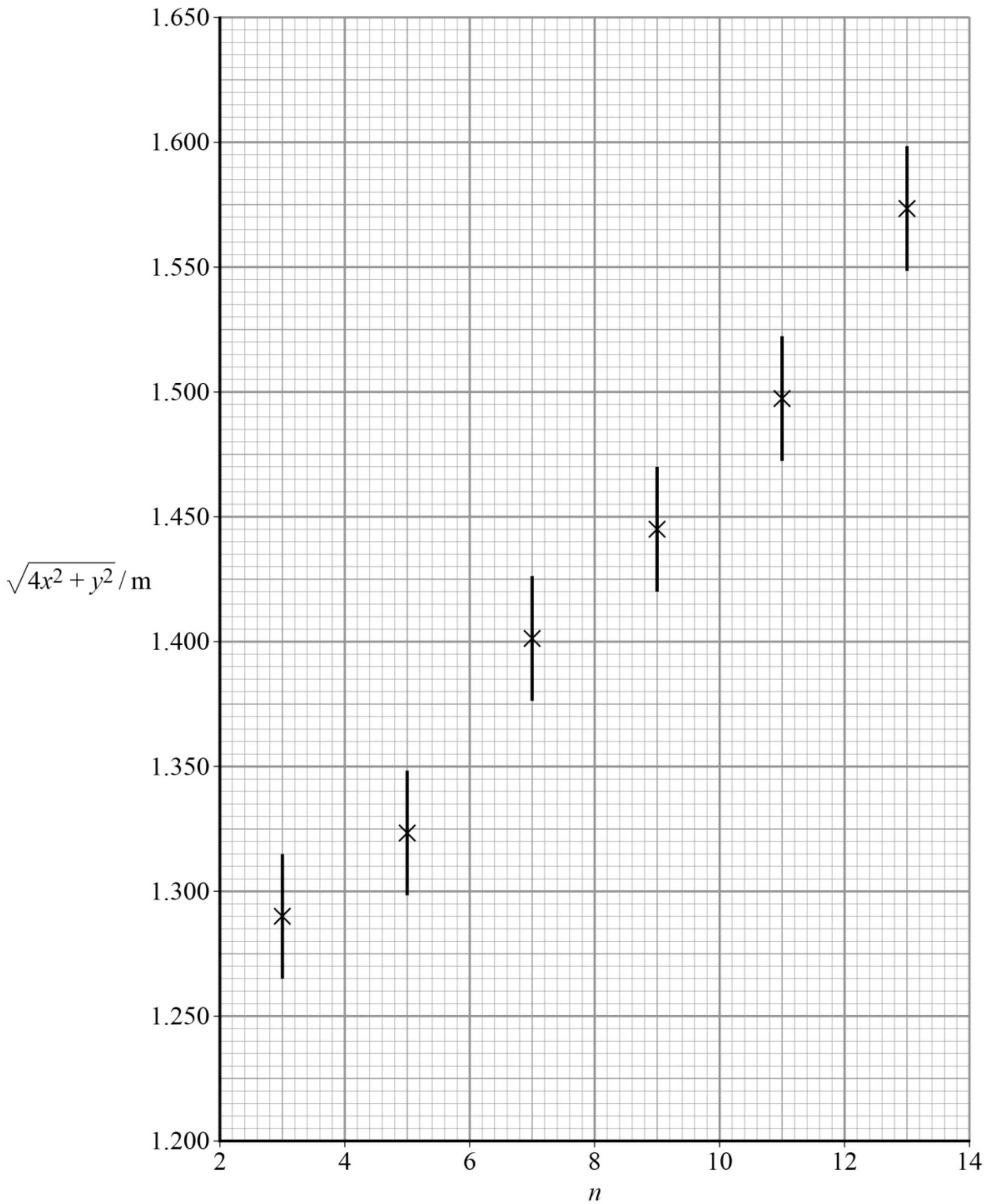

Fig. 8.5

The student estimates the uncertainty in each value of $\sqrt{4x^2 + y^2}$ to be 0.025 m and adds error bars (as indicated by the vertical lines at each point) to the graph.

Determine

(i) the maximum gradient G_{max} of a line that passes through all the error bars,

G_{max} = ………………….. m [2]

(ii) the minimum gradient G_{min} of a line that passes through all the error bars,

G_{min} = ………………….. m [2]

(iii) the average value of λ,

λ = ………………….. m [1]

(iv) the band of the microwave that is used in the experiment,

……………………………………………………………………………………… [1]

(v) the percentage uncertainty in value of λ found.

percentage uncertainty = ………………….. %   [2]

(e) Another student performed a separate set of experiments by varying the values of y to obtain the different values of x for which the first minimum reading is obtained by the ammeter.

The set of readings obtained is shown in Fig. 8.6.

y / cm	4.5	22.3	55.5	99.5
x / cm	2.9	5.8	9.0	12.0

Fig. 8.6

The student proposed that x and y are proportional to each other.

Use the values in Fig. 8.6 to conclude whether this student's proposal is valid.

……………………………………………………………………………………………………...

…………………………………………………………………………………………………   [2]

(f) The experiment is repeated by a third student who has initially placed the thin plate M very close to the transmitter T instead, as shown in Fig. 8.7.

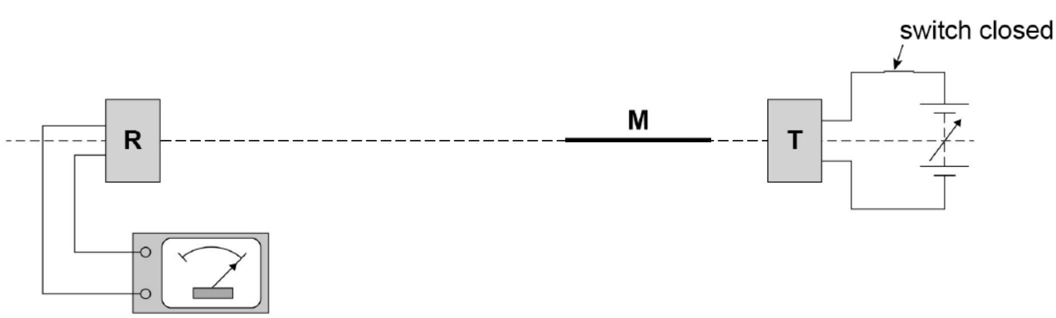

Fig. 8.7

Plate M is again moved away parallel to the marked line over a small distance. Explain why the ammeter reading does not vary.

……………………………………………………………………………………………………….

……………………………………………………………………………………………………….

…………………………………………………………………………………………….. [2]

[Total: 23]

BLANK PAGE

BLANK PAGE

BLANK PAGE