Reflection, transmission and refraction of microwaves (Item No.: P2460303)

Curricular Relevance

Area of Expertise: Physics

Education Level: University

Topic: Electricity and Magnetism

Subtopic: Maxwell's Equations, Magnetism, Electromagnetic Waves

Experiment: Reflection, transmission and refraction of microwaves

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Easy	20 Minutes	10 Minutes	1 Student

Additional Requirements:

Experiment Variations:

Keywords:

Microwaves, electromagnetic waves, reflection, transmission, refraction, absorption, polarisation

Introduction

Overview

When electromagnetic waves impinge on an obstacle, reflection, transmission and refraction may occur. The aim of this experiment is to demonstrate and describe these phenomena with the aid of microwaves.

Fig. 1: Experiment set-up (law of reflection).

Background knowledge

When electromagnetic waves impinge on a surface, different interactions may result: Part of the radiation will be reflected, transmitted and absorbed (energy will be transferred to the material). The reflection follows the law of reflection (angle of incidence = angle of reflection). During the transition into another medium, a change in propagation time and, thereby, a change of the direction of propagation of the wave (refraction) may occur. The aim of this experiment is to investigate these phenomena and to verify the law of reflection.

Equipment

Position No.	Material	Order No.	Quantity
1	Microwave set II, 110...240 V	11743-99	1

Overview of the parts of the microwave set.

Tasks

First, demonstrate the phenomena of reflection, transmission and refraction based on various materials. Then verify the law of reflection (angle of incidence = angle of reflection).

Set-up and procedure

First part: Reflection, transmission and refraction

Transmission and absoprtion of microwaves by various materials

Set the experiment up as shown in Fig. 2.

Fig. 2: Experiment set-up using metal sheet.

Connect the microwave transmitter, receiver, and loudspeaker to the power supply via the three ways cable, and connect the receiver and the loudspeaker with the receiver - loudspeaker connection cable (Fig. 3).

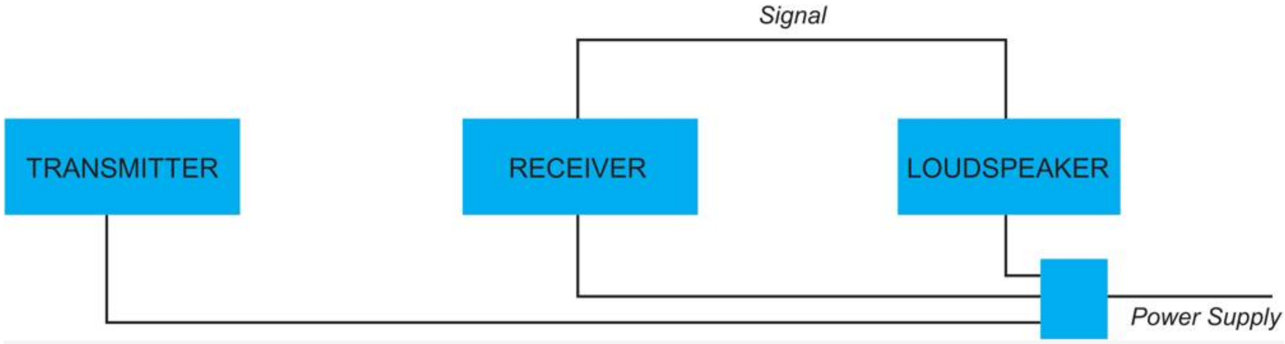

Fig. 3: Set-up of the experiment connections.

To assemble the articulated track with protractor, (1) first hook the short arm (having connection flange) to the long one (having pivot). (2) Then put the washer in the pivot. (3) Insert the protractor on the pivot at 0°, and (4) screw the black PVC yoke onto the pin (Fig. 4).

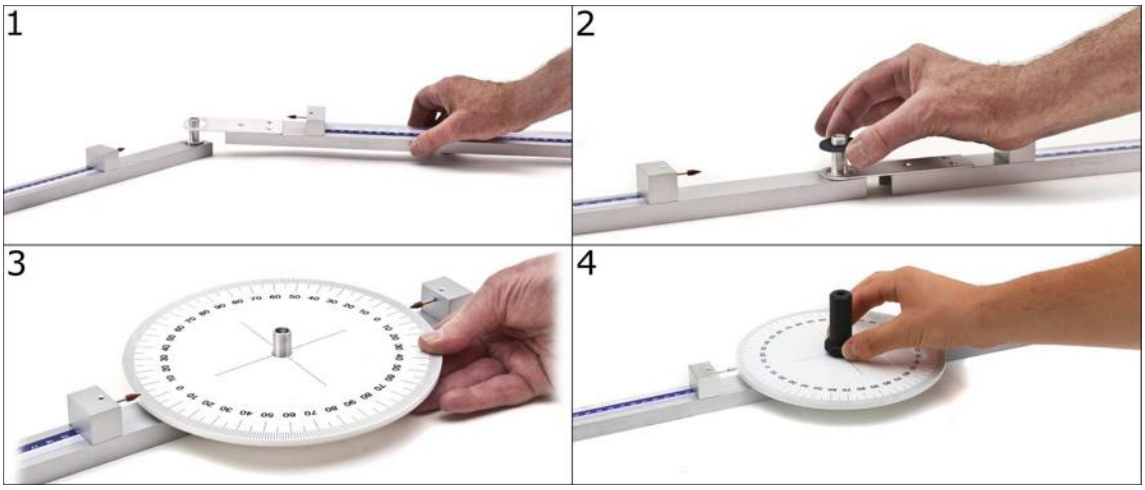

Fig. 4: Set-up of rail.

Position the transmitter and the receiver both 25-30 cm away from the centre of rotation of the rail. Plug in the power supply. Turn the volume knob on the loudspeaker slightly to the right to obtain a sound that can be heard at a distance of a few meters.

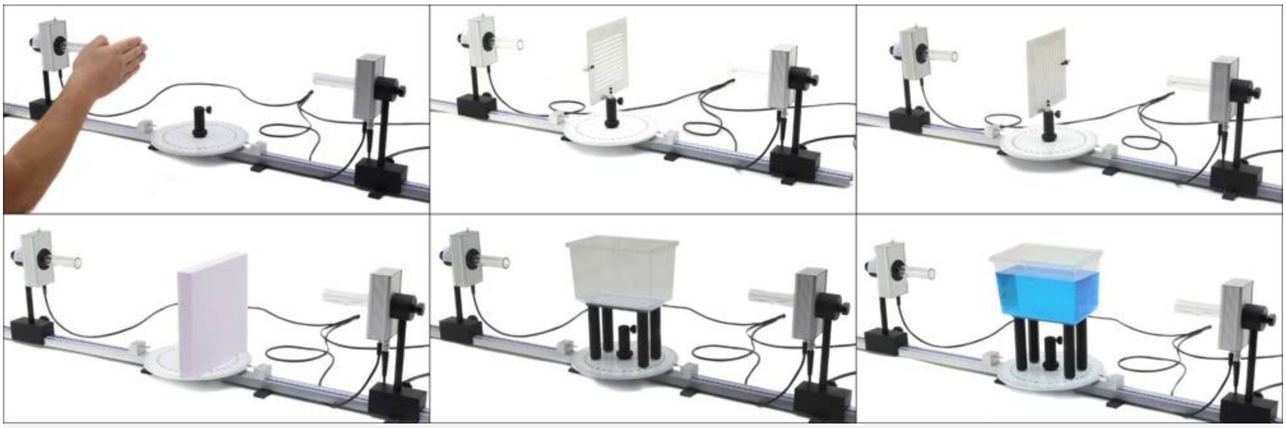

Fig. 5: Various materials in the beam path (examples).

Position the following objects one after the other in the beam path in the centre of rotation of the protractor (see Fig. 5): metal sheet (Fig. 2), hand, grating (horizontal and vertical alignment), polystyrene panel, empty plexiglass tray (on tray support), and tray filled with water. Use other objects from your environment as well, e.g. a writing pad, a microwave dish, or a lunch box made of plastic. If necessary, use the additional protractor with pin or the tray support to hold larger objects.

Record what happens to the signal for each of the objects placed in the beam path.

Refraction with prism

Remove all of the objects from the beam path and position the paraffin prism in the centre of rotation on the protractor with pin (see Fig. 6).

Fig. 6: Positioning of the prism on protractor with pin.

Just as an optical prism is able to produce the refraction of light, a paraffin prism produces a refractive effect on the microwaves that follows the same optical laws as the refraction of light rays. Set-up the next experiment as show in Fig. 7.

In this position the angle at the vertex is $A = 45^\circ$, while the value of the angle of incidence i can be read on the upper goniometer. Choose, for example, that $i = 30^\circ$ (refer to equation 2 and Fig. 13).

Fig. 7: Set-up for microwave refraction using the prism.

With the receiver aligned with the transmitter, note down the signal response. Then hold the left branch, slowly rotate the right one and take note of the position at which the signal reaches the maximum value (Fig. 8). You can thus evaluate the total deviation angle d, taking into account the position on the lower protractor, of the branch's index on which the receiver is placed.

Fig. 8: Rotated prism.

With a known angle at the vertex A, angle of incidence i, and total deviation angle d, the value of the angle e exiting the prism can be determined.

Second part: Law of reflection

Microwaves reflection

Set the experiment up as shown in Fig. 9.

Fig. 9: Experiment set-up (law of reflection).

The reflecting plate (metal sheet) must be aligned with the zero of the protractor while the branch on which the transmitter is arranged must form an angle of 45° with the zero on the protractor.

Switch on the devices and select the internal modulation. Adjust the volume of the signal received just below the audibility threshold. Then, while holding the left branch of the guide, slowly rotate the right one. Rotate until the angle formed by the left branch with the zero of the protractor is 45°, as seen in Fig. 10. Take note of what happens to the received signal intensity.

Fig. 10: Final positioning of system.

Total reflection of microwaves

In the next experiment, you will use the phenomenon of total reflection that shows itself in the passage of a wave from a propagation medium with a refractive index n to the air. The purpose of this experience is to determine the refractive index of the supplied paraffin, at a frequency of 10.5 GHz, which will approximately have a value included between 1 and 1.4.

Arrange the system as shown in Fig. 7, and place the prism as shown in Fig. 6. The wave reaches the prism in a perpendicular direction, so it is not deflected. It then continues in the same direction and reaches the inclined face of the prism according to an angle of 45° (Fig. 11).

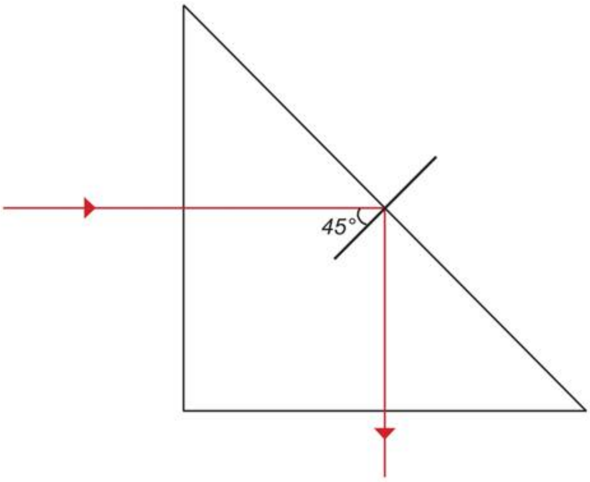

Fig. 11: Prism at 45° angle.

Rotate the arm at 90° (Fig. 12), and take note of what happens to the signal.

Fig. 12: Arm rotated about 90°.

Note

During the experiment, do not stand in the direct vicinity of the beam path. The human body reflects microwaves so that the measurement result may be invalidated. The same applies to all types of metallic objects. If several experiments are performed simultaneously in a laboratory, ensure sufficient distance between the experiment stations in order to avoid interference signals caused by reflected radiation and/or scattered radiation from the other set-ups. Stay in the direct vicinity of the set-up only for adjusting the angle.

Evaluation and results

First part: Reflection, transmission and refraction

Transmission and absoprtion of microwaves by various materials

Absorption and transmission of microwaves give important qualitative information about the physical properties of substances that interact with electromagnetic waves. Take into account, for example, the absorption. When crossing a layer of thickness x, it is observed that the intensity of the transmitted radiation follows Lambert's law:

$$I = I_0 \cdot e^{-kx} \quad (1)$$

where k is the absorption coefficient of the material at a known frequency.

If, for a given frequency, a material has $k = 0$, then it has zero absorption. Of course, the same material can be transparent for certain frequency and absorbent for other ones. It is known that electrical insulators are generally transparent to microwaves and visible light, instead they strongly absorb ultraviolet radiation. It is a common experience that solid insulators such as diamond, quartz, and kitchen salt are transparent crystals. If the insulating material is an ionic crystal, we can observe a strong absorption in the infrared frequencies. The first type of absorption is due to the electrons of the solid, the second one is due to the oscillations of the ions. Semiconductors absorb visible light. This is the reason why silicon solar cell panels appear black. A high absorption coefficient is associated with an high reflectivity. Metals absorb and reflect on the whole spectrum, even in the far infrared and in the microwave region.

When placing a metal body (e.g. the metal sheet) between the transmitter and receiver, there is no microwave passage and the signal is totally absent.

The transmissivity of the grating depends on the angle (vertical or horizontal: see also the experiment P2460203 "Polarisation of microwaves"). In the horizontal position, the acoustic signal maintains its intensity. In the vertical position, the acoustic signal is extinguished.

There is no attenuation of the signal with the polystyrene panel. The plexiglass tray without water also results in no signal attenuation. The result will remain the same with other electrically insulating materials (e.g. wood, cork, etc.): the insulating materials let the microwaves go through. It should be noted that depending on the type of material, a partial, more or less evident, reflection of the microwaves may occur.

When the tray is filled with water, the signal is totally absent; the microwaves are absorbed by the water. The law that describes this phenomenon of absorption is Lambert's law (equation 1). This means that the water layer does not allow microwaves to reach the receiver. It is precisely for this reason that submarines and boats use sonar and not the radar system. Check if the same thing happens even when the microwaves cross the short side of the tray.

A further confirmation that the microwaves are absorbed by the water can be seen by placing the hand between the transmission and the receiver as in Fig. 5. Also in this case the signal is almost totally attenuated. The explanation of the phenomenon lies in the fact that the human body contains on average 75% of water. The peak of water absorption is at the frequency of 2,450 GHz.

By emitting electromagnetic energy at the same vibration frequency of the water molecule, the phenomenon of electromagnetic resonance occurs. In such conditions, the total absorption of electromagnetic energy by the water is induced, obtaining the maximum possible heating. This explains why a microwave oven, with a power of a few hundred watts, is able to heat in a few moments a food that, in a traditional oven, requires ten minutes of heating to reach the same temperature level. In the microwave oven the methods of diffusion of heat in the food are different: while in the traditional oven the heat attacks the surface of the food and then, by conduction, the heat also spreads inside (which entails the greatest "burn" of the surface), with the microwave oven the heat spreads very homogeneously. In fact it is the internal matter (water in this case) to collect the electromagnetic energy and to transmit it around itself.

Refraction with prism

In addition to reflection and transmission, waves can experience refraction when passing through different media. This is why you will find the maximum intensity at an angle when the prism is present in the optical path.

If the receiver is aligned with the transmitter, it receives no signal because the wave beam sent by the transmitter is deviated from the prism.

After the bench is rotated, and the total deviation d is determined, the value of the angle e exiting the prism can be determined.

For geometric considerations, we have that

$$d = i + e - A. \quad (2)$$

Using this formula, knowing the values of i, A, and d, you are able to calculate the angle's value e (Fig. 13).

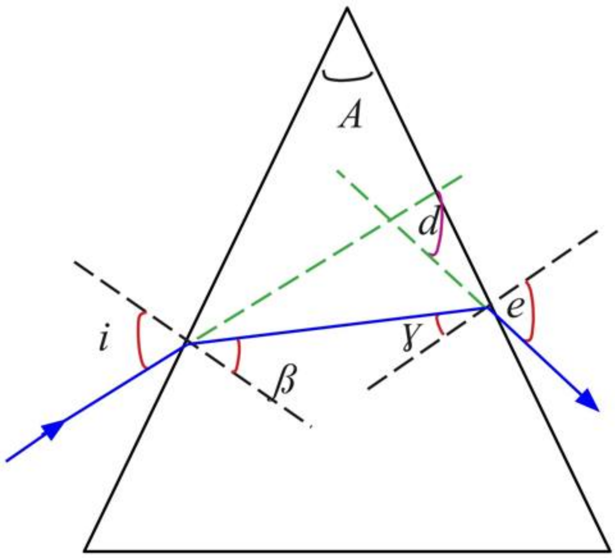

Fig. 13: Geometric representation.

Second part: Law of reflection

Microwaves reflection

During the experiment, once the rail is rotated slowly, you will notice that the received signal increases in intensity and becomes maximum when also the angle formed by the left branch with the zero of the protractor is 45° to prove that the signal reflected by the plate in maximum when the angle of reflection is equal to the angle of incidence (see Fig. 10).

Total reflection of microwaves

The refraction index n is a quantity that depends, at a given temperature, both on the material and on the wavelength of the incident radiation. Paraffin is a variable mixture of alkanes (C_nH_{2n+2}), characterized by refractive indices ranging from 1 to 1.4, in case of microwaves.

The index of refraction n is linked to the limit angle l from the relation

$$n = 1/sin(l). \quad (3)$$

Thus the value of l must be known to calculate the value of n.

If this angle is greater than the limit angle, then the ray is totally reflected, otherwise it is refracted. In the experiment with a prism inclined face angle at 45° and the rail arm rotated to 90°, the signal is found to be maximum when the arm is rotated about 90°, in the direction of the totally reflected ray (Fig. 12). This means that l is slightly less than 45° which corresponds to a refractive index of about 1.4.