Conservation of energy during the reflection and transmission of microwaves (Item No.: P2460601)

Curricular Relevance

Area of Expertise: Physics

Education Level: University

Topic: Electricity and Magnetism

Subtopic: Maxwell's Equations, Magnetism, Electromagnetic Waves

Experiment: Conservation of energy during the reflection and transmission of microwaves

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Intermediate	10 Minutes	20 Minutes	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Microwaves, electromagnetic waves, reflection, transmission, polarisation, conservation of energy, conservation laws

Overview

Introduction

When electromagnetic waves impinge on an obstacle, reflection, transmission, and refraction may occur. The aim of this experiment is to describe the relationship between reflection and transmission with the aid of a polarisation grating and to verify conservation of energy.

Note

Prior to performing this experiment, it would be helpful, though not mandatory, to perform the experiments P2460201 "Polarisation of microwaves", P2460301 "Reflection, transmission and refraction of microwaves" and P2460501 "Standing waves in the microwave range".

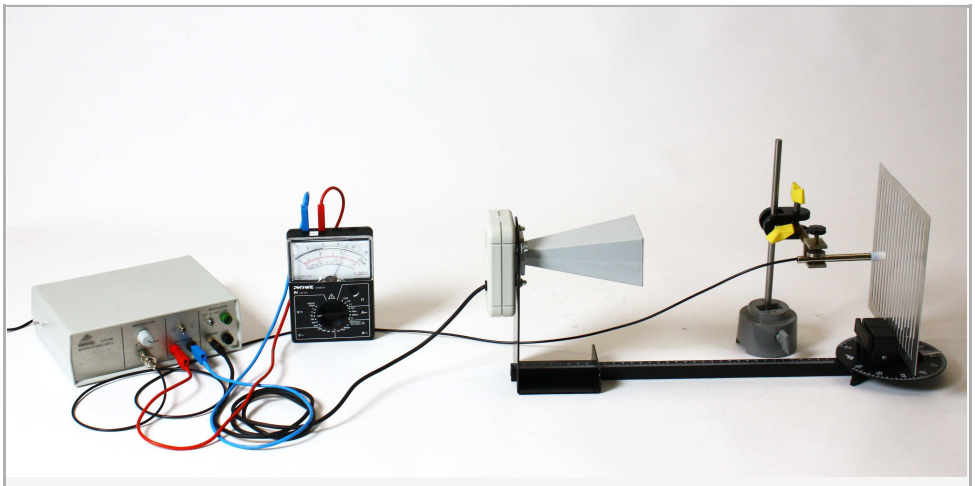


Fig. 1: Experiment set-up

Equipment

Position No.	Material	Order No.	Quantity
	Microwave set:	11742-93	1
1	Microwave control unit		(1)
3	Microwave transmitter		(1)
4	Microwave probe		(1)
5	Angle scale		(1)
6	Meter rule		(1)
11	Grating		(1)
	Additionally required:		
14	Multi-range meter, analogue	07028-01	1
15	Connecting cord, 32 A, 750 mm, red	07362-01	1
16	Connecting cord, 32 A, 750 mm, blue	07362-04	1
17	Barrel base PHYWE	02006-55	1
18	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	1
19	Right angle clamp PHYWE	02040-55	1
20	Plate holder	02062-00	1
	Optional:		
21	Geometry set square	09937-10	(1)



Overview of the parts of the microwave set

Tasks

Use a polarisation grating in order to demonstrate the relationship between reflection and transmission.

Theory

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 (see also the experiment P2460301 "Reflection, transmission and refraction of microwaves").

The aim of the following experiment is to examine the partial reflection from and transmission through a polarisation grating.

In order to understand the phenomena of reflection and transmission, we will look at the amplitude of the electric field strength during the reflection. Since a standing wave forms between the reflecting object (here: metal plate) and the transmitter (metallic housing) (see also the experiment P2460501 "Standing waves"), the amplitude E_S that is measured in the antinode includes the part E_R (amplitude of the reflected wave) and the part E_0 (amplitude of the primary radiation of the transmitter). The following applies:

$$E_S = E_0 + E_R \tag{1}$$

The following is true for the part of the radiation that is reflected:

$$R = \frac{E_R}{E_0} \tag{2}$$

Accordingly, the following is true for the part of the radiation that is transmitted:

$$T = \frac{E_T}{E_0} \tag{3}$$

Here, E_T is the amplitude of the transmitted radiation. The sum of the reflected part R and transmitted part T is constant due to the conservation of energy. Since it is a relative quantity (percentage) by definition, the following must be true for the sum:

$$R + T = 1 \tag{4}$$

As far as this experiment is concerned, the quantities R and T are not directly accessible, since intensities (and not amplitudes) are measured. Since the amplitudes are included in the intensity in a square manner, they can be obtained from the voltage signals, which is proportional to the intensity.

$$R = \frac{E_R}{E_0} = \sqrt{\frac{U_R}{U_0}} \tag{5}$$

or

$$T = \frac{E_T}{E_0} = \sqrt{\frac{U_T}{U_0}} \tag{6}$$

When determining the reflected part R, it must be taken into consideration that, at the location of the measurement, the reflected intensity is superimposed by the primary beam of the microwave transmitter (see equation 1). This is why, for the determination of U_R, first the superimposed signal U_S is measured. Then, it its corrected based on the proportion of the primary beam U_0:

$$\sqrt{U_R} = \sqrt{U_S} - \sqrt{U_0} \tag{7}$$

In the present experiment, a polarisation grating is used for adjusting various reflection and transmission parts. With this grating made of metal bars, the transmissivity depends on the angular orientation of the grating (angle α) relative to the constant polarisation of the microwaves as it is defined by the transmitter: Only the projection of the electric field vector in the transmitting direction will actually be transmitted; the remaining part of the radiation will be reflected by the metallic grating (a detailed description concerning the polarisation can be found in the experiment P2460201 "Polarisation of microwaves"). The part of the transmitted intensity $I(\alpha)$ follows

$$I(\alpha) = I_0 \cdot \cos^2(\alpha) \tag{8}$$

As a consequence, the reflection and transmission parts can be adjusted in an infinitely variable manner by turning the grating in the beam. For this experiment, five angular alignments are used as an example for the demonstration of the law of conservation of energy. The absorption on the grating can be neglected.

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Please note that microwaves that are reflected by the grating will be reflected to the transmitter. This transmitter has a metallic housing, which is also reflective, so that a standing wave will form between the transmitter and grating. This means that, among other things, the intensity will disappear at the location of the grating, since there is an oscillation node. If the reflected part of the intensity is to be determined, this must be performed at a different location, i.e. at the location of the antinode. A detailed description of standing waves can be found in the experiment P2460501 "Standing waves in the microwave range".

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Set-up and procedure

Set the experiment up as shown in Fig. 2.

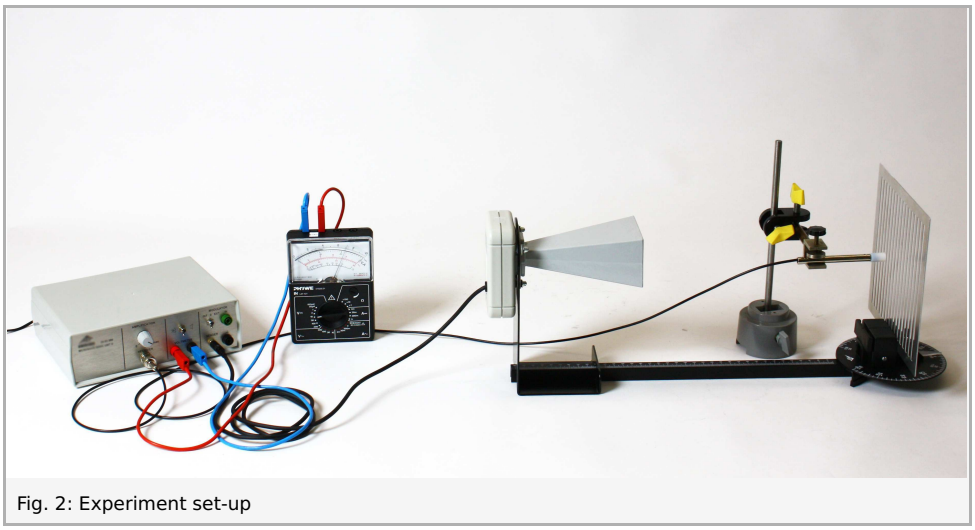


Fig. 2: Experiment set-up

Connect the microwave transmitter and probe to their associated sockets of the control unit. Connect the multi-range meter to the voltmeter output of the control unit and select the 10 V measuring range (direct voltage). The loudspeaker and internal or external modulation are not required for this experiment.
Combine the angle scale and meter rule by way of the screw on the back of the angle scale and the recess in the meter rule. Turn the meter rule in order to align the reference mark (arrow) on the angle scale with the one of the meter rule so that they coincide (see Fig. 3).

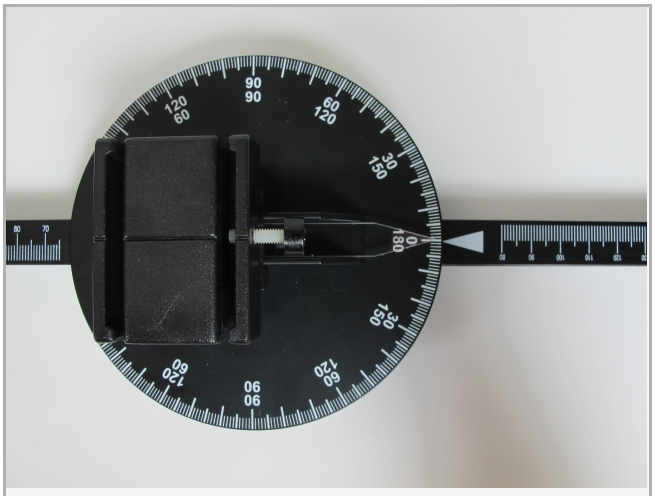


Fig. 3: Set-up and alignment of the angle scale and meter rule

Install the grating in the holder in the centre of rotation of the angle scale so that the grating rods are aligned horizontally. Secure the grating by way of the screws so that it cannot tilt or fall over. It must be absolutely ensured that the grating maintains its upright position during the experiment. Otherwise, the measurement would be severely invalidated.
Mount the probe on the support rod in the barrel base by way of the right angle clamp and plate holder (see Fig. 4). Ensure that the round mark near the measuring head points upwards. Position the transmitter at the far end of the angle scale (e.g. at 20 mm).

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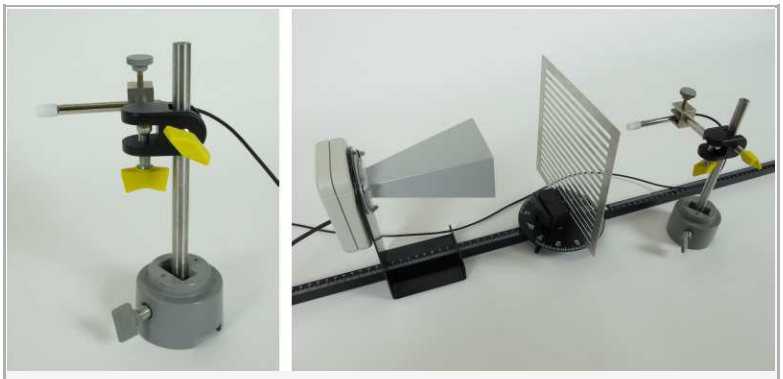


Fig. 4: Fastening of the probe and transmission measurement (here: horizontally aligned grating)

Position the probe in the beam path behind the grating so that the measuring head is located directly above the meter rule without being turned with regard to the direction of propagation of the radiation (see Fig. 4). Switch the microwave transmitter on by connecting the control unit to the mains power supply and set the amplitude controller to maximum. Check the height of the probe in its holder by varying the height of the right angle clamp in order to maximise the voltmeter reading. Move and turn the probe in order to test and ensure that it receives the maximum signal of the transmitted radiation.

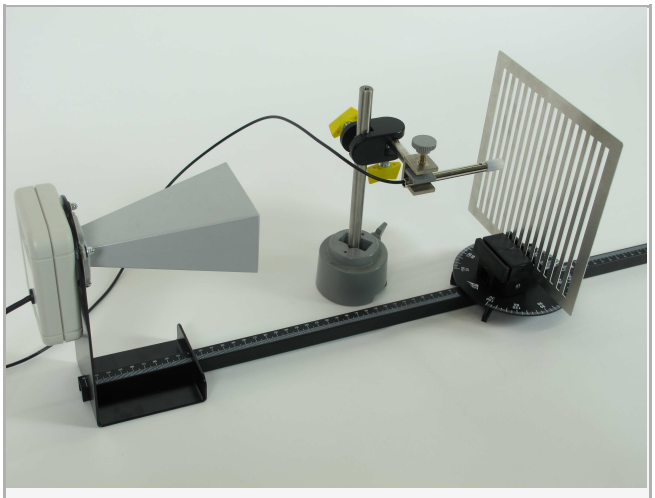


Fig. 5: Reflection measurement (here: vertically aligned grating)

Measure the voltage U_T as a measure of the intensity of the transmitted microwaves. Then, position the probe in front of the grating so that the measuring head faces the grating (see Fig. 5). Align the probe in the beam path as described above and ensure the exact determination of the position in the direction of the beam. To do so, move the probe in the direction of the beam to the location of the antinode of the standing wave between the transmitter and grating (see above). Measure the voltage (U_S) at this location. Then, remove the grating from the beam path in order to measure the intensity without the grating (U_0). Repeat the measurement of the three voltages U_T, U_S, and U_0 for various angles α by fastening the grating in the holder several times, each time turned by 45° (see Fig. 6). Use the set square in order to verify the angle (see also the experiment P2460201 "Polarisation of microwaves").

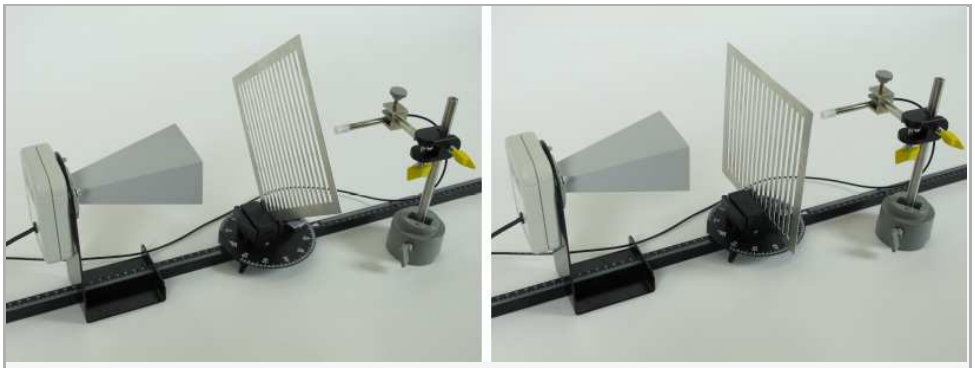


Fig. 6: Transmission measurement with various angles

Note

During the experiment, do not stand in the direct vicinity of the beam path when reading the voltmeter values. 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.

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Evaluation and results

Determine the reflection part R and the transmission part T for various angles and compare the sum $R+T$ to the expected value of 1.

Angle in °	-90	-45	0	45	90
U_T **in V**	3.625	1.400	0.300	1.700	4.700
U_S **in V**	4.850	8.100	9.200	7.000	5.100
U_0 **in V**	4.150	3.500	3.050	3.800	3.700
$\sqrt{U_T}$ **in** $\sqrt{\mathrm{V}}$	1.904	1.183	0.548	1.304	2.168
$\sqrt{U_S}$ **in** $\sqrt{\mathrm{V}}$	2.202	2.846	3.033	2.646	2.258
$\sqrt{U_0}$ **in** $\sqrt{\mathrm{V}}$	2.037	1.871	1.746	1.949	1.924
$\sqrt{U_R}$ **in** $\sqrt{\mathrm{V}}$	0.165	0.975	1.287	0.696	0.335
$R=\sqrt{U_R}/\sqrt{U_0}$	0.081	0.521	0.737	0.357	0.174
$T=\sqrt{U_T}/\sqrt{U_0}$	0.935	0.632	0.314	0.669	1.127
$R+T$	1.016	1.154	1.050	1.026	1.301
Deviation in %	1.6	15.4	5.0	2.6	30.1

Table 1: Reflection and transmission parts for various angles

Table 1 shows that the measurement values are subject to considerable errors. The prediction that $R+T=1$ could be confirmed (within the scope of the measurement accuracy).
If the values result in $R+T\neq 1$, this may be caused by a deviation of the probe position from the location of the antinode during the measurement of the reflected part or by turning the probe against the beam path. If the grating is not aligned absolutely precisely with regard to the intended angles, the result will also differ. In addition, a tilted grating or a grating that is twisted in the two remaining directions of rotation, or interference signals caused by reflections in the surroundings, may invalidate the measurement result regardless of any reading inaccuracies. A loss of radiation intensity through absorption or the transfer of heat into the grating (energy dissipation) does not have to be taken into consideration with the present set-up.

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