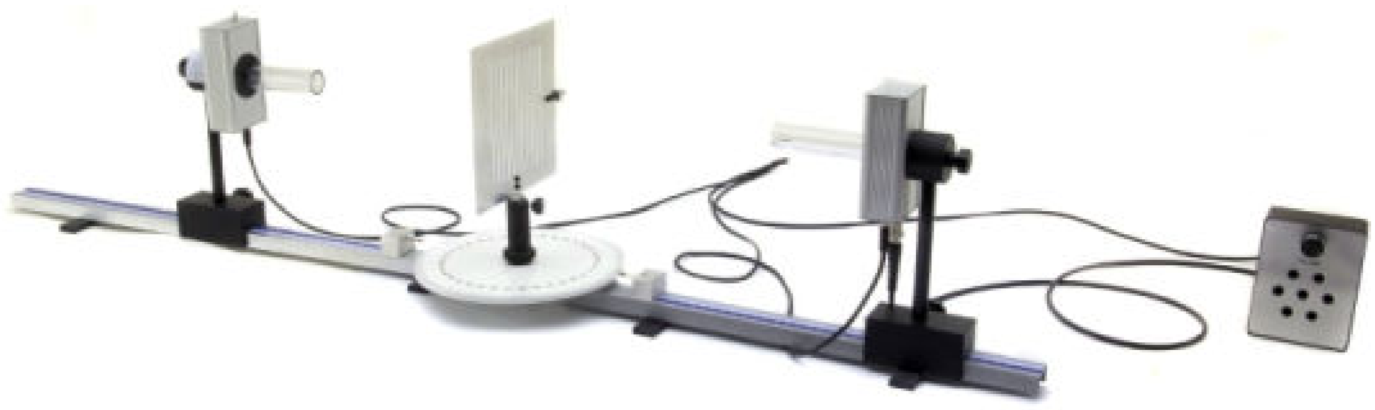
Conservation of Energy in Reflection and Transmission of Microwaves



P2460603

Physics	Mechanics	Vibrations & waves

Difficulty level	Group size	Preparation time	Execution time
-	2	20 minutes	30 minutes

This content can also be found online at:

http://localhost:1337/c/60585b0fb622c60003db462b

General information

Application

Microwaves communication towers

Microwaves are a type of electromagnetic waves, which can be reflected and transmitted when passing through a medium or an obstacle. The applications of microwaves can be found in:

- communications
- radar systems
- microwave heating system

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Other information (1/2)

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Prior knowledge

According the law of reflection, angle of incidence is equal to angle of reflection. Meanwhile, refraction of electromagnetic waves follows Snell's Law, which states that, $n_1 \, sin \, \theta_1 = n_2 \, sin \, \theta_2$.

Scientific principle

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.

Other information (2/2)

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Learning objective

Investigating transmission and reflection of microwaves through a grating.

Tasks

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

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Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

For H- and P-phrases please consult the safety data sheet of the respective chemical.

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.

Theory (1/5)

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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 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), 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).

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Theory (2/5)

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The following applies:

$$E_S = E_0 + E_R \qquad (1)$$

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

$$R = \frac{E_R}{E_0} \qquad (2)$$

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

$$T = \frac{E_T}{E_0} \qquad (3)$$

Here, E_T is the amplitude of the transmitted radiation.

Theory (3/5)

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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:

$$R + T = 1 \qquad (4)$$

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.

$$R = \frac{E_R}{E_0} = \sqrt{\frac{U_R}{U_0}} \qquad (5)$$

or

$$T = \frac{E_T}{E_0} = \sqrt{\frac{U_T}{U_0}} \qquad (6)$$

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Theory (4/5)

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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 :

$$\sqrt{U_R} = \sqrt{U_s} - \sqrt{U_0} \qquad (7)$$

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.

Theory (5/5)

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The part of the transmitted intensity $I(\alpha)$ follows

$$I(\alpha) = I_0 \cdot cos^2(\alpha) \qquad (8)$$

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.

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.

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Equipment

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

Setup and procedure

Setup (1/2)

Experimental set-up

Connect the microwave transmitter and receiver 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.

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Setup (2/2)

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.

Position the transmitter at the far end of the angle scale (e.g. at 20 mm).

Position the receiver 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. 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 receiver in order to test and ensure that it receives the maximum signal of the transmitted radiation.

Procedure

Measure the voltage U_T as a measure of the intensity of the transmitted microwaves. Then, position the receiver in front of the grating so that the measuring head faces the grating.

Align the receiver 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 receiver in the direction of the beam to the location of the antinode of the standing wave between the transmitter and grating.

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°. Use the set square in order to verify the angle (see also the experiment P2460201 "Polarisation of microwaves").

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Evaluation (1/2)

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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 $\sqrt{V}$	1.904	1.183	0.548	1.304	2.168
$\sqrt{U_S}$ in $\sqrt{V}$	2.202	2.846	3.033	2.646	2.258
$\sqrt{U_0}$ in $\sqrt{V}$	2.037	1.871	1.746	1.949	1.924
$\sqrt{U_R}$ in $\sqrt{V}$	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

Reflection and transmission parts for various angles.

Table 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.

Evaluation (2/2)

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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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