Absorption of thermal radiation through black and white bodies

There are three types of heat transfer by means of which thermal energy is transferred from a hot body to a colder body. Matter is necessary for thermal conduction and thermal convection with the aid of which this transfer takes place. Thermal radiation does not require matter. This is also the case with regard to the radiation of the sun which travels through space.
How much energy an object absorbs depends on the color of its surface. A black tube and a test tube are filled with water in an experiment and illuminated with an incandescent bulb. The heating of the water is measured.

Material

	Experiment on the board	P1427801
1	Demo physics board	02150.00
2	Clamping holder, *d* = 28 ... 36, on carrier material	02151.06
1	Holder for hand-held meters	02161.00
1	Clamp on holder	02164.00
1	Support rod, stainless steel, / = 500 mm, *d* = 10 mm	02032.00
2	Felt sheet 100 mm x 100 mm	04404.20
1	Ceramic lamp socket E27, safety plug	06751.00
1	Filament lamp 200V/120W, with a reflector	06759.93
1	Test tube d = 30 mm, black	36294.06
1	Test tube d = 30 mm, white	36294.05
1	Beaker, tall, 250 ml	36013.01
1	Graduated cylinder 10 ml, BORO 3.3	36629.00
1	Pipette with rubber bulb	64701.00
1	Stop clock, mechanical, d = 210 mm	03074.00
2	Immersion probe NiCr-Ni	13615.03
1	Temp. meter 2xNiCr-Ni, hand-held	07140.00
1	Large-scale display, digital, RS-232 port	07157.93
1	Data cable RS 232, SUB-D/USB	07157.01

	Experiment with stands, clamps and accessories	P1427802
1	Tripod base “PASS”	02002.55
1	Support base “PASS”	02005.55
2	Support rod “PASS”, *l* = 400 mm	02026.55
1	Support rod “PASS”, *l* = 630 mm	02027.55
1	Support rod, stainless steel, / = 100 mm, *d* = 10 mm	02030.00
3	Right angle clamp -PASS-	02040.00
2	Universal clamp	35715.00
1	Ceramic lamp socket E27, safety plug	06751.00
1	Filament lamp 200V/120W, with a reflector	06759.93
1	Test tube d = 30 mm, black	36294.06
1	Test tube d = 30 mm, white	36294.05
1	Beaker, short, 250 ml	36013.01
1	Graduated cylinder 10 ml, BORO 3.3	36629.00
1	Pipette with rubber bulb	64701.00
1	Stop clock, mechanical, d = 210 mm	03074.00
2	Immersion probe NiCr-Ni	13615.03
1	Temp. meter 2xNiCr-Ni, hand-held	07140.00
1	Large-scale display, digital, RS-232 port	07157.93
1	Data cable RS 232, SUB-D/USB	07157.01

The experiment can be performed on the board (Fig. 1) or with support material (Fig. 2). Here the experiment is described on the board.

Fig. 1

Fig. 2

Setup
- The experiment is constructed according to Fig. 1
- Screw the clamp on holder firmly tight on the lower edge of the board
- Insert the 500 mm rod in such a way that it completely protrudes forwards
- Attach the ceramic lamp socket with the reflector lamp at the tip of the rod in such a way that it illuminates an area in the lower third.
- Initially place magnetically adhesive holders in the center of the board
- Wrap the felt sheet around the black and white test tube respectively for thermal insulation in the area of the stopper and place them in the holders
- Slide the holders with the test tubes into the area that is illuminated by the lamp in the experiment. Illuminate the lower halves of the test tube (only switch the lamp only briefly to inspect it!), align the tubes in the same manner if possible, the average gap between the lamp and the glasses should be approx. 15 cm.
- Put the hand-held meter in its holder on the board and connect it to the large-scale display with the data cable
- Connect the temperature sensors (immersion probes) to the hand-held meter

Implementation
- Fill the 250 ml beaker with room temperature water (storage vessel should be in place some time before the experiment)
- Measure 50 ml water respectively in the graduated cylinder and fill it into the two test tubes
- Immerse the temperature sensors in the test tubes, stir them, measure the initial temperatures of the water and enter them in table 1 at t = 0 min
- Turn on the light and start the stop-watch
- Regularly stir the water in both test tubes and measure the water temperatures ϑ_{black} und ϑ_{white} every minute
- End the measurement after 10 min

Remarks
The water temperatures can also be measured at greater time intervals. It is important that it is regularly stirred well as the glass is otherwise warmer than the water and the measurement is inaccurate.

Measurement results

Table 1

$\frac{t}{\text{min}}$	$\frac{\vartheta_{\text{black}}}{°\text{C}}$	$\frac{\vartheta_{\text{white}}}{°\text{C}}$	$\frac{\Delta\vartheta_{\text{black}}}{°\text{C}}$	$\frac{\Delta\vartheta_{\text{white}}}{°\text{C}}$
0	22.0	22.0	0.0	0.0
1	23.4	22.8	1.4	0.8
2	24.5	23.7	2.5	1.7
3	26.0	24.3	4.0	2.3
4	27.1	25.0	5.1	3.0
5	28.5	25.7	6.5	3.7
6	29.8	26.4	7.8	4.4
7	31.1	27.0	9.1	5.0
8	32.1	27.9	10.1	5.9
9	33.2	28.6	11.2	6.6
10	34.3	29.4	12.3	7.4

Evaluation
Objects can be heated with the light of a filament lamp. There is a linear connection between the increase in temperature and time (Fig. 3)

The temperature differences ϑ between the measured value and the initial temperature are calculated and entered in table 1. After 10 minutes the temperature difference in the black test tube is much greater than in the white one.

The experiment can also be evaluated graphically by plotting the temperatures measured vs. time (fig. 3). The measured values are on a straight line respectively the straight line for the black test tube is steeper than for the white one (the straight line has a higher slope).

A body with a dark surface absorbs thermal radiation better than a body with a bright surface.

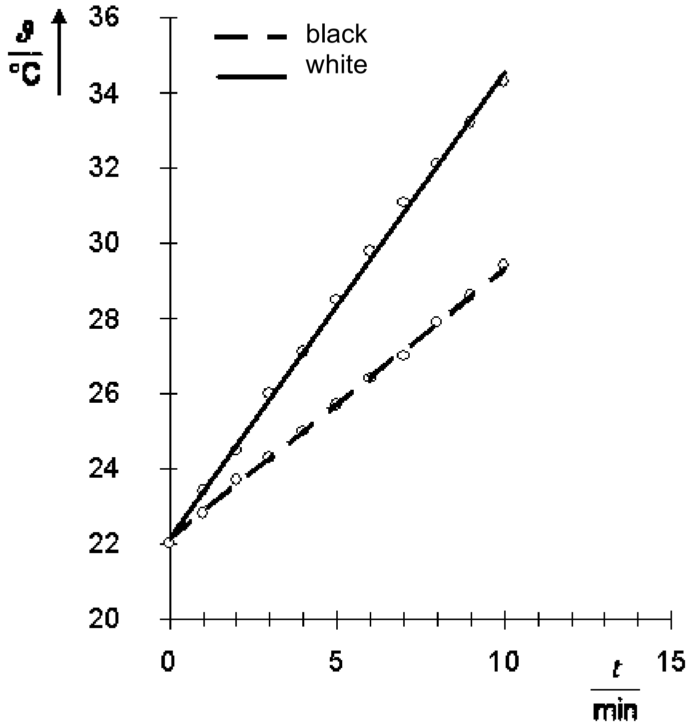

Fig. 3 Absorption of thermal radiation: Heating of 50 ml of water in the black and white test tube.

Remarks
1. The measurement results depend very strongly on the selected geometric dimensions. Naturally, the temperature rises less at greater distances.

2. The infrared spectral range that has longer waves than visible light is described as thermal radiation. In the experiment a filament lamp is used instead of an infrared lamp(04036.93) to make the illumination of test tubes visible for the students. Filament lamp light has a large proportion of infrared light in addition to the visible light.

3. An experiment concerning the emission of thermal radiation

should not be performed by cooling the water in the test tubes. The frequently recommended method of simply allowing the test tubes to cool down again after measuring the emissions has a major "blemish". The initial temperatures in the black and in the white test tube are not the same, the black glass is warmer, a warm vessel cools more quickly and that is the essential reason for the effect observed. Therefore, the "proof" is not conclusive!

The temperature reduction is less than 2 to 3°C after 10 minutes and the values possibly fluctuate as you stir. Determining differences in emissions is not a convincing method. The attempt to pour hot water into the test tubes to create the same starting conditions and achieve higher temperature differences generally fail due to temperature losses at the start. Here too differences can hardly be established in the cooling in general.

The measurement of the thermal radiation only provides reliable values if you use a radiation cube (04555.00) and a thermopile (08479.00). The radiation cube has a black, a white, a polished metallic and a dull metallic lateral surface. Hot water that is approx. 80°C is poured into it and the emission of thermal radiation is measured from each side. In the case of the radiation cube the black and the white surface have the same temperature. Table 2 demonstrates an example measurement under certain experiment conditions (temperature, distance).

Black emits heat slightly better than white but the differences are not as great as they are in terms of the absorption of light. This is due to the fact the absorption and emission are observed in completely different wavelength ranges. Absorption is measured in the range of visible light and near infrared light (800 nm). The water in the Leslie cube has a temperature of 80°C and transmits thermal radiation with a wavelength of 5 µm.

Table 2: Emission

Surface	$\frac{U_{th}}{\mu V}$
Black	318
White	295
Dull metallic	38
Shiny metallic	30