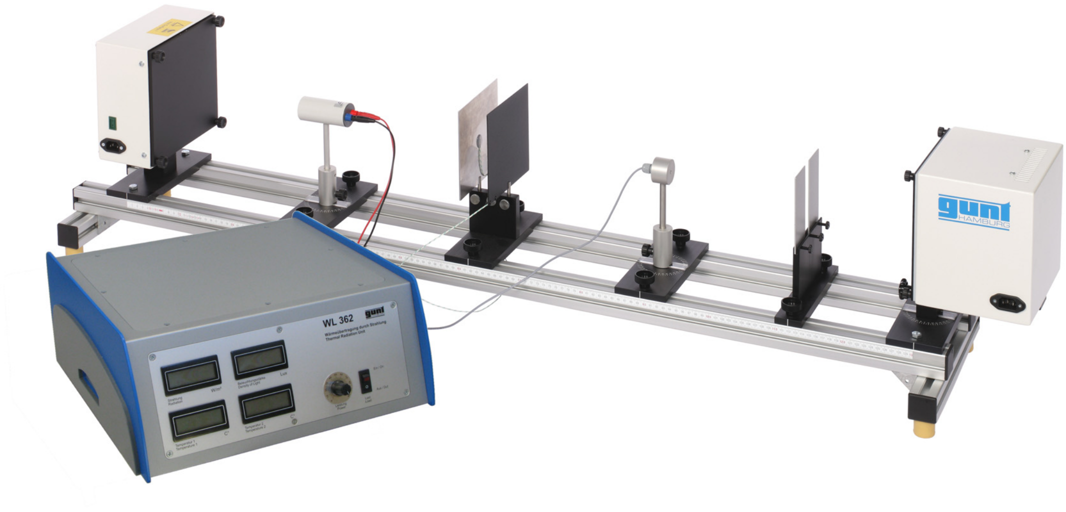
Experiment Instructions

WL 360/362   Thermal Radiation Unit



Experiment Instructions

Dipl.-Ing. Peter Mittasch

This manual must be kept by the unit.

Before operating the unit:
- Read this manual.
- All participants must be instructed on handling of the unit and, where appropriate, on the necessary safety precautions.

Table of Contents

1 Introduction

The **WL 362 Thermal Radiation Unit** is intended for the investigation of radiation laws using thermal and optical radiation as examples.

The unit has a heat source, in the form of a black-body radiator, and a thermopile that measures the intensity of the radiation. It also has a light source, a luxmeter to measure illuminance, and thermocouples to measure temperatures.

Furthermore, colour filters and an aperture are supplied for observing the effect of coloured light on the illuminance. In order to be able to study Kirchhoff's laws, various absorption plates complete with thermocouples are also provided. All the components can be easily mounted on a frame.

With the aid of the data acquisition card and software provided (only WL 362) , the values measured can be fed to a PC (not supplied) and evaluated.

The following topics can be addressed with the unit:

- Lambert's Direction Law (Cosine Law)
- Lambert's Distance Law
- Stefan-Boltzmann's Law
- Kirchhoff's Laws
(absorption, reflection, emission)
- Investigations on the wavelengths of light

2 Safety

2.1 Intended use

The unit is to be used only for teaching purposes.

2.2 Structure of safety instructions

The signal words DANGER, WARNING or CAUTION indicate the probability and potential severity of injury.

An additional symbol indicates the nature of the hazard or a required action.

Signal word	Explanation
⚠ DANGER	Indicates a situation which, if not avoided, **will** result in **death or serious injury**.
⚠ WARNING	Indicates a situation which, if not avoided, **may** result in **death or serious injury**.
⚠ CAUTION	Indicates a situation which, if not avoided, may result in **minor or moderately serious injury**.
NOTICE	Indicates a situation which may result in **damage to equipment**, or provides instructions on **operation of the equipment**.

Symbol	Explanation
	Electrical voltage
	Hot surface
	Notice

2.3 Safety Instructions

WARNING

Risk of electric shock when working on the opened measuring amplifier.

Have work on the measuring amplifier carried out only by a qualified electrician. Prior to opening the measuring amplifier, unplug the mains power plug.

WARNING

Risk of electric shock due to wetness and moisture on the control cabinet

Do not allow the measuring amplifier to get wet.

WARNING

Risk of burns by touching the heat source plate (~ 155 °C / ~ 311 °F).

Do not touch hot heat source plate.

Wait for the heat emission plate to cool down fully (~ 1 hour) before carrying out work on it.

WARNING

Risk of burns by touching the lamp.

Do not touch hot lamp.

Wait for the bulb to cool down fully before carrying out work on it.

NOTICE

Max. lamp power 42W!
There is a risk of overheating with a higher power lamp!

3 Unit Description

3.1 Unit Construction

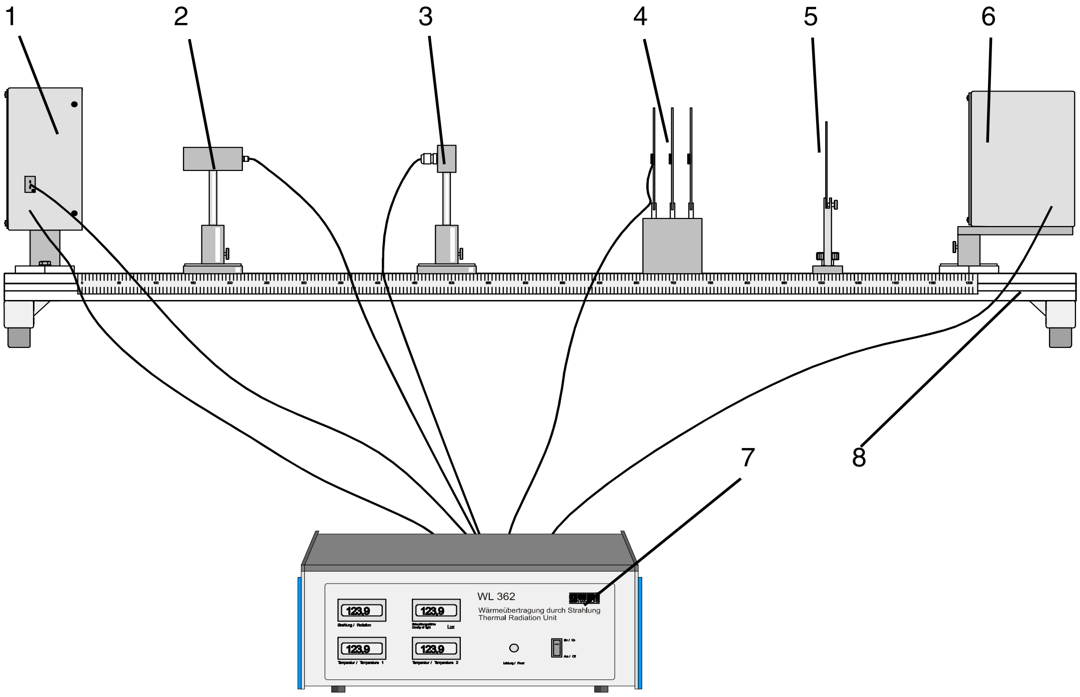


Fig. 3.1 Unit construction

Pos.	Item
1	Heat source
2	Thermopile for measuring the radiation, on rotating mounting
3	Luxmeter for measuring the luminous intensity, on rotating mounting
4	Absorption plates with temperature measurement points
5	Colour filters (red, green, infrared) and an aperture (not shown) with clamping mount
6	Swivelling light source
7	Measuring amplifier with connection cable
8	Frame for the components

3.2 Operation

3.2.1 Positioning the Fittings

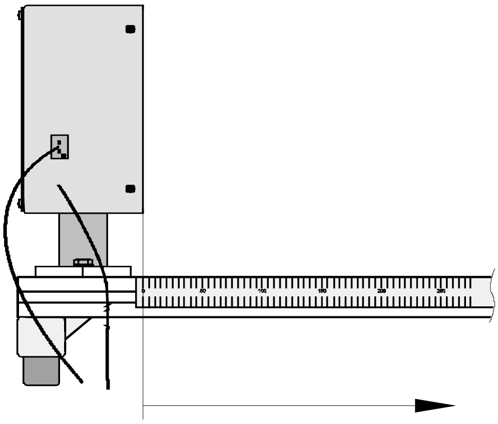


Fig. 3.2 Ruler Zero Point

The heat source and the light source are fixed to the frame. All other elements can be slid along the T channel in the aluminium rails and fixed in position using knurled screws.

A ruler is bonded to the aluminium rail, the zero point of which is positioned exactly at the outlet of the heat source (Fig. 3.2)

The mounting plates for the fittings are marked for reading off the distance from the heat or light source.

3.2.2 Measuring Amplifier

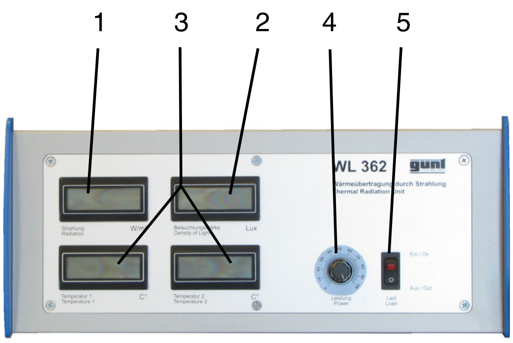


Fig. 3.3 Operation of Measuring Amplifier

The measuring amplifier serves to display the irradiance (1) in W/m^2, the illuminance (2) in Lux, and the temperatures of the thermocouples connected (3) in °C. A power regulator (4) is used to change the voltage supplied via the power supply connector (9) to the load that is connected and thus the load's output power (in % of the max. supply voltage). Loads are switched on via the load switch (5).

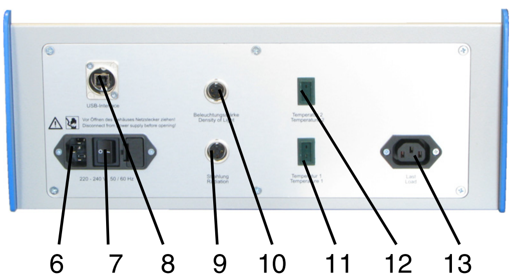


Fig. 3.4 Rear of the Measuring Amplifier

The following connections are to be found on the rear of the unit:

- Mains connector (6) with main switch (7) and grounding
- Connector for PC data acquisition (8)
- Power supply connector (13) for the heat source or light source

- Illuminance (10) (light) and irradiance (9) (radiation) connectors
- Connectors for the temperature sensors 2 (12) and 1 (11)

3.2.3 Setting Up the Measurement Apparatus

The unit is so conceived that either the heat source or the light source can be used per experiment. The power supply cable included must therefore be re-connected as appropriate.

The following temperatures can be measured:

- Heat source absolute temperature
- Absorption plate temperatures

Two temperatures can be measured simultaneously.

3.3 PC Measurement Data Acquisition (WL 362 only)

The data acquisition program is supplied with the **WL 362**. It is not included in **WL 360**.

3.3.1 Installation of the Software

The following is needed for the installation:

- A fully operational PC with USB port (for minimum requirements see Chapter 6.1, Page 55).
- G.U.N.T. CD-ROM.

  All components necessary to install and run the program are contained on the CD-ROM delivered by G.U.N.T.

Installation Routine

NOTICE
The trainer must not be connected to the PC's USB port during the installation of the program. Only after the software has been installed can the trainer be connected.

- Boot the PC.
- Load the G.U.N.T. CD-ROM.
- From the “Installer” folder, launch the “**Setup.exe**” installation program.
- Follow the installation procedure onscreen.
- After starting, the installation runs automatically. During the course of the installation, various program components are loaded onto the PC:
  - Program for PC-data acquisition

– Driver routines for the „LabJack®“ USB converter

- Reboot the PC after installation is finished.
- Select and start the program by choosing: **Start / All Programs / G.U.N.T. / WL 362**
- When the software is run for the first time after installation, the language to be used for the program is requested.

  The language selected can subsequently be changed at any time on the “**Language**” menu.

Fig. 3.5 Language selection

3.4 Operation of the Software (WL 362 only)

When the software starts up the following window is displayed:

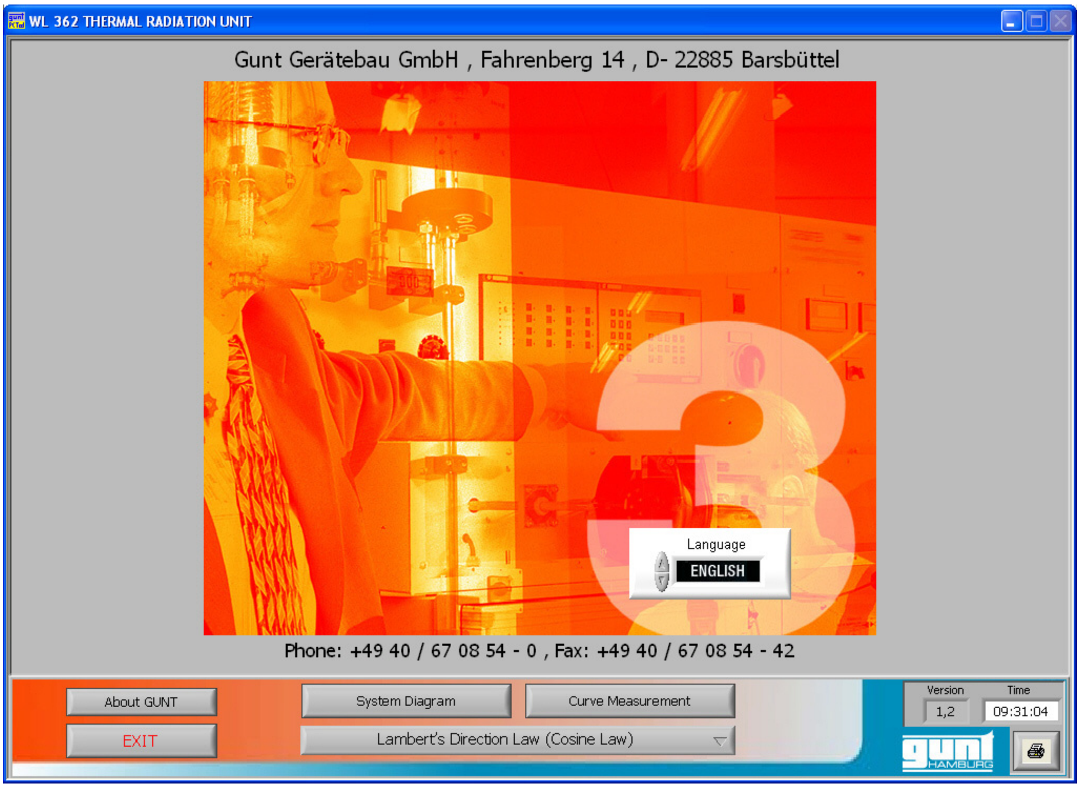


Fig. 3.6 Start window / About GUNT

All experiment screens can be accessed by way of the buttons. A print function and a program quit button are included. It is also possible to change language here at any time.

The user control area with the buttons also remains accessible after selecting the system diagram and the curve view of an experiment.

3.4.1 Controls, General

The software is essentially self-explanatory. The following sections provide instructions on how to perform a variety of tasks, including how to plot curves.

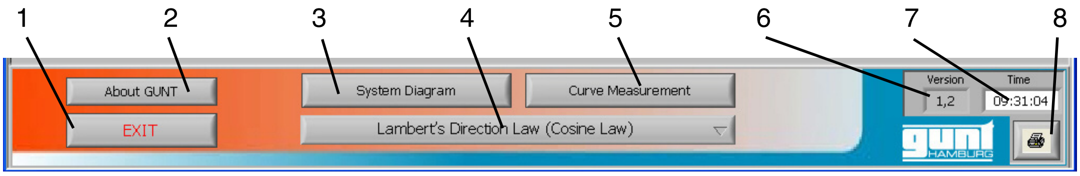


Fig. 3.7 User control area with buttons

1 Exits the program.
2 Displays the window as shown in Fig. 3.6, Page 12.
3 Displays the setup of the experiment selected by way of the button (4)
4 Experiment selection button – the experiment to be performed can be selected here.
5 Displays a diagram in which a measured value curve of the experiment selected via (4) can be plotted.
6 Version number of this program.
7 Time setting on this PC.
8 Print the current screen view to the PC's default printer.

The various experiments can be selected by way of the button (4) The displayed experimental setup changes accordingly. The curve display mode also varies depending on the selected experiment. The following experiments are supported by this data acquisition software:

- Lambert's Distance Law
- Lambert's Direction Law
- Stefan Boltzmann's Law
- Kirchhoff's Law

- Investigation of the wavelength of light

As soon as a new experiment is selected by way of the button (4) the data of the previous experiment are discarded. Before changing experiments, print out the data you need by clicking the button (8).

The curve view screen for the various experiments provides a number of standard functions which may be available depending on the experiment and its progress.

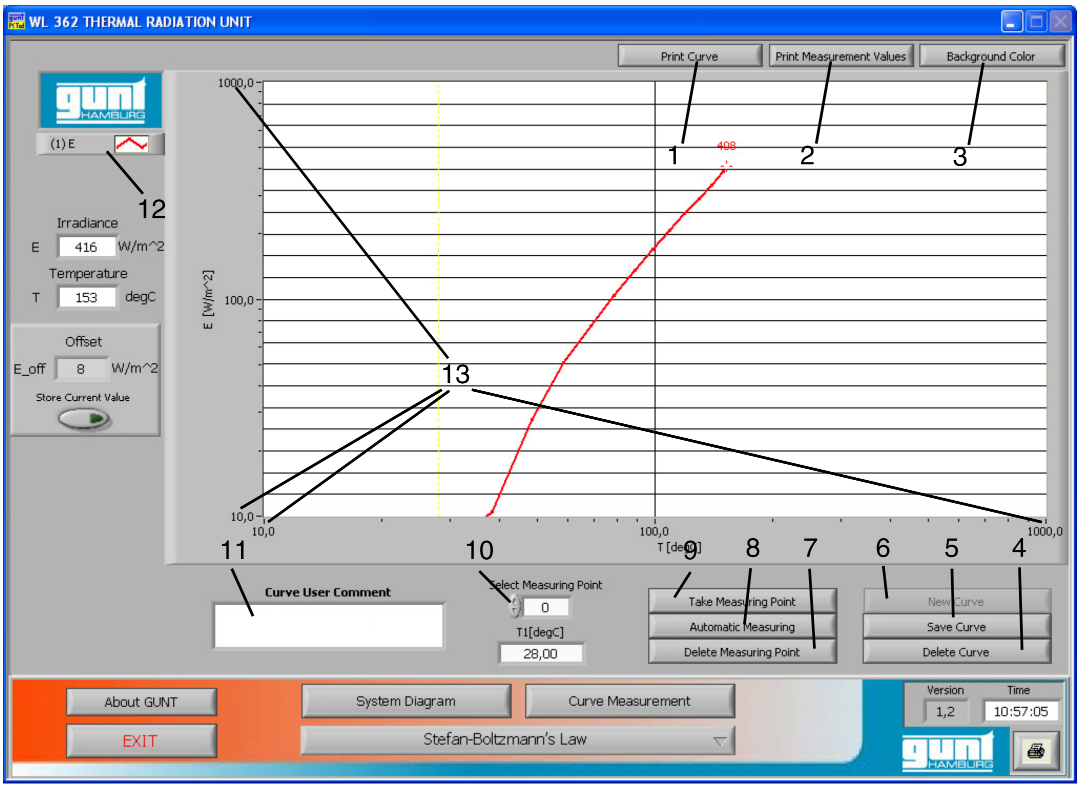


Fig. 3.8 Curve plotting screen

1	Prints a lab sheet with a graph of the measured curve to the default printer.
2	Prints a lab sheet with a table of the measured values to the default printer.
3	Allow the graph's background colour to be changed.
4	Deletes the current curve view and the associated measured values.
5	Saves the measured values to a file.
6	Prepares the program for plotting of a new curve.
7	Deletes the measurement point selected under (11).
8	Starts an automatic measurement. The measurement is ended manually by clicking the same button.
9	Includes the current measured value as a measurement point in the curve.
10	Select an existing measurement point. (Not automatically counted)
11	Input option for a custom text.
12	Allows the properties of the curve to be changed.
13	The display range can be varied by directly altering the Max-Min values of the axes.

It is only possible to plot a curve after clicking the button (6).

Saved measured values cannot be loaded back into this software. They can be processed in MS-Excel® however.

The system diagram screen for the various experiments includes a display of the experimental setup.

3.4.2 Notes on Lambert's Distance Law

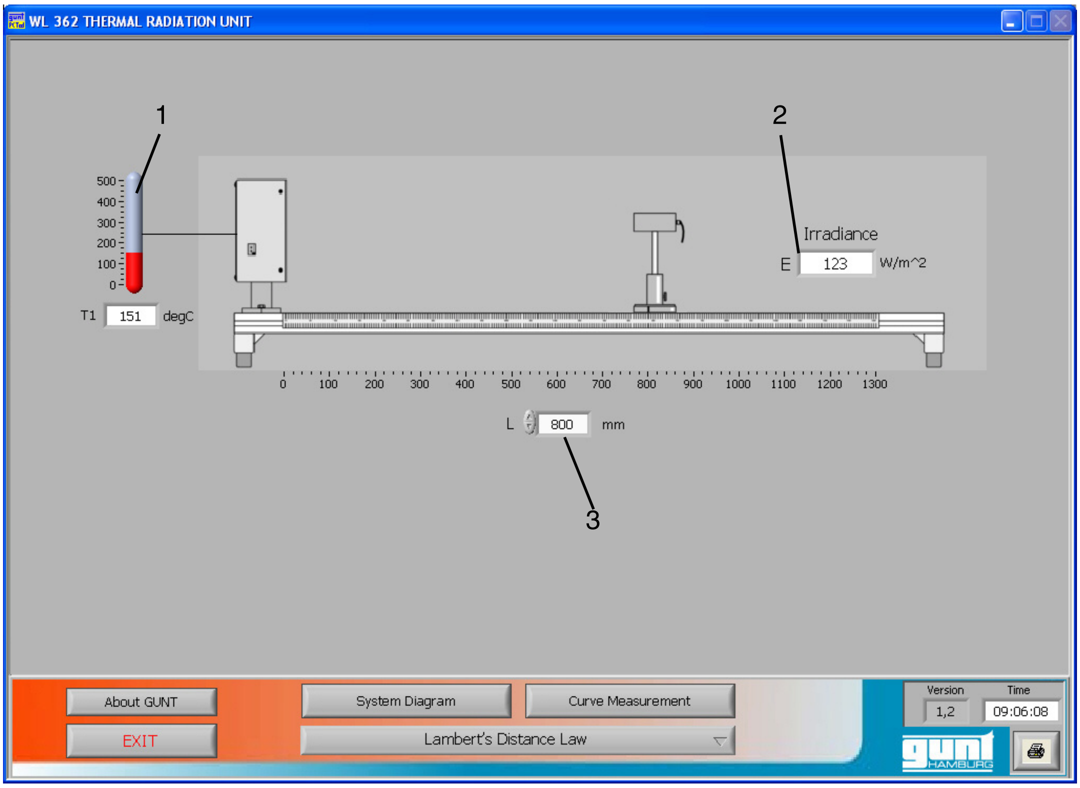


Fig. 3.9 System Diagram

The system diagram displays the measured temperature of the heat emitter (1) and the radiation measured by the thermopile (2). The distance *L* (3) is entered manually.

It is not possible to plot the curve by way of the system diagram. It must be plotted on the curve plotting screen.

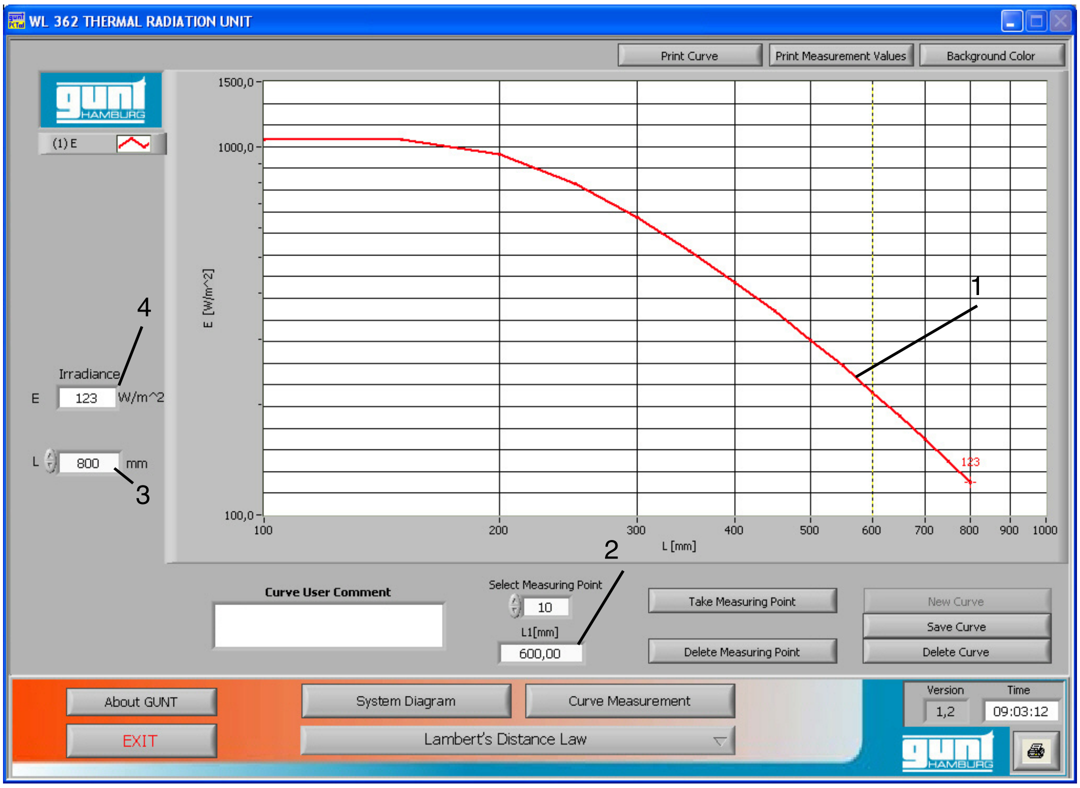


Fig. 3.10 Curve plotting

1 Plotted curve.
2 Distance of the selected measurement point.
3 Current distance of the measurement point to be set – is entered manually.
4 Current measured irradiance.

3.4.3 Notes on Lambert's Direction Law

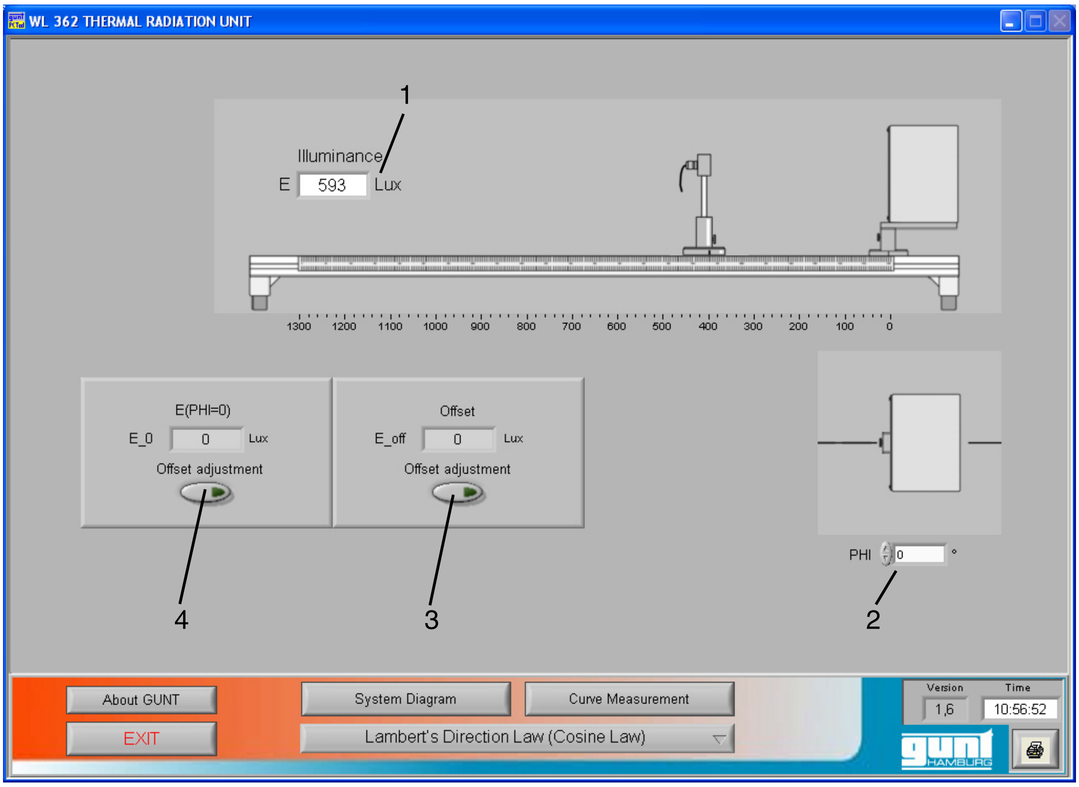


Fig. 3.11 System Diagram

The system diagram displays the luminous intensity (1) measured by the luxmeter. The angle φ (2) is entered for each measurement point manually. This can also be done with the mouse, by "picking up" and "dragging" the red triangle in the light source view. The offset – in this case the ambient light – is applied by clicking the button (3). With the button (4) the current measured value can be added to the curve as a measurement point in the curve plotting view.

It is possible to plot the curve by way of the system diagram. However, it is advisable to use the curve plotting screen for this.

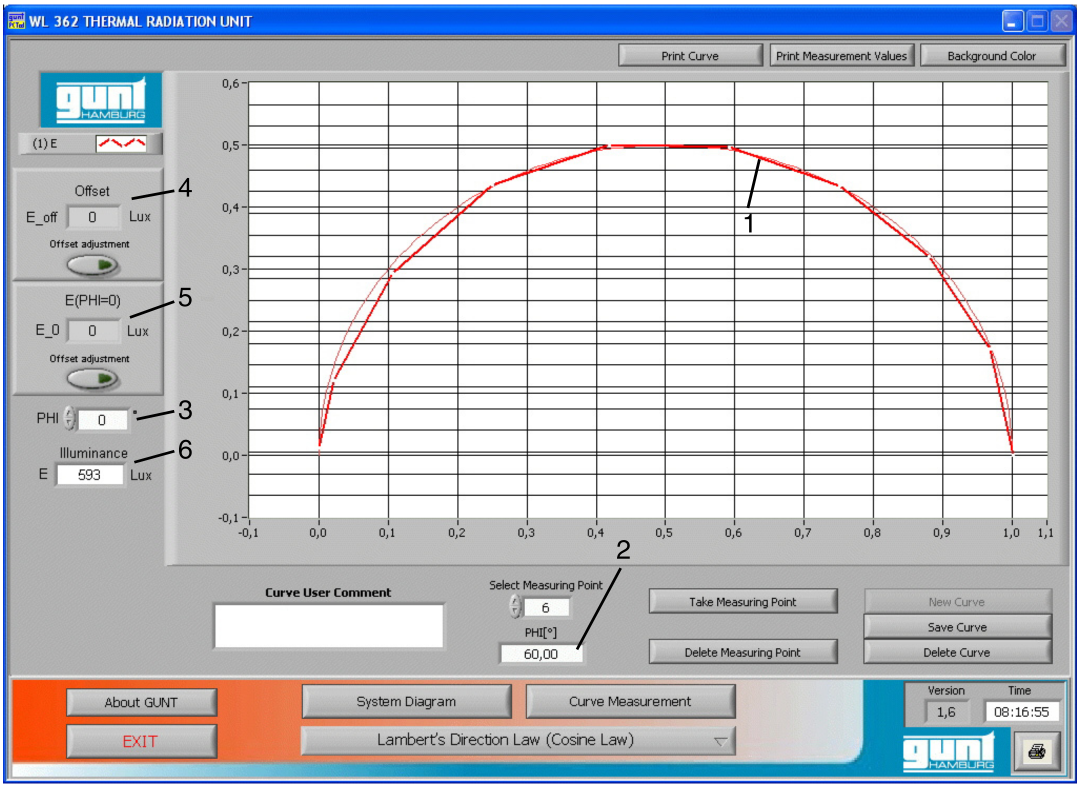


Fig. 3.12 Curve plotting

1 Plotted curve.
2 Angle of the selected measurement point.
3 Current angle of the measurement point to be set – is entered manually.
4 With this button the measured offset is recorded.
5 With this button the current measured luminous intensity, less the previously recorded offset, is saved as a measurement point.
6 Displays the current luminous intensity measured by the luxmeter, including the offset.

Before plotting the curve in the unit circle, the offset (light source switched off) must be saved by way of the button (4). The offset is incorporated at every measurement point. If the light conditions vary from measurement point to measurement point, a new offset can be recorded immediately prior to each measurement.

3.4.4 Notes on Stefan Boltzmann's Law

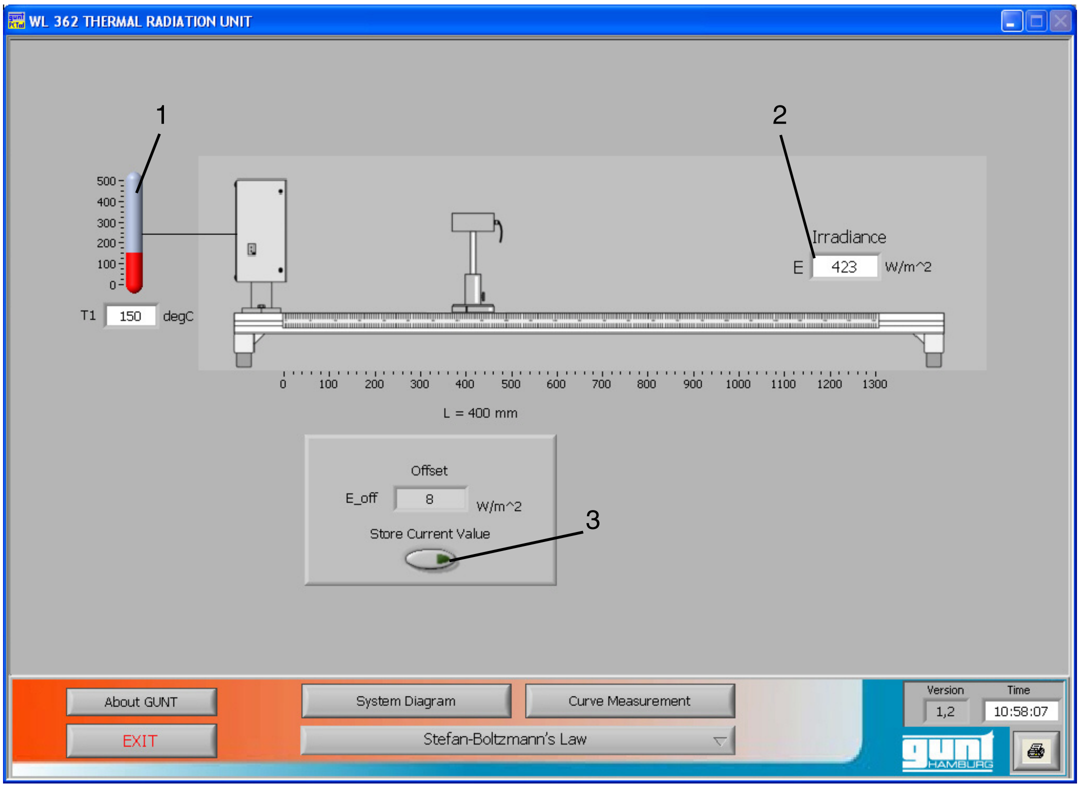


Fig. 3.13 System Diagram

The system diagram displays the measured temperature of the heat emitter (1) and the radiation measured by the thermopile (2). The offset of the ambient radiation is recorded by way of the button (3).

It is not possible to plot the curve by way of the system diagram. It must be plotted on the curve plotting screen.

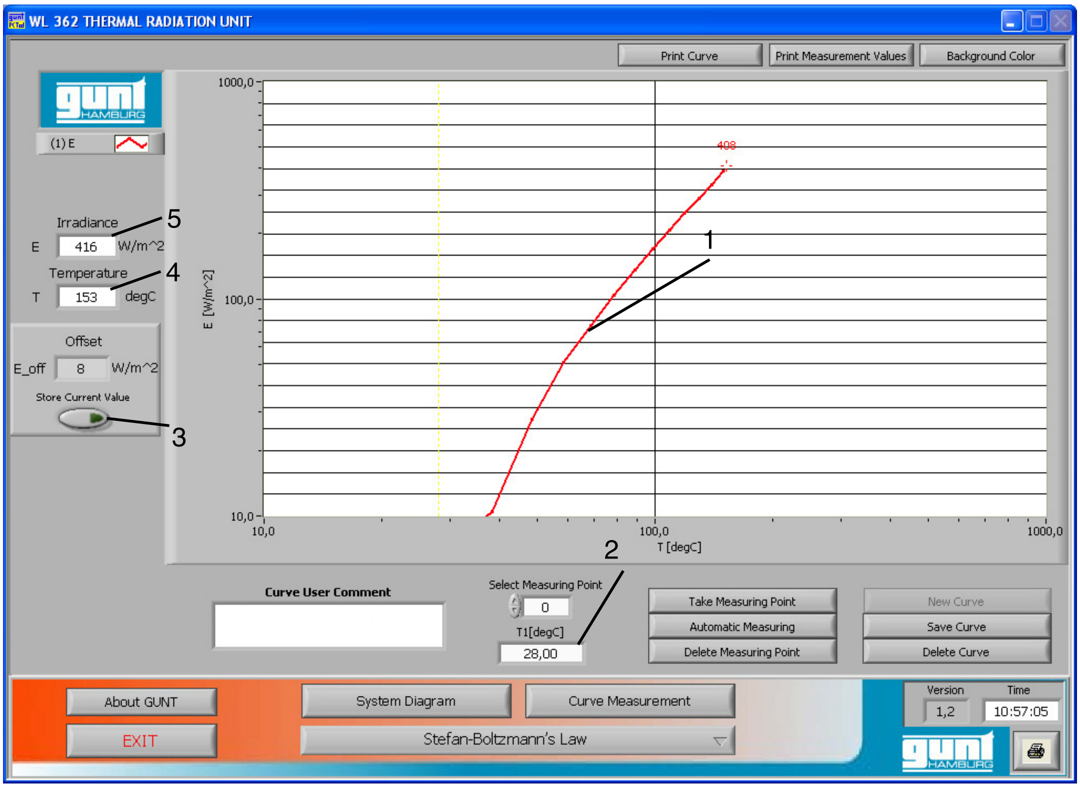


Fig. 3.14 Curve plotting

1 Plotted curve.
2 Temperature of the selected measurement point.
3 With this button the measured offset of the ambient radiation is recorded.
4 Current temperature of heat emitter.
5 Current measured irradiance.

Before plotting the curve, the offset (heat emitter switched off and at room temperature) must be saved by way of the button (4). The offset is incorporated at every measurement point. An automatic measurement is possible here.

The thermopile records only the radiation of the heat source, but here the ambient radiation must also be plotted.

3.4.5 Notes on Kirchhoff's Law

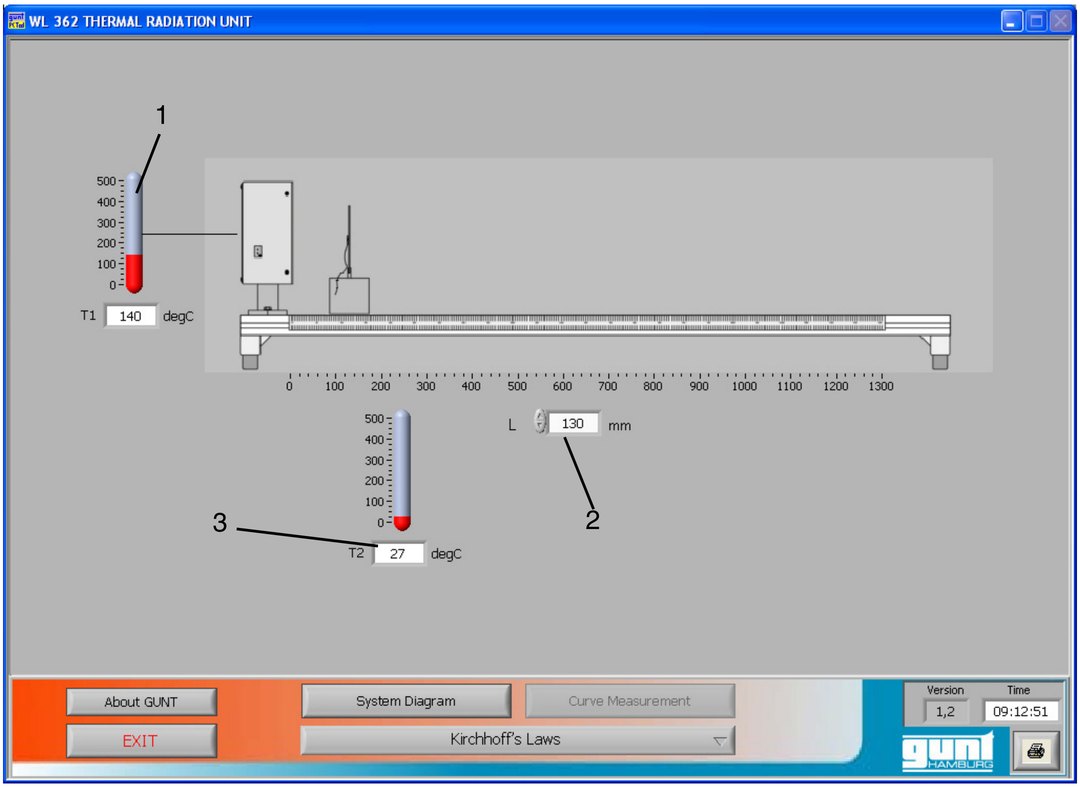


Fig. 3.15 System Diagram

The system diagram displays the measured temperature of the heat emitter (1) and the temperature measured on the absorption plate (3). The distance *L* (3) is entered manually.

No provisions is made for plotting a curve.

3.4.6 Notes on Investigation of the Wavelength of Light

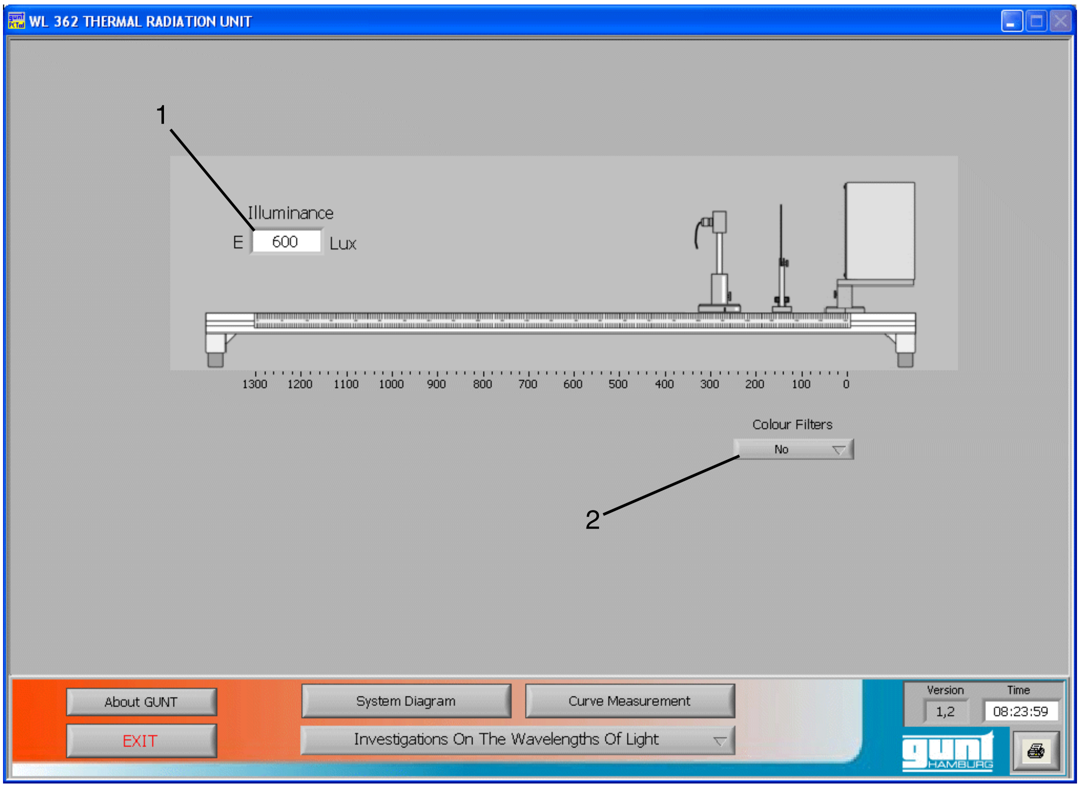


Fig. 3.16 System Diagram

The system diagram displays the luminous intensity (1) measured by the luxmeter. A colour filter can be specified by way of a selection box.

It is not possible to plot the diagram by way of the system diagram. It must be plotted on the curve plotting screen.

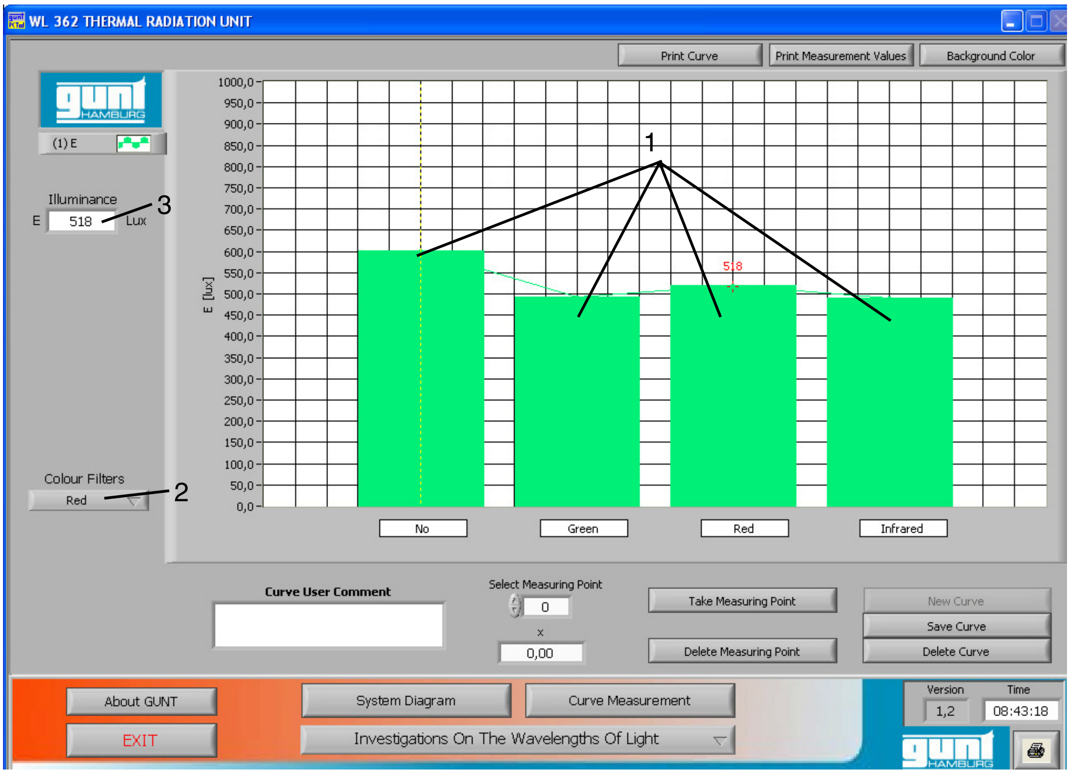


Fig. 3.17 Curve plotting

1 Recorded bars.
2 Definition of current colour filter.
3 Current measured luminous intensity.

4 Theoretical Principles

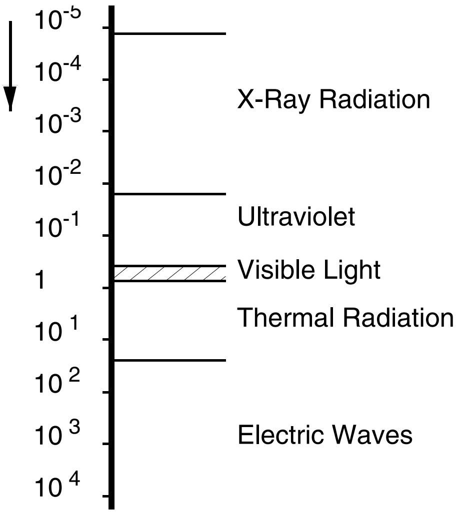


Fig. 4.1 Frequency Spectrum of Electromagnetic Radiation

The **transfer of heat by electromagnetic waves** is known as **thermal radiation**. The related laws are fundamentally different to those for thermal conduction and the thermal convection (Convection).

The waves involved in the radiation can be of varying frequency. Thermal radiation normally lies in the frequency range λ = 0.8...400 µm, visible light is at λ = 0.35...0.75 µm (Fig. 4.1).

The experiments describe the most important physical laws on thermal and optical radiation.

4.1 Lambert‘s Distance Law

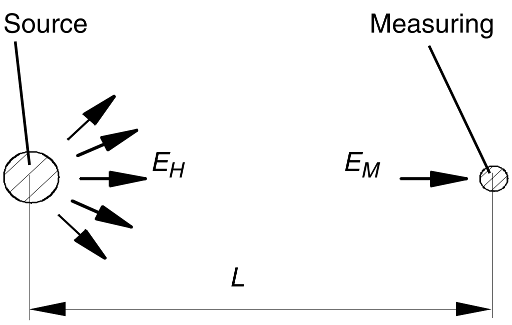


Fig. 4.2 Lambert’s’ Distance Law

This law states that the **irradiance** (≙ illuminance) of the radiation emitted by a point source **decreases with the square of the distance**:

$$E_M \sim \frac{1}{L^2} \tag{4.1}$$

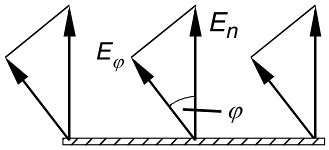
with

E_M irradiance at the measuring point

E_H irradiance of the source

L Distance of the measuring point from the point source in m.

4.2 Lambert‘s Direction Law (Cosine Law)



The radiant intensity I of the radiation emitted by a flat source is the same from any direction. However the irradiance E drops with the cosine of the angle φ:

$$E_\varphi = E_n \cdot \cos\varphi \quad (4.2)$$

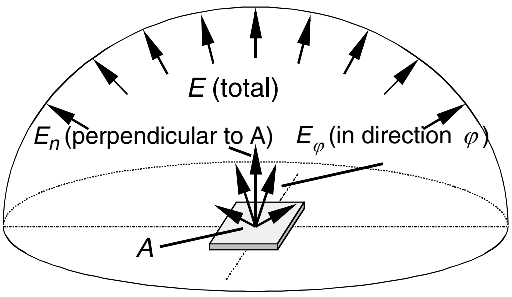


Fig. 4.3 Radiation from a Surface A

The total irradiance is found by integrating over the hemisphere

$$E = \pi \cdot E_n \quad (4.3)$$

4.3 Stefan-Boltzmann-Law

The total irradiance Es a blackbody radiator is proportional to the fourth power of the absolute temperature T (in Kelvin):

$$E_S = \sigma \cdot T^4 \quad (4.4)$$

σ is a physical constant known as the "Stefan-Boltzmann Constant". The law is mostly used in the "easier to handle" form:

$$E_S = C_S \cdot \left(\frac{T}{100}\right)^4 \quad (4.5)$$

with the radiation constant of the blackbody

$$C_S = 5{,}67\ \frac{\mathrm{W}}{\mathrm{m^2K^4}}$$

4.4 Kirchhoff‘s Law

An experiment relating to Kirchhoff's Laws (emission and absorption) can be performed using the absorption plates. For this, the thermocouples on the absorption plates must be connected to the measuring amplifier as required.

Kirchhoff's Law states that

a) for all bodies at a given temperature the ratio of the emission and absorption capacity is constant.

$$\frac{E}{\varepsilon} = \mathrm{const.} \tag{4.6}$$

and

b) is equal to the amount of the emission capacity of a black emitter (E_S) at that temperature.

$$\frac{E}{\varepsilon} = E_S \tag{4.7}$$

and

c) good absorbers are also good emitters.

For radiation exchange in the longwave range (in particular heat radiation at not too high temperatures) dielectrics (electrical non-conductors) can often be treated approximately as diffuse grey emitters and

$$\alpha = \varepsilon \tag{4.8}$$

Metals are not usually grey emitters. Oxide layers or dirt contamination may, however, substantially alter the radiation properties of metals and cause them to approach those of dielectrics.

The metallically bright plates are made of aluminium. Aluminium always generally has heavily oxidised surfaces. The surfaces of the black plates consist of a non-metallic paint layer.

So the properties of dielectrics should apply to both surfaces.

Point c) is proven to a high degree of probability in an experiment by having the plates with bright and black surfaces act alternately as emitters and absorbers and determining the respective emission and absorption values.

In both variants the heat input per time unit W is the same, i.e. $W_1 = W_2$.

Definition:

- Index 1 represents the bright surface
- Index 2 represents the black surface
- The apostrophe (‘) signifies the absorption plate
- No apostrophe signifies the emission plate

So, for example, the black emission plate has the index 2 and the bright absorption plate the index 1‘

The temperature of the bright absorption plate (1‘) is

$$T_1' \sim \varepsilon_2 \cdot \alpha_1' \cdot T_2 \tag{4.9}$$

The temperature of the black absorption plate (2‘) is

$$T_2' \sim \varepsilon_1 \cdot \alpha_2' \cdot T_1 \tag{4.10}$$

Thus where $T_1'=T_2'$ (absorber plate temperature):

$$T_2 \cdot \varepsilon_2 \cdot \alpha_1' = \varepsilon_1 \cdot \alpha_2' \cdot T_1 \tag{4.11}$$

Thus where $T_1=T_2$ (emission temperature):

$$\varepsilon_2 \cdot \alpha_1' = \varepsilon_1 \cdot \alpha_2' \tag{4.12}$$

Consequently:

$$\frac{\varepsilon_2}{\alpha_2'} = \frac{\varepsilon_1}{\alpha_1'} \qquad (4.13)$$

The above equation states:

If the plates with bright and black surfaces are used alternately as emitters and absorbers, and if the respective temperatures of the emitters and absorbers are equal, the ratio of the emission coefficient to the absorption coefficient of both surfaces is constant.

This property occurs in the case of dielectrics, as their ratio of the emission coefficient to the absorption coefficient of both surfaces is 1.

4.5 Transmission Measurements

Transmission is a measure of the capacity of a medium to allow waves to pass through it, such as electromagnetic waves (e.g. light). When a wave impacts on a medium, depending on the material properties of the obstacle, it is partially reflected on the barrier surfaces and wholly or partially absorbed as it passes through.

The transmission coefficient τ is defined as the quotient between the wave intensity ϕ_0 in front of the obstacle and the intensity ϕ behind it:

$$\tau = \frac{\phi}{\phi_0} \qquad (4.14)$$

The transmission coefficient is thus a measure of "transmitted" intensity, and assumes values between 0 and 1.

5 Experiments

General Notes on Measurements

For correct measurement results, please note the following points:

- Illuminance measurements should always be made in darkness to avoid the effects of stray light.
- When performing radiation measurements, it must be ensured that there are no thermally radiating walls, apparatus, etc., in the field of view of the thermopile (behind the heat source).
- Experiments should not be performed in areas where there is a strong air flow, so as to allow the temperature of the heat emitter to remain constant.

The following section describes experiments that can be performed using this experimental unit. The selection of experiments makes no claims of completeness but is intended to be used as a stimulus for your own experiments.

The measured results listed should not be viewed as reference or calibration values for all conditions. Depending on the construction of the individual components, experimental skills and environmental conditions, deviations from the measurement results may occur in experiments. Nevertheless, the laws can be clearly demonstrated.

5.1 Lambert’s Distance Law

Experiment duration from 45 minutes to 60 minutes

5.1.1 Objective

The Distance Law states that the irradiance (≙ illuminance) of the radiation emitted by a point source decreases with the square of the distance.

In this experiment it is intended to demonstrate this inverse square law relationship with the heat source.

5.1.2 Preparation

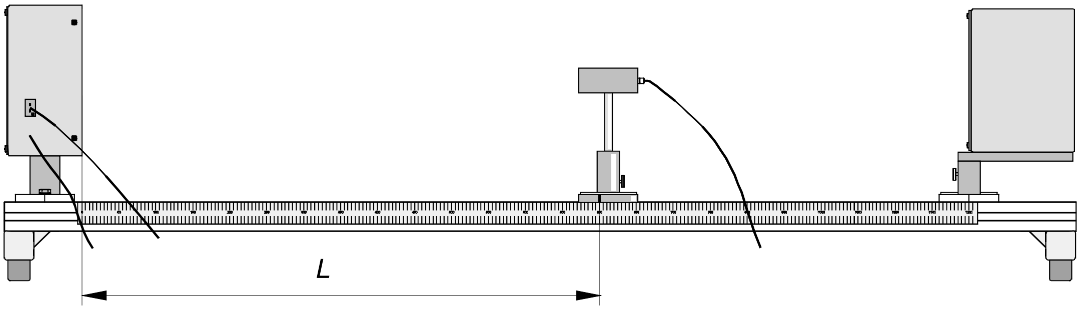


Fig. 5.1 Experimental Setup, Performance of Experiments with the Heat Source

- Mount the thermopile at a separation of L = 800 mm from the heat source, connect to the measuring amplifier (’Strahlung/Radiation’ connector). Remove all other fittings in between.
- Connect up the heat source (’Last/Load’ connector and ’Temperatur/Temperature 1’ connector).

5.1.3 Experimentation

- Switch on the measuring amplifier, the offset should be very low (background radiation).
- Switch on the heat source.
- Set the power regulator on the measuring amplifier to approx. 50 and wait until a constant temperature has been reached.
- Take the series of measurements by reducing the separation *L* in reasonable steps, and measuring the irradiance *E* and reading off the separation *L*.

Separation from Radiating Source *L* in mm	Irradiance *E* in W/m^2
100	1224
150	1228
200	1082
250	892
300	713
350	572
400	470
450	387
500	329
550	275
600	235
650	203
700	178
750	155
800	137

Tab. 5.1 Example Measurement Sequence: Reduction in Irradiance for the Heat Source (T=144°C)

5.1.4 Evaluation of Results

Tab. 5.1 gives an example measurement sequence. If the values are plotted on **log-log diagram** (Fig. 5.2), then in the far section of the range of distances there is a **straight portion**. A straight line on log-log diagram means a relationship of the form

$$E = k \cdot L^a \qquad (5.1)$$

where a is the slope of the line:

$$a = \frac{\Delta y}{\Delta x} \qquad (5.2)$$

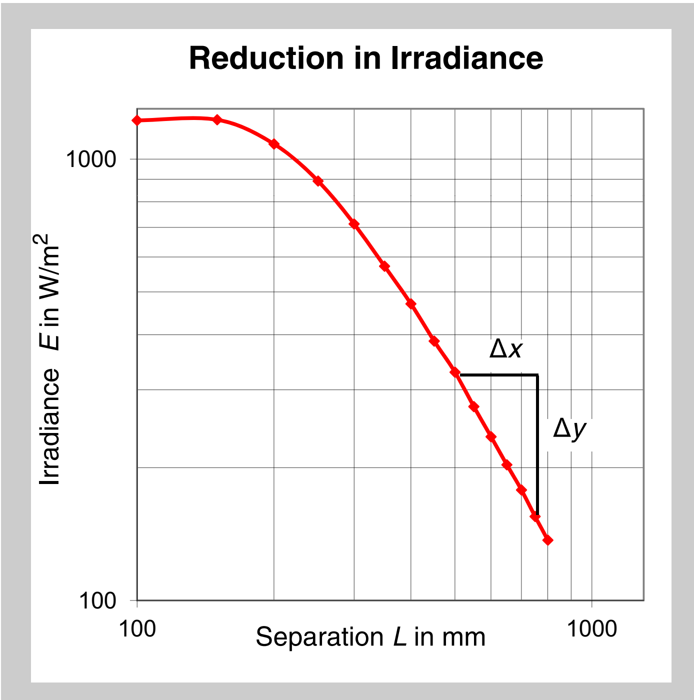


Fig. 5.2 Reduction in Irradiance for the Heat Source (T=144°C)

The slope yields a value of *a*= -2. Thus the square law relationship between irradiance *E* and separation *L* is demonstrated:

$$E \sim \frac{1}{L^2} \tag{5.3}$$

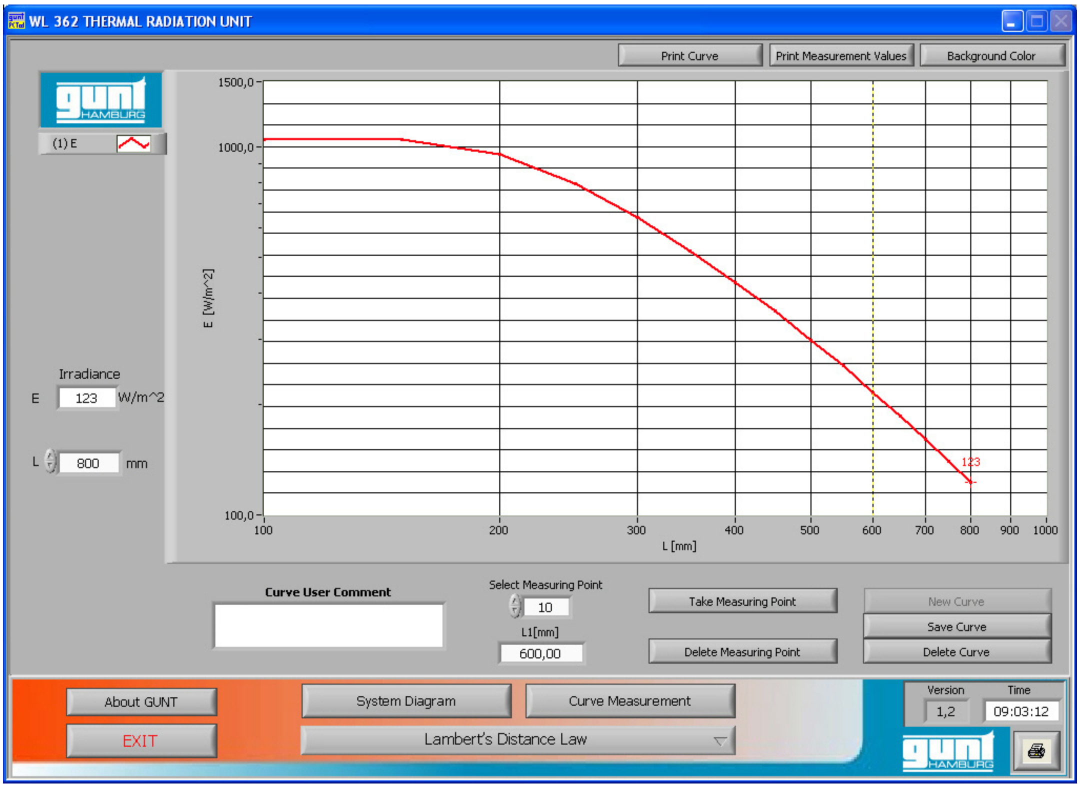


Fig. 5.3 Software Screenshot (WL 362 only)

5.1.5 Critical Considerations

The heat source is actually not a point source but a source of finite area. In the area below *L*=300 mm this results in the combination of radiation emitted radially from a point source with the radiation emitted parallel to the surface, this leads to the corruption of the measured value.

5.2 Lambert's Direction Law (Cosine Law)

Experiment duration approx. 15 minutes

5.2.1 Objective

The irradiance E of the radiation emitted by a flat source drops with the cosine of the angle φ.

In this experiment the Cosine Law will be checked.

5.2.2 Preparation

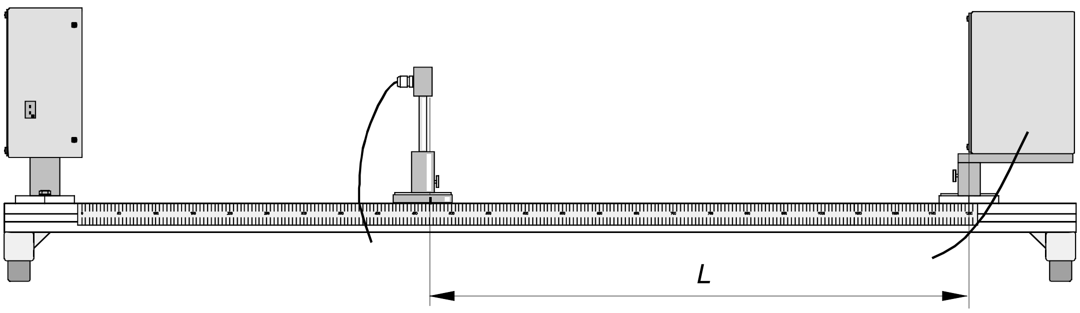


Fig. 5.4 Experimental Setup, Performance of Experiments with the Light Source

The experiment for checking the Cosine Law should be performed in conditions as dark as possible:

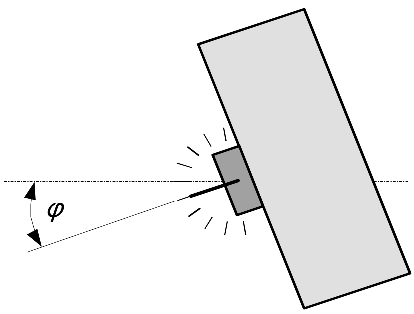


Fig. 5.5 View of the Light Source from Above

- Mount the luxmeter at a separation of $L = 400$ mm from the light source; connect to the measuring amplifier ('Beleuchtungsstärke/Density of Light' connector). Remove all other fittings in between.
- Mount the light source in position $\varphi = 0°$, connect ('Last/Load' connector)
- Remove the black apertured plate from luxmeter and mount the matt plate.

5.2.3 Experimentation

- Switch on the measuring amplifier, note the offset displayed (ambient light).

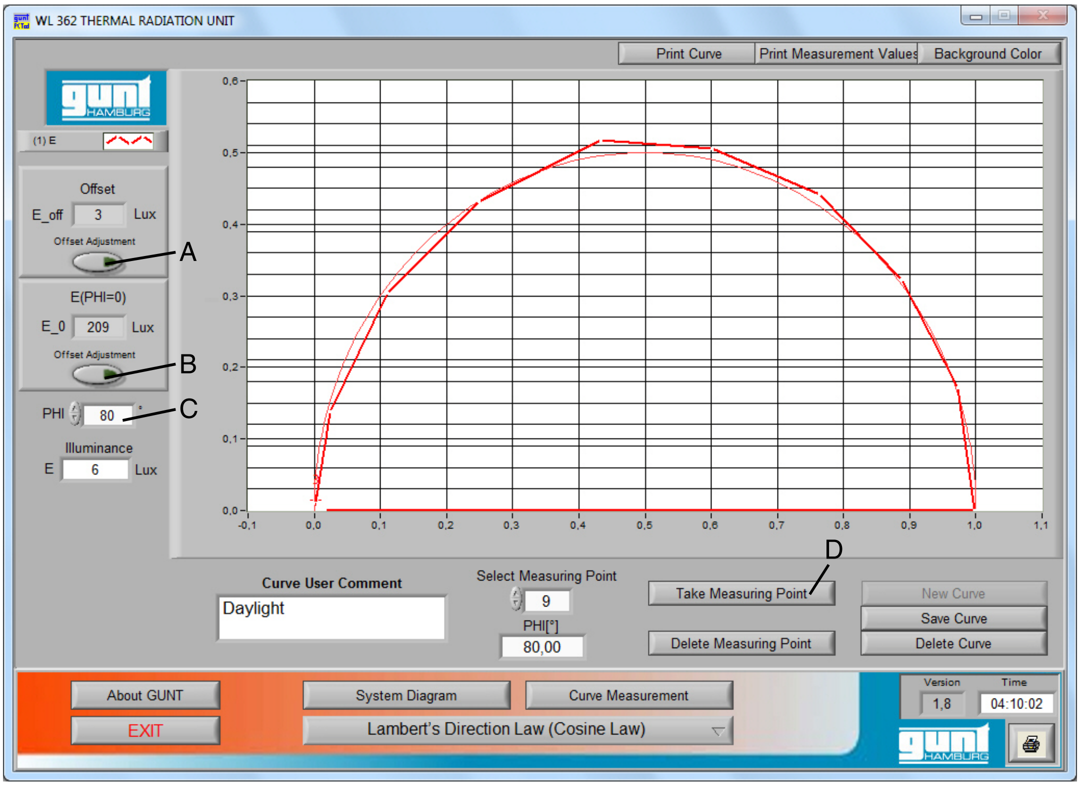


Fig. 5.6 Curve plotting

- Press button A.
  The measured offset is recorded.
- Switch on the light source.
- Turn the power regulator to full.
- Press button B.
  The current measured luminous intensity, less the previously recorded offset, is recorded.
  This is done only once at the beginning of a measurement series.
- Take a measurement for $\varphi = 0°$ as follows:

- Enter „0“ in field C.
- Read the illuminance *E* and note the value or press button D to record a measurement.

- Take the series of measurements, e.g. in steps of 10°. For each measurement:
  - Increase the angle of incidence φ and enter the value in field C.
  - Note the offset displayed or press button A.
  - Read the illuminance *E* and note the value or press button D to record a measurement.

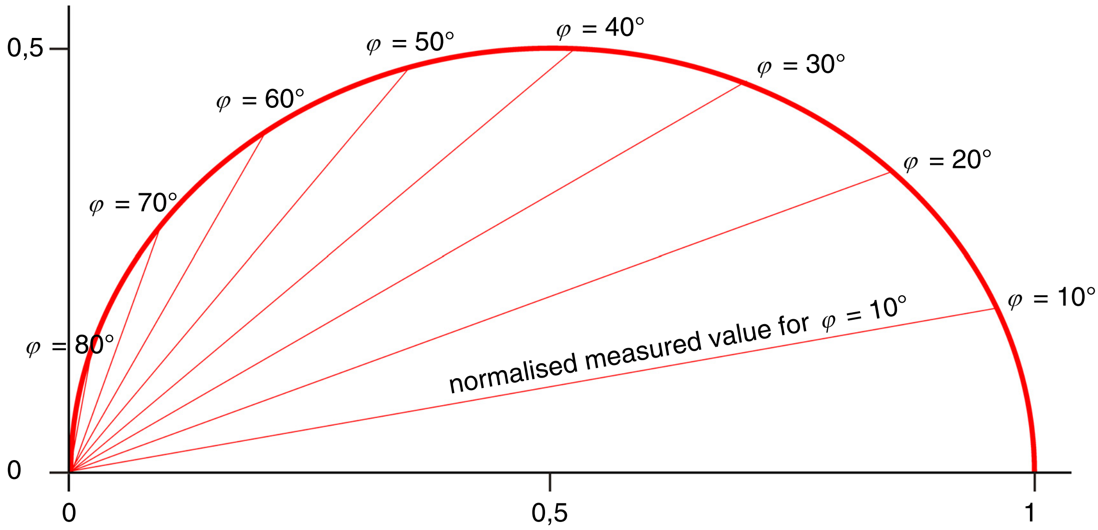


Fig. 5.7 Unit circle

5.2.4 Evaluation of Results

Since the results are to evaluated with respect to the cosine function, the measured values are normalised and marked on a circle with diameter 1 (Fig. 5.8, Page 40). The variations of the normalised measured values to the nominal curve (vertical separation of the measured points from the unit circle) are small. Thus the validity of the Direction Law is confirmed in this experiment.

Angle of Incidence on the Luxmeter referred to the Axis of the Light	Offset in Lux	Illuminance *E* in Lux	Illuminance *E* (- Offset) in Lux	Normalised Value $\bar{E}$ (Unit of 1)
0	2	211	209	1,00
10	3	209	206	0,99
20	3	200	197	0,94
30	4	188	184	0,88
40	5	169	164	0,78
50	5	146	141	0,67
60	5	108	103	0,49
70	4	72	68	0,33
80	3	32	29	0,14
90	3	5	2	0,01

Tab. 5.2 Example Measurement Sequence: Illuminance as a Function of the Angle of Incidence

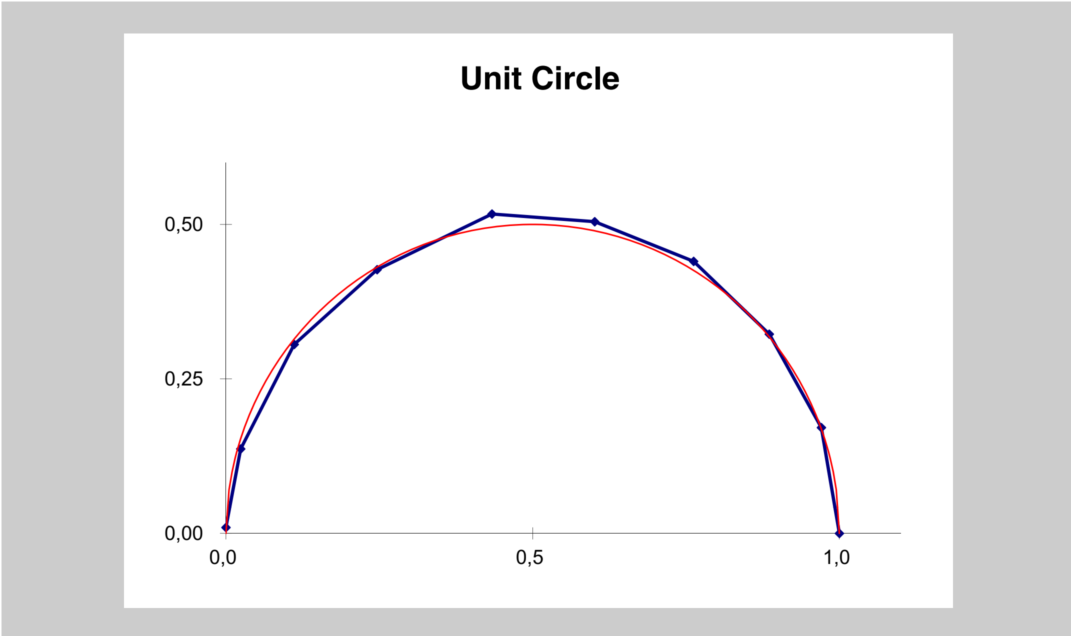


Fig. 5.8 Normalised Illuminance Around the Unit Circle

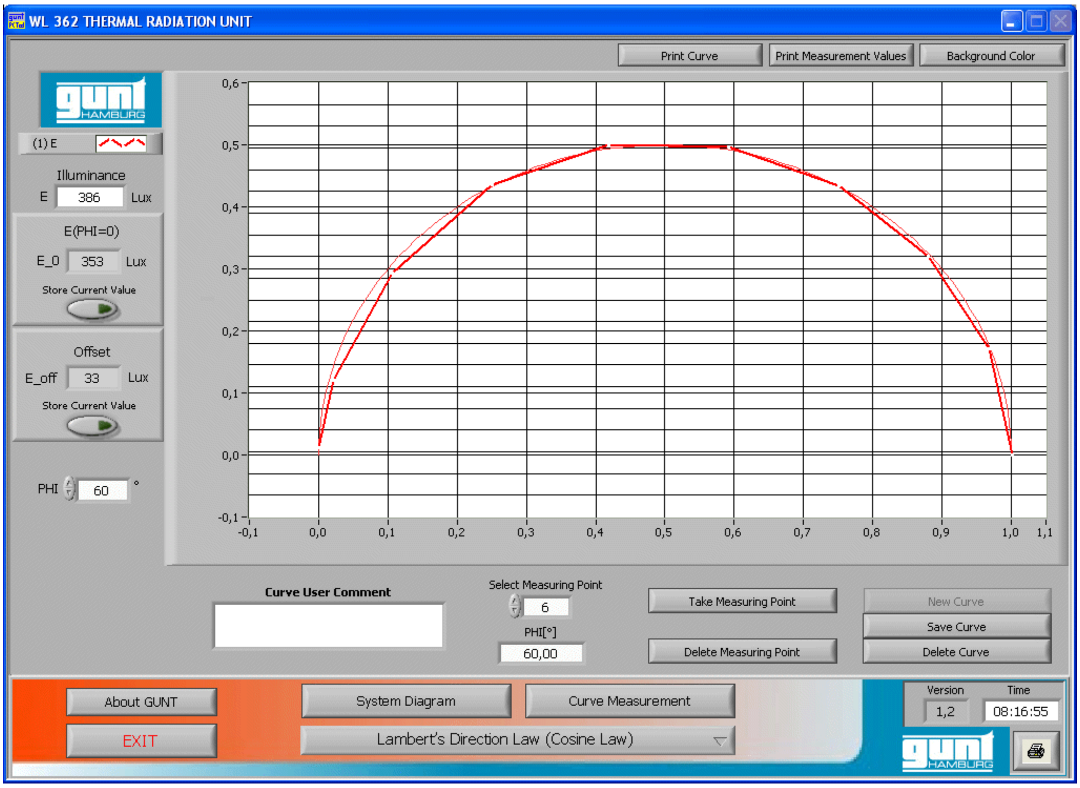


Fig. 5.9 Software Screenshot (WL 362 only)

5.3 Stefan Boltzmann's Law

Experiment duration approx. 60 minutes

5.3.1 Objective

The total radiation E_S of a blackbody radiator is proportional to the fourth power of the absolute temperature T (in Kelvin).

The law is verified in this experiment with the heat source by demonstrating the dependency of the measured radiation on the fourth power of the temperature of the heat source.

5.3.2 Preparation

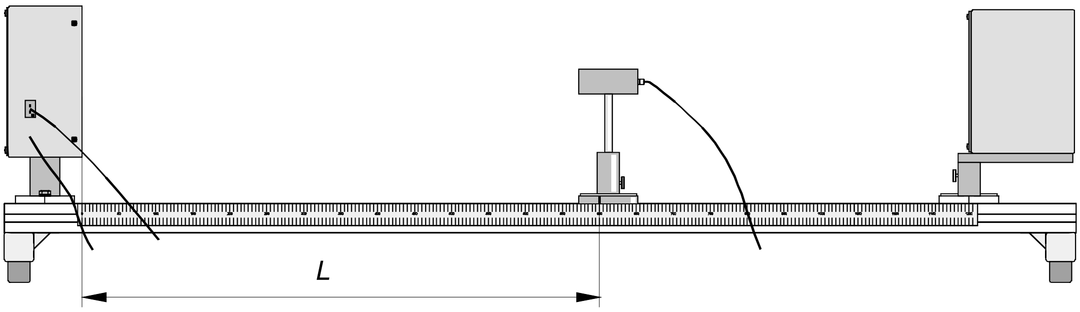


Fig. 5.10 Experimental Setup, Performance of Experiments with the Heat Source

- Mount the thermopile at a separation of L = 130 mm from the heat source, connect to the measuring amplifier ('Strahlung/Radiation' connector). Remove all other fittings in between.
- Connect up the heat source ('Last/Load' connector and 'Temperatur/Temperature 1' connector).

5.3.3 Experimentation

- Switch on the measuring amplifier, note the offset displayed (background radiation).
- Switch on the heat source.
- Set the power regulator on the measuring amplifier to 70. The temperature climbs slowly.
- Take the series of measurements by noting the temperature and the irradiance indicated every 10K.

Temperature T Displayed in °C	Irradiance E_H in W/m^2
20	3
30	28
40	58
50	115
60	170
70	237
80	310
90	388
100	471
110	569
120	697
130	782
140	897
150	1009

Tab. 5.3 Example Measurement Sequence: Dependence of Thermal Radiation on Temperature (L=130mm)

5.3.4 Evaluation of Results

Stefan-Boltzmann's law is confirmed by plotting the measured values on log-log diagram in a similar manner to that given in (Fig. 5.11, Page 45) and determining the slope. The thermopile is measuring only the radiation of the heat source E_H, but for the equation there must be used the total radiation E_S, including the ambient radiation E_{amb} :

$$E_S = E_H + E_{amb} \tag{5.4}$$

The ambient radiation results from the ambient temperature:

$$E_{amb} = C_S \cdot \left(\frac{273{,}15 + T_{amb}}{100}\right)^4 \tag{5.5}$$

$$E_{amb} = C_S \cdot \left(\frac{273{,}15 + 20}{100}\right)^4 = 418{,}7 \frac{\mathrm{W}}{\mathrm{m}^2}$$

The emission coefficient results from the radiation of the heat source and the theoretical radiation:

$$\varepsilon = \frac{E_S}{E_{theo}} \cdot 100\% \tag{5.6}$$

$$E_{theo} = C_S \cdot \left(\frac{273{,}15 + T}{100}\right)^4 \tag{5.7}$$

Plotting the measured values in a log-log diagram and determining the slope of the equalising curve results in a slope of (Fig. 4.9)

$$a = \frac{\Delta y}{\Delta x} = 4{,}0 \text{ results in} \tag{5.8}$$

$$E_S \sim T^4 \tag{5.9}$$

This is the evidence of the law of Stefan Boltzmann.

Temperature *T* Displayed in °C	**Irradiance E_H in W/m²**	**E_{theo} in W/m²**	**ε in %**	**E_S in W/m²**
20	3	419	- / -	422
30	28	479	93	447
40	58	545	87	477
50	115	618	86	534
60	170	698	84	589
70	237	786	83	656
80	310	882	83	729
90	388	986	82	807
100	471	1099	81	890
110	569	1222	81	988
120	697	1355	82	1116
130	782	1498	80	1201
140	897	1652	80	1316
150	1009	1818	79	1428

Tab. 5.4 Example Measurement Sequence: Dependence of Thermal Radiation on Temperature (L=130 mm)

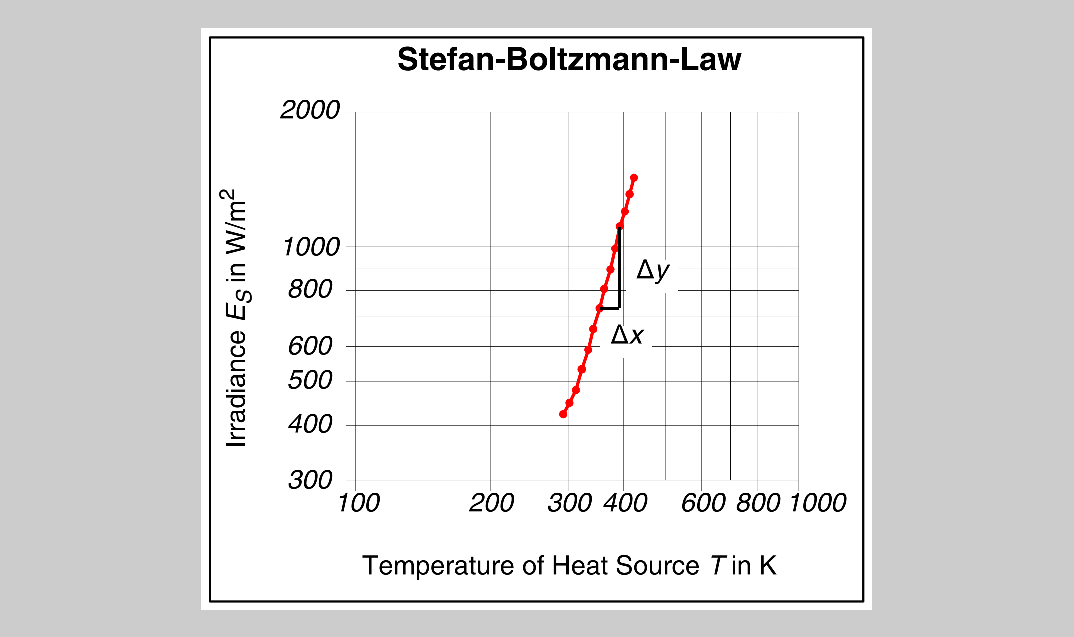


Fig. 5.11 Dependence of Thermal Radiation on Temperature (L=130mm)

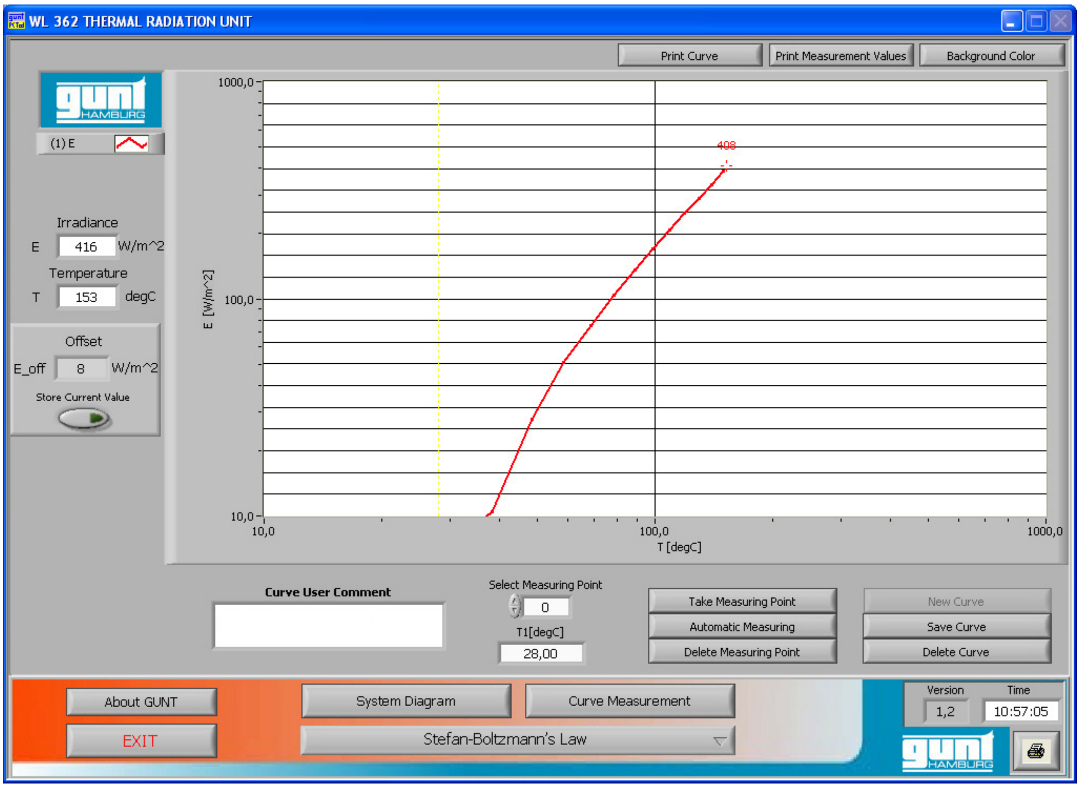


Fig. 5.12 Software Screenshot (WL 362 only)

5.4 Kirchhoff's Law

Experiment duration approx. 90 minutes

5.4.1 Objective

Kirchhoff's Law states – among other things – that good absorbers are also good emitters.

In this experiment this is proven to a high degree of probability in an experiment by having the plates with bright and black surfaces act alternately as emitters and absorbers and determining the respective emission and absorption values.

5.4.2 Preparation

Fig. 5.13 Experimental Setup, Performance of Experiments with the Heat Source

- Mount absorption plate with a distance of 75 mm from the heat source. Remove all other fittings in between.
- Connect up the heat source ('Last/Load' connector and 'Temperatur/Temperature 1' connector).

5.4.3 Experimentation

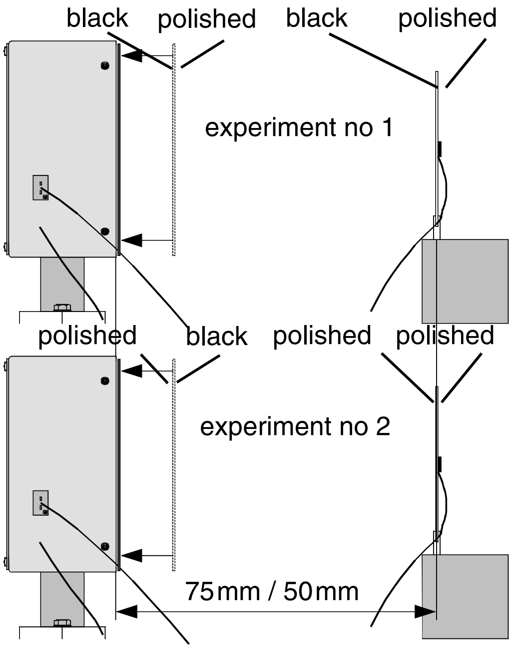


Fig. 5.14 Orientation of the Absorption Faces

- Mount black/polished emission plate to the heat source, black face is visible.
- Mount absorption plate black/polished with a distance of 75 mm to the heat source, with black side face to face to the heat source (Fig. 5.14).
- connect thermopile of the absorption plate to the amplifier ('Temperatur/Temperature 2' connector).
- Set the power regulator on the measuring amplifier to 0.
- Notify ambient temperature.
- Switch on the heat source.
- Set the power regulator on the measuring amplifier to 70. The temperature climbs slowly.
- Wait until the temperature stillstands (approx. 30 min) and notify the temperatures on both sides.
- Mount absorption plate with a distance of 50 mm to the heat source.
- Wait until the temperature stillstands (approx. 5 min) and notify the temperatures on both sides.
- Switch of the heat source and wait until the emission plate has cool down to approx. 40 °C.
- Repeat experiment, but now with the black side of the emission plate mounted face to face to the heat source. Use now the polished/polished absorption plate (Fig. 5.14).

- Index 1 symbolized the polished face
- Index 2 symbolized the black face
- Primed (‘) symbolized the absorption plate
- Not primed symbolized the emission plate

So, for example, the black emission plate has the index 2 and the bright absorption plate the index 1‘

combination of plates	measuring point heat source *T* in °C	measuring point absorption plate *T* in °C
polished - black	$T_1 = 140$	$T_2' = 27$
black - polished	$T_2 = 140$	$T_1' = 27$

Tab. 5.5 Example Measurement Sequence: Distance of Plates $L = 75\,mm$ $T_{amb} = 24\,°C$

combination of plates	measuring point heat source *T* in °C	measuring point absorption plate *T* in °C
polished - black	$T_1 = 140$	$T_2' = 27$
black - polished	$T_2 = 140$	$T_1' = 27$

Tab. 5.6 Example Measurement Sequence: Distance of Plates $L = 50\,mm$ $T_{amb} = 24\,°C$

combination of plates both black	measuring point heat source *T* in °C	measuring point absorption plate *T* in °C
$L = 75\,mm$	$T_2 = 140$	$T_2' = 47$
$L = 50\,mm$	$T_2 = 140$	$T_2' = 53$

Tab. 5.7 Example Measurement Sequence: Only Demonstration $T_{amb} = 23\,°C$

5.4.4 Evaluation of Results

The statement is:

If the plates with bright and black surfaces are used alternately as emitters and absorbers, and if the respective temperatures of the emitters and absorbers are equal, the ratio of the emission coefficient to the absorption coefficient of both surfaces is constant.

The same temperatures were reached in each experiment.

So it can be assumed that these two surfaces have the properties of dielectrics.

5.4.5 Critical Considerations

This effect can also occur in the case of metals (electrical conductors). A random combination of two surface materials each with a constant ratio of emission coefficient to absorption coefficient is highly unlikely however.

5.5 Transmission coefficient

Experiment duration approx. 30 minutes

5.5.1 Objective

The colour filters (green, red, infrared) are intended for experiments with the light source, in order to determine the transmission of visible light by specific colours (=various transmission coefficients).

5.5.2 Preparation

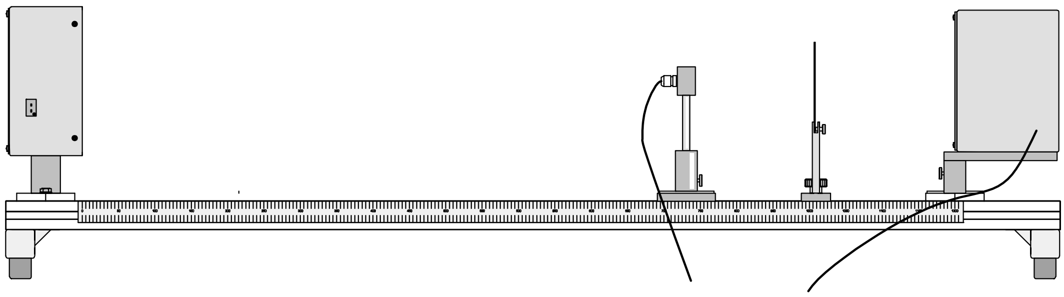


Fig. 5.15 Experimental Setup, Performance of Experiments with the Light Source

The experiment for investigation of the coefficients of transmission should be performed in conditions as dark as possible:

- Mount the luxmeter at a separation of $L = 350\,\text{mm}$ from the light source; connect to the measuring amplifier ('Beleuchtungsstärke/Density of Light' connector). Remove all other fittings in between.
- Mount the clamping mount at half of the distance between light source and luxmeter.
- Mount the light source in position $\varphi = 0°$, connect ('Last/Load' connector)
- Remove matt plate from luxmeter and mount the black apertured plate

5.5.3 Experimentation

- Switch on the measuring amplifier.
- Switch on the light source.
- Turn the power regulator to full.
- Measure and record values (for luminous intensity) with various filters and with no filters respectively. Do this at various settings of the power controller (which performs a kind of dimming function here).

Filter	Lux	%	Lux	%	Lux	%	Lux	%	Lux	%
without	600	100	500	100	400	100	300	100	200	100
green	495	82,47	428	85,57	343	85,75	258	86,00	173	86,50
red	519	86,48	440	87,98	357	89,25	266	88,67	178	89,00
infrared	490	81,64	423	84,57	341	85,25	257	85,67	169	84,50

Tab. 5.8 Example Measurement Sequence: Illuminance without Filter is set to 100%

5.5.4 Evaluation of Results

The light source emits electromagnetic radiation as light not only in the visible area but also in the infrared spectrum. This range of invisible light must be subtracted from the measured luminous intensities of the colour filters, since the luxmeter also measures this range.

This is identifiable by the transmission coefficient of the light of the infrared filter.

This value must be subtracted from the other results of the red and green filter.

Green	Red	Infrared
85,26%	88,27%	84,32%

Tab. 5.9 Measured transmission

The arithmetic means of the relative percentages of the example measured values produce the averaged percentages shown on the left.

First the measured infrared portion is subtracted from the overall spectrum of the bulb. This leaves a portion of 15,68% for the visible light.

The portions of the colour filters within the remaining 15,68% visible light are then determined. This value is determined by subtracting the percentage infrared portion from the measured percentages of the colour filters.

Visible light	Green	Red
15,68%	0,94%	3,95%

Tab. 5.10 Portions from the overall spectrum

For the red filter, for example, this would result in 88,27% - 84,32% = 3,95% transmission coefficient of the visible light component.

The transmission coefficient is calculated according to a formula (4.14), Page 30 (in the following based on the example of red):

$$\tau_r = \frac{\phi_r}{\phi_0} = \frac{3{,}95}{100} = 0{,}035 \approx 0{,}04$$

Visible light	Green	Red
0,16	0,01	0,04

Tab. 5.11 Transmission coefficients

The measured values produce the calculated transmission coefficients shown on the left.

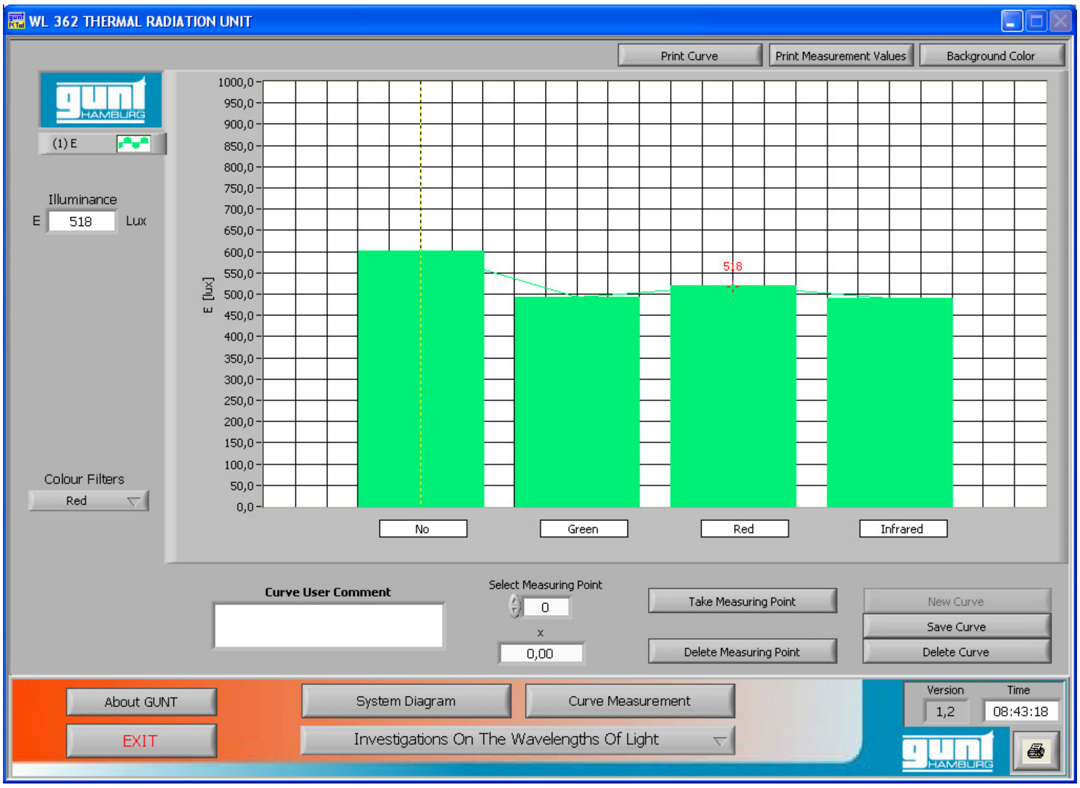


Fig. 5.16 Software Screenshot (WL 362 only)

6 Appendix

6.1 Technical Data

Dimensions		
(B x T x H)	approx. 1460 x 310 x 390	mm
Weight	approx. 20	kg
Power supply	230 VAC / 50	Hz
Nominal consumption (power)	0,6	kW
Alternatives optional, see type plate		
Light Source		
Range of rotation	0 ° to 90 °,	both sides
Lamp power	42	W
Socket	E	27
Illuminated area	0,0289	m^2
Colour of light	white	
Heat Source		
max. power consumption (version 240 V)	400	W
max. power consumption (version 120 V)	340	W
max. Temperature	150	°C
(peakpoint up to 155 °C)		
Radiating area	0,0320	m^2
Photometer (Luxmeter)		
Range of rotation	0 ° to 90 °,	both sides
Measurement range	0 Lux to 2000	Lux
Thermopile		
Range of rotation	0 ° to 90 °,	both sides

Thermocouple

Measurement range 0 °C to 200 °C

Data acquisition

Program environment:

LabVIEW Runtime

System requirements:

PC with processor Pentium IV, 1 GHz

Minimum 1024 MB RAM

Minimum 1 GB available memory on hard disk

1 CD-ROM drive

1 USB port

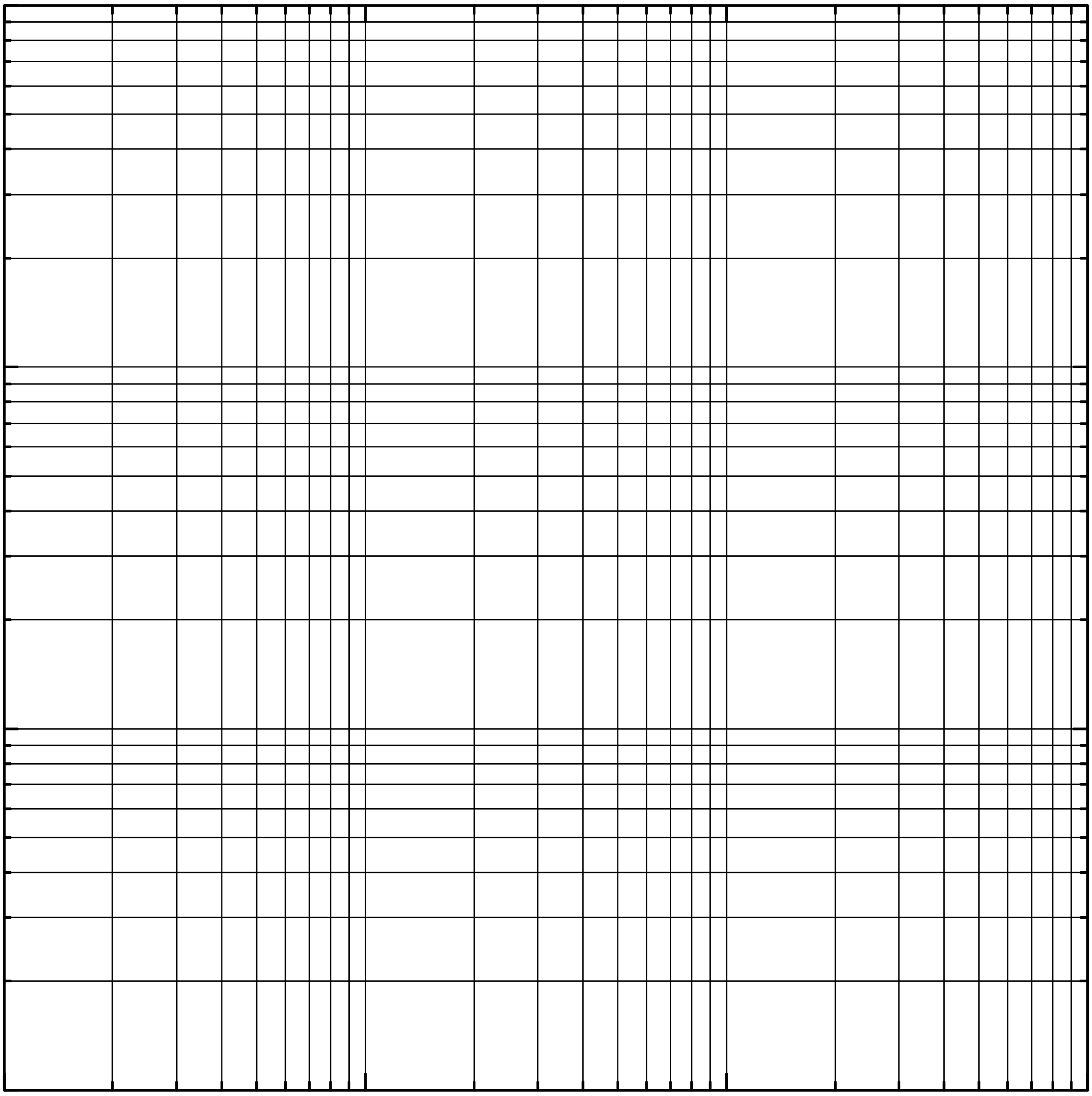
Graphics card resolution min. 1024 x 768 pixels, True Color

Windows Vista / Windows 7

6.2 Symbols and Units

α	Coefficient of Absorption	1
C_S	Radiation Constant of the Blackbody	$\frac{W}{m^2 \cdot K^4}$
ε	Emission Coefficient	1
E	Irradiance	W/m^2
E_S	Irradiance of a Blackbody	W/m^2
I	Radiant Intensity	W
σ	Stefan-Boltzmann-Constant	$\frac{W}{m^2 \cdot K^4}$
T	Absolute Temperature	K
τ	Transmittance	1

6.3 Log-log-Paper for Copying



6.4 Index

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