“L A M B E R T”

GDYNIA MARITIME UNIVERSITY
FACULTY OF MECHANICAL

PHYSICS LABORATORY
DEPARTMENT OF PHYSICS

Theoretical Introduction

Experiment “L A M B E R T”

Visible light is electromagnetic radiation with wavelengths in the range of 380-780 nm. Longer waves are infrared radiation, 780 nm - 1000 µm, and shorter waves are ultraviolet radiation, approximately 10 nm - 380 nm. Visible light produces colour sensations, and white light is a mixture of waves of different wavelengths.

Light — colour and the corresponding wavelength of electromagnetic radiation

Luminous flux Φ- the power of electromagnetic radiation, in the visible range, measured in lumens. One **lumen** is the luminous flux emitted into a solid angle of 1 sr, steradian, by an isotropic light source, placed at the vertex of this angle, having a luminous intensity of 1 cd, candela:

1 lm = 1 cd·sr

lluminance $\boldsymbol{E}$- the power of electromagnetic radiation, in the visible range, incident per unit area, measured in **lux.** One lux is the illuminance produced by a luminous flux of 1 lm, lumen, falling perpendicularly on an area of $1\ \mathrm{m}^2$: 1 m^2:

1 lx = 1 lm/m^2 = 1 cd·sr/m^2

Luminous intensity $\boldsymbol{I}$, intensity of a light source - the derivative of luminous flux $\Phi$with respect to the solid angle Ωaround the direction in which the flux is emitted by a point light source. Luminous intensity is defined with respect to a specified direction. In other words: it is the ratio of the luminous flux $d\Phi$, emitted by a point light source into an infinitesimally small solid angle $d\Omega$around a given direction, to the value of this angle: I = dΦ/dΩ.
It is measured in candelas. One **candela** is the luminous intensity, in a given direction, of a source emitting monochromatic radiation with a frequency of: 540×10^{12} and emitting in this direction a luminous flux of: 1/683 watts per steradian.

Photometers - instruments used to measure photometric quantities. Spectrophotometers are used to examine the brightness of a light source as a function of light wavelength. Special types of photometers include lux meters, for measuring illuminance, photometric benches, measuring luminous intensity, densitometers, measuring optical density, nephelometers, measuring the luminous intensity of scattered light, and colorimeters.

Lambert’s law. If the light source is point-like and radiates isotropically, then the power of light radiation per unit area, illuminance, decreases with distance and depends on the angle of incidence:

$$E = \frac{I}{r^2}\cos\alpha$$

The above dependence is called Lambert’s law, although historically, 1760, Lambert’s law is the dependence:
E = I cosα and concerns the luminous intensity of a surface, satisfied for a perfectly black body; for matte bodies there is a deviation.

“L A M B E R T”

Preparation Questions:

1. Give the definition of light.
2. What is the process of emission of light by bodies?
3. What does optics deal with?
4. What does photometry deal with?
5. Give the definition of illuminance, its dimension and unit.
6. Give the definition of luminous flux, its dimension and unit.
7. Give the definition of luminous intensity and its unit.
8. What are photometers used for?
9. Lambert’s law.
10. At what speed does light propagate in vacuum?
11. What is the value and unit of Planck’s constant?
12. What is a quantum of light?
13. What is the name of light radiation marked with the abbreviation IR?
14. What is the name of light radiation marked with the abbreviation VIS?
15. Is ultraviolet radiation visible or invisible light?

Instructions for Performing the Measurements

1. Switch off all external light sources.
2. Switch on the tested light source.
3. Place the lux meter probe at the position $\alpha = 0°$on the disc and at a distance $r$of about 30 cm from the light source.

(The following activities take into account the different aims of Student 1, determination, and Student 2, verification).

Dependence of Illuminance $E_r$on Distance r (determination and verification)

4. Determine the value of illuminance $E_r$at the distance r.
5. Move the meter probe away from the light source and perform measurements of illuminance E_r. The changes in distance may be arbitrary, but not smaller than 5 cm.
6. Using the entire length of the optical bench, perform a series of 10 measurements of illuminance E_r, all at the deflection angle: $\alpha = 0°$.

NOTE:

The distance $r$is measured from the light source, the beginning of the scale, to the meter probe placed in the centre of the system with the protractor. The length read from the optical bench should be appropriately increased or decreased by 20 mm in order to take into account the width of the stand clamp.

Dependence of Illuminance $E_\alpha$on Angle α (verification only)

7. Place the probe at the position: $\alpha = 0°$ and at a distance $r$of about 30 cm from the light source. Measure the value of illuminance.
8. Increase the deflection angle of the lux meter probe and read the values of illuminance $E_\alpha$and angles αin the range from $0°$to $70°$. Deflect the lux meter towards the blackened wall, which gives smaller reflections and therefore smaller uncertainties.
9. Perform 10 measurements of $E_\alpha$at one fixed distance r, for example 30 cm.

Final Activities

10. Perform calculations according to the instruction and prepare a trial graph in a spreadsheet. In the calculations, remember to use the basic SI units.
11. Prepare a protocol of the performed measurements and estimated measurement uncertainties.

"L A M B E R T"

Methodological Template

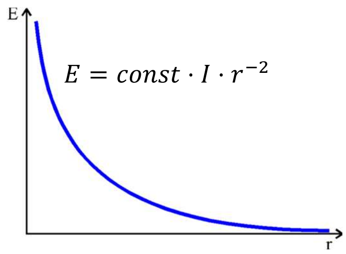
Student 1: Determination of the intensity of a light source using Lambert's method.

Student 2: Verification of Lambert's law.

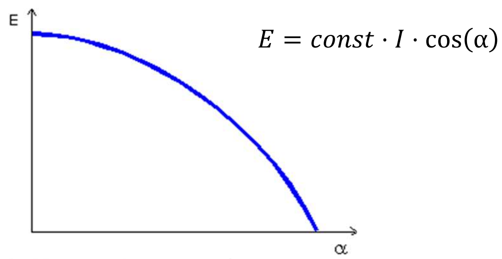
Theoretical Basis

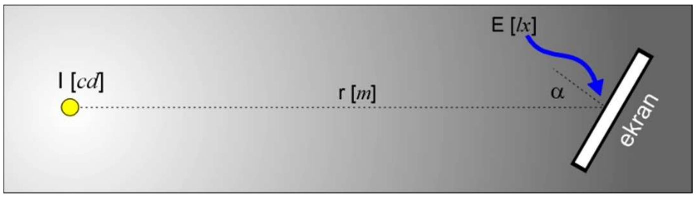
Lambert's law: $E = \frac{I}{r^2} \cdot \cos\alpha$ describes the dependence of surface illuminance on distance and angle of incidence.

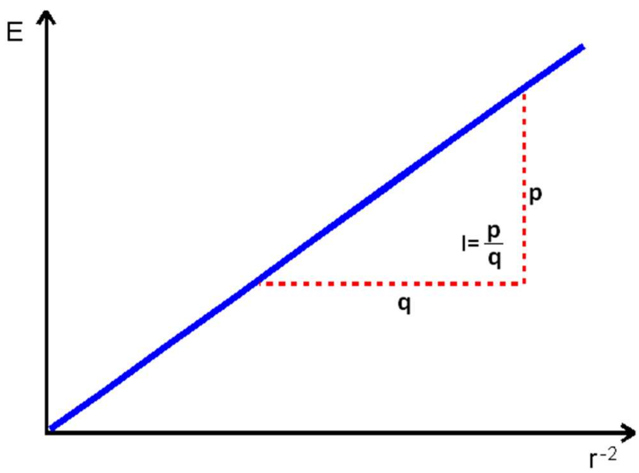
If α is constant:

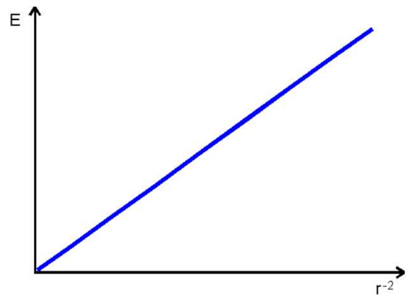


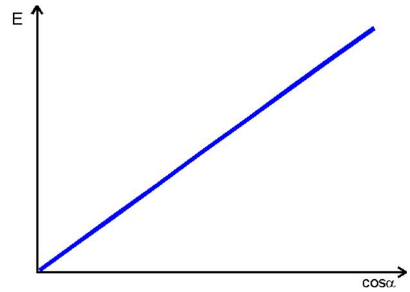
If r is constant:











Therefore, in order to determine the intensity of the light source I, one should:

- perform measurements of the dependence of illuminance E_r on the distance from the source r for the angle: $\alpha = 0°$,
- prepare a graph of the dependence of illuminance E_r on r^{-2},
- read the value of the source intensity.

Therefore, in order to verify Lambert's law, one should:

- perform measurements of illuminance E_r depending on the distance from the source r for the angle of incidence: $\alpha = 0°$
- perform measurements of illuminance E_α depending on angle α for a constant distance r,
- prepare graphs of the dependence of illuminance E_r on: r^{-2} and illuminance E_α on: $\cos\alpha$
- analyse their linearity.

"L A M B E R T"

Report Guidelines – Determination

Student 1: Determination of the intensity of a light source using Lambert's method.

I. Methodology (conceptual plan of the exercise)
II. Course of the exercise
    II.1. Course of activities
    II.2. Sketch of the measurement setup
III. Results
III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
r	[m]										
E_r	[lx]										

Δr = ...
ΔE_r = ...

2. Calculations (example calculations - referring, for example, to measurement no. 4)

$$\frac{1}{r^2} = \ldots$$
$$\Delta \frac{1}{r^2} = \left| \frac{1}{r^2} - \frac{1}{(r+\Delta r)^2} \right| = \ldots$$

3. Calculation results

		1	2	3	4	5	6	7	8	9	10
$\frac{1}{r^2}$	[...]										
$\Delta \frac{1}{r^2}$	[...]										
E_r	[lx]										

ΔE_r = ...

4. Graph

- calculation of I, the slope of the "best-fit" straight line
- calculation of I', the slope of the deviated straight line
- calculation of the accuracy of the method: $\Delta I = | I - I' |$

5. Summary

The determined value of ... is ...
Accuracy of the method: ...
Additional conclusions, observations, causes of measurement uncertainties.

"L A M B E R T"

Report Guidelines – Verification

Student 2: Verification of Lambert's law.

I. Methodology (conceptual plan of the exercise)

II. Course of the exercise

II.1. Course of activities

II.2. Sketch of the measurement setup

III. Results

III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
r	[m]										
E_r	[lx]										

Δr =… ΔE_r = …

		1	2	3	4	5	6	7	8	9	10
α	[°]										
E_α	[lx]										

$\Delta\alpha$ = … [°] = ΔE_α = …

III.2. Calculations (example calculations - referring, for example, to measurement no. 4)

$$\frac{1}{r^2} = \ldots$$

$$\Delta\frac{1}{r^2} = \left|\frac{1}{r^2} - \frac{1}{(r+\Delta r)^2}\right| = \ldots$$

cos α = …

Δ cos α = |cos(α) – cos (α +Δα)| = …

III.3. Calculation results

		1	2	3	4	5	6	7	8	9	10
$\frac{1}{r^2}$	[…]										
$\Delta\frac{1}{r^2}$	[…]										
E_r	[lx]										

ΔE_r = …

		1	2	3	4	5	6	7	8	9	10
cos α	[…]										
Δ cos α	[…]										
E_α	[lx]										

ΔE_α = …

III.4. Graph

IV. Summary

Since on the graphs … it is possible to draw straight lines passing through all measurement uncertainty rectangles, there are no grounds to conclude a deviation from …

Alternatively:

The deviation from linearity in the range … may result from …

Additional conclusions, observations, causes of measurement uncertainties.