Laboratory exercises

Laboratory rules

Laboratory work organization

Lab safety rules – students' signature !!

Assessment conditions (deadline by 16th February 2025)

compulsory practical lab measurements (**fully passed**)

successful delivery of **all** measurement reports (A - E)

Important notes (see the work organization):

14 days for the report delivery

maximum number of F classifications = **5**

maximum number of compensatory measurement dates = **5**

1st measurement – Task Nr. 0 (2nd term week)

Measurement and processing of time and dimensions data

Homework – read the instructions !

Laboratory groups (by 4th term week)

Laboratory measurements timetable – task Nr. 0 + 4 tasks

measurement every 2 weeks

the other weeks – presentations

– theory of the next tasks

knowledge testing – oral examination

– notes are allowed

Measurement report

A well-organized measurement report consist of:

- heading with the task name (website)
- specification of the task
- theoretical principle of the task
- definition of all important quantities with units
- short description of the measurement procedure
- wiring diagrams (if needed)
- a list of uncertainty calculation formulas

Preparation part

- clear general solution of the physical formulas
- precise values substitution and calculation of results with physical units (uncertainty calculation included)
- supplement sheets with the data regression (if needed)
- a list of the data signed by the teacher

Post-processing

Theory of uncertainty

measurement - estimation of level of confidence

exact (true) value – hard to get in a real measurement

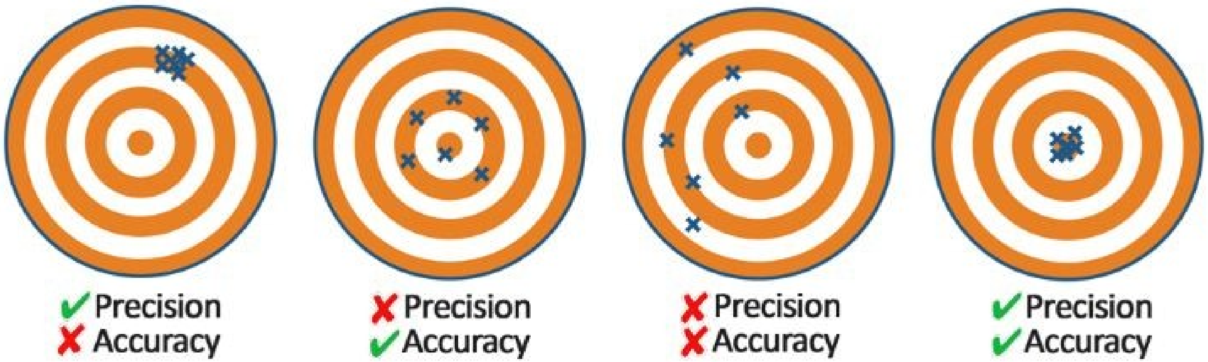
definition of range that surely includes true value

measurement = (best estimate ± uncertainty) {physical unit}

accuracy = ability to get the result near the true value

precision = ability to get a narrow range of obtained data

true value can be outside this range (inaccurate) !!



Error vs. Uncertainty

measurement errors = difference between the measured value and the 'true value'

measurement uncertainties = quantification of the doubt about the measurement result

Expression of Errors

Absolute Error κ_x of a quantity *X*

same unit as the physical quantity

Relative Error of a quantity *X*

ratio of absolute error to the value of quantity

"r" for "relative"

$$\kappa_{rx} = \frac{\kappa_x}{x}$$

relative value (no unit)

Types of Errors

Random Errors = statistic fluctuations of results

due to precision limits of the tool (instrument)

could be reduced by averaging of large number of data

Systematic Errors = reproducible inaccuracies

hard to detect, impossible to analyse by statistics

sometimes predictable by instrument calibration

Estimating of the Errors - single measurements

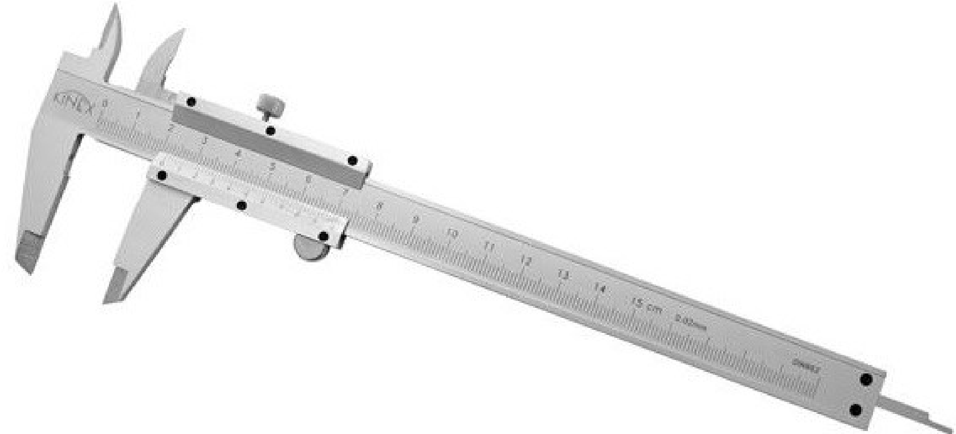
Dimensions: standard error m_x (= κ_x)

Tape measure: m_x = 1 mm

Calliper: m_x = 0.1 mm

Micrometre: m_x = 0.01 mm

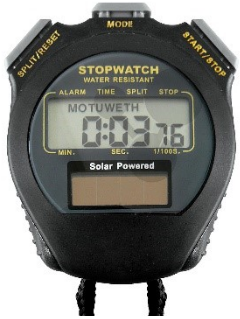

2m
Ergo




0.01mm
0-25mm

Time: stop-watch standard error m_x = 0.01 s

human reaction time m_x = 0.5 s



Electrical quantities – analogue instruments

accuracy class T_p

≈ maximum relative

error within selected

range $\boldsymbol{x}_{max}$

$$m_x = \frac{1}{100} T_p x_{max}$$

Electrical quantities – digital instruments

example from user's manual: m_x = 0,01% rdg. + 2 digits

base error = percentage of the obtained value (reading)

digits of instrument resolution = dependent on the range

last digital place (considering the decimal place)

e.g. U = 12.778 V → one digit ≈ 0.001 V

Estimating of the Errors - repeated measurements

mean (average) value

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

standard deviation of the mean value (data spread)

$$s_{\bar{x}} = \sqrt{\frac{\sum_{i=1}^{n} (\bar{x} - x_i)^2}{n(n-1)}}$$

Uncertainties

Type A = uncertainty estimated by statistics

Type B = other sources (instrument errors, etc.)

Expression of Uncertainty

Absolute uncertainty u_X of a quantity X

same unit as the physical quantity

Relative Uncertainty u_{rX} of a quantity X

ratio of absolute error to the value of quantity

$$u_{rx} = \frac{u_x}{X}$$

"r" for "relative"

relative value (no unit)

Uncertainty for a Type A evaluation

$$u_{xA} = s_{\bar{x}} = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Uncertainty for a Type B evaluation

$$u_{zB} = \frac{\Delta z_{\max}}{\chi}$$

Δz_{max} is the maximum of all detectable systematic errors (= m_x)

$$\chi = \sqrt{3}$$

for the uniform distribution

Combining standard uncertainties A and B Type

law of summation in quadrature $$u_x = \sqrt{u_{xA}^2 + u_{xB}^2}$$

Combining standard uncertainties – general approach

for quantity $Y = f(X_1, X_1, \ldots. X_n)$

$$u_Y = \sqrt{\left(\frac{\partial Y}{\partial X_1}\right)^2 u_{X_1}^2 + \left(\frac{\partial Y}{\partial X_2}\right)^2 u_{X_2}^2 + \cdots + \left(\frac{\partial Y}{\partial X_n}\right)^2 u_{X_n}^2}$$

Calculation of sum for Type A and Type B estimation

a set of sub-uncertainties $u_{X_1A}, u_{X_2A} \ldots. u_{X_nA}, \; u_{X_1B}, u_{X_2B} \ldots. u_{X_nB}$

$$u_{YA} = \sqrt{\left(\frac{\partial Y}{\partial X_1}\right)^2 u_{X_1A}^2 + \left(\frac{\partial Y}{\partial X_2}\right)^2 u_{X_2A}^2 + \cdots + \left(\frac{\partial Y}{\partial X_n}\right)^2 u_{X_nA}^2}$$

$$u_{YB} = \sqrt{\left(\frac{\partial Y}{\partial X_1}\right)^2 u_{X_1B}^2 + \left(\frac{\partial Y}{\partial X_2}\right)^2 u_{X_2B}^2 + \cdots + \left(\frac{\partial Y}{\partial X_n}\right)^2 u_{X_nB}^2}$$

$$u_Y = \sqrt{u_{YA}^2 + u_{YB}^2}$$

Simplification for two quantities in basic operations

values ***a*** and ***b*** are real constants

m and ***n*** are natural indices

Operation	Formula	Uncertainty calculation
Addition or subtraction	$Y = X_1 \pm X_2$	$u_Y = \sqrt{u_{X_1}^2 + u_{X_2}^2}$
	$Y = aX_1 \pm bX_2$	$u_Y = \sqrt{a^2 u_{X_1}^2 + b^2 u_{X_2}^2}$
Multiplication or division	$Y = X_1 X_2$	$u_{rY} = \sqrt{u_{rX_1}^2 + u_{rX_2}^2}$
	$Y = aX_1^m X_2^n$	$u_{rY} = \sqrt{m^2 u_{rX_1}^2 + n^2 u_{rX_2}^2}$

Expression of the result

$$Y \pm u_Y$$

uncertainty value - round up in all the cases

number of significant figures = 2

result *Y* - same number of decimal places as the uncertainty

$$\lambda = (632.8 \pm 1.3)\ \mathrm{nm}$$
$$T = (1.235 \pm 0.032)\ \mathrm{s}$$
$$E = (2.05 \pm 0.12).10^{11}\ \mathrm{Pa}$$