Measurement in technical sciences
Systems of units - SI

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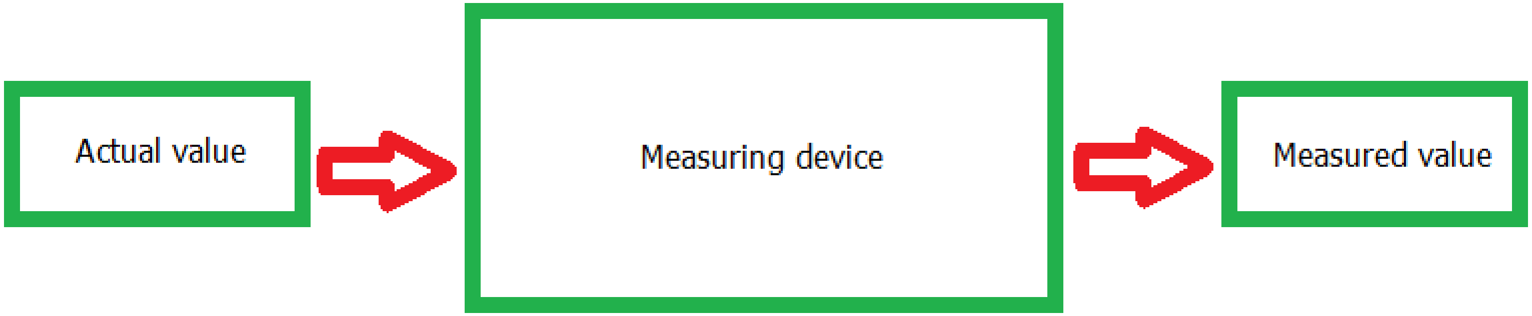
- Subject's requirements on the WEB - page

The measurement

- During the measurement, the goal is to determine the measure that characterizes the measured quantity, which requires the selection of a suitable measuring device.

  During the measurement, the unit of measure used to express the numerical value must be agreed in advance.
- *Measured value – value determined during the measurement*
- *Actual value – value determined during the measurement*



Actual value

Measuring device

Measured value

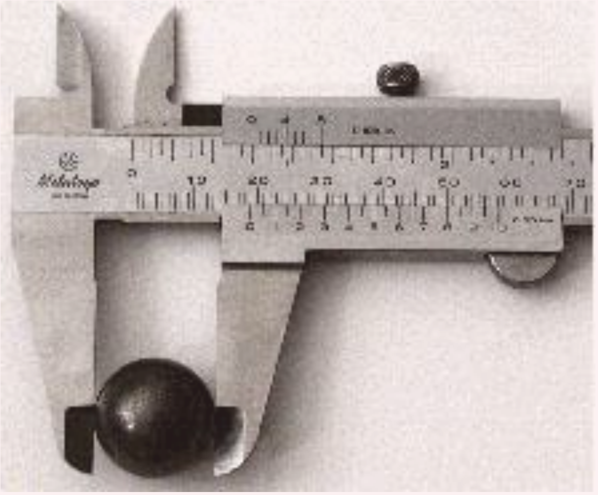
- the actual value cannot be determined with absolute certainty!
- the difference between the actual value ($\tilde{a}$) and the measured value (a) is called the uncertainty (error) of the measurement.
- the result of a measurement must therefore always be characterized by the uncertainty of the measurement in addition to the measured value!

Types of measurements I.

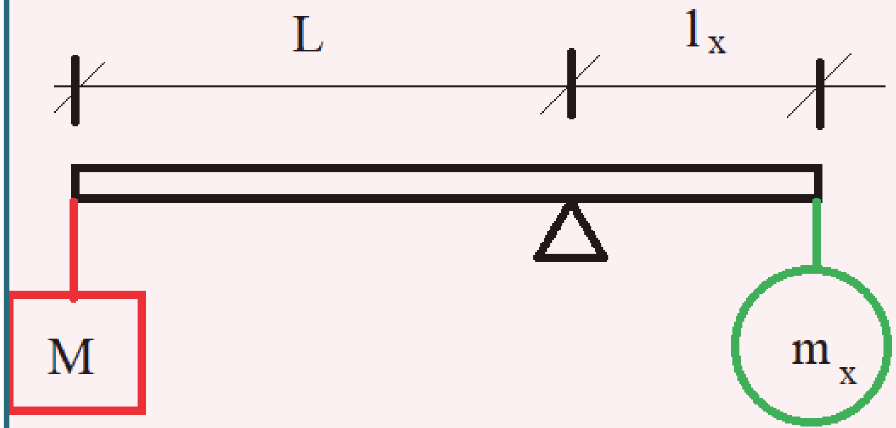
- *absolute measurement –* gives the measurement result in the predefined unit (standard) (distance measurement in meters)

- *relative measurement –* compares the quantity to be measured to a preselected quantity of the same type (mass measurement on a scale)

- absolute



- relative



$$m_x = \frac{L}{l_x} M$$

Types of measurements II.

- *direct measurement* – based on the definition of the quantity to be measured (density measurement based on the definition)

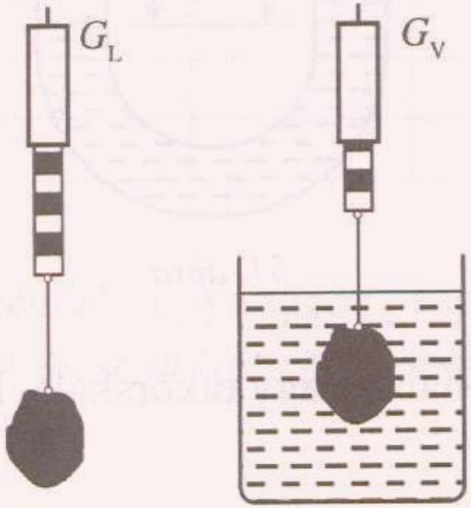
- *indirect measurement* – based on some law that is related to the quantity to be measured (measurement of density from buoyancy force - law of Archimedes)

- Direct measurement

$$\rho = \frac{m}{V}$$

- measurement of mass
- measurement of volume

- Indirect measurement

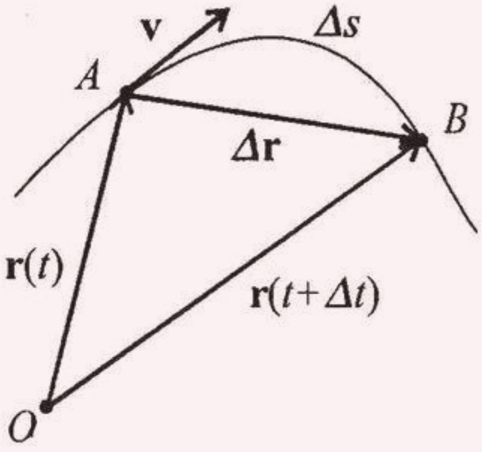


$$\rho = \frac{G_L}{G_L - G_V}\rho_f$$

Types of measurement III.

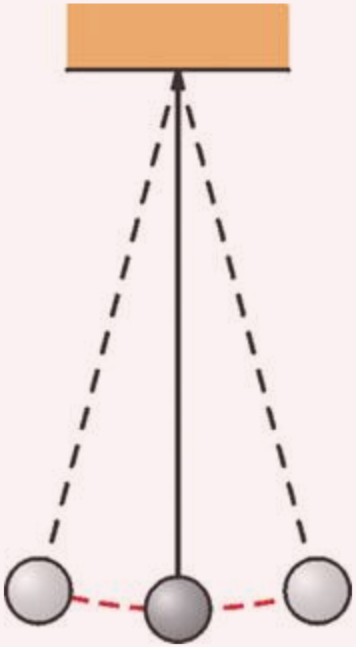
- *static measurement* – the quantity to be measured is determined based on quantities stabilized over time (the average speed is measured based on the displacement and the time required for it)
- *dynamic measurement* – we determine the quantity to be measured based on time-varying quantities (determining the period of a swinging pendulum)

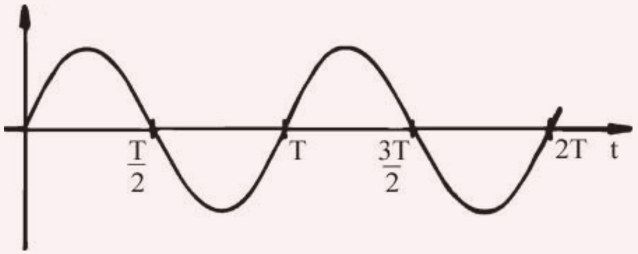
- Static measurement



$$\vec{V}_{atl}=\frac{\Delta r}{\Delta t}$$

- Dynamic measurement

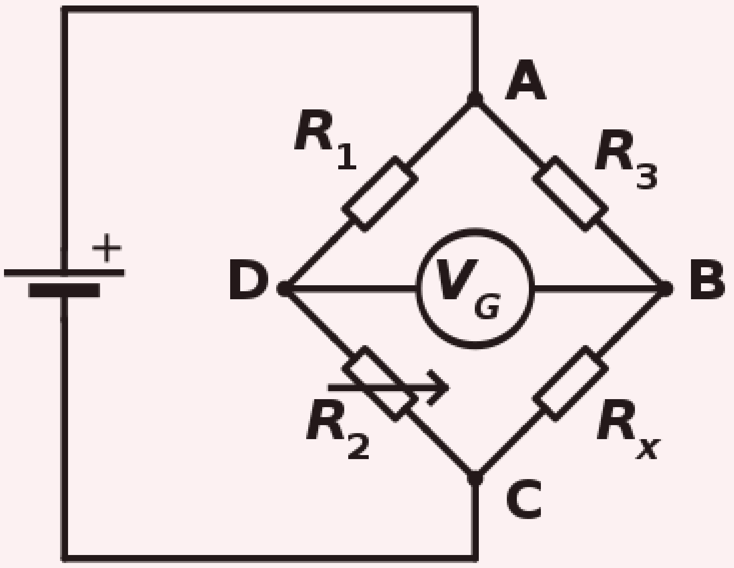




Types of measurement IV.

- *compensation measurement* – the effect caused by the quantity to be measured is balanced by another effect of the same type, but opposite (Wheatston - bridge, fully canceled interference) - *enables very sensitive and accurate measurements*

Compensation measurement
Wheatston – bridge



- R_2 – its value is changed until V_G becomes zero - *balanced bridge*

- for balanced bridge:

$$R_1 R_x = R_2 R_3$$

thus

$$R_x = \frac{R_2 R_3}{R_1}$$

Systems of units

- The measured value only makes sense in some *system of units*. The measured number itself does not say anything about the measured value!

- In the beginning some units of measurement were derived from the physical attributes of important people. (inch, foot, etc.) These were usually just difficult to use (the important person was not always available), so they made copies of these „units", which were already made available in a place accessible to all users. (Units of length placed in larger marketplaces, walls of churches, etc.)

- The industrial revolution brought with it the demand that it would be good to create a widely accepted, unified system of units. *CGS system* (suggested by F. Gauss) used *cm, g* and *s* as base units.

SI – system of units

- It has been used since the 60s of last century, mainly in Europe.

- Defines *7 basic units* (some based on *standard*, some based on *measurement procedure*).

- So – called *derived units* follow from the 7 basic units using *laws of nature.*

Basic units of SI

Unit	Notation	Quantity
1 meter	1 m	distance
1 kilogram	1 kg	mass
1 second	1 s	time
1 amper	1 A	electric current
1 kelvin	1 K	temperature
1 candela	1 cd	luminouse intensity
1 mole	1 mol	amount of substance

Allowed units in SI: minute, hour, day, degree of angle, minute of angle, second of angle, hectare, liter, ton

- *1 m is length of the path travelled by light in a vacuum in 1/299792458 of a second.*

- *1 kg is defined as the mass of a particular international prototype made of platinum-iridium and kept at the International Bureau of Weights and Measures.*

- *1 second is defined by taking the fixed numerical value of the* ^{133}*Cs frequency – the unperturbed ground-state hyperfine transition frequency of the* ^{133}*Cs atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to* s^{-1}.

- *1 amper is an electrical current equivalent to* 10^{19} *elementary charges moving every 1.602176634 seconds or* 6.241509074×10^{18} *elementary charges moving in a second.*

- 1 kelvin is equal to a change in the thermodynamic temperature T that results in a change of thermal energy kT by 1.380649×10^{-23} J.

- 1 candela is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency 540×10^{12} Hz, K_{cd}, to be 683 when expressed in the unit sr/W.

- 1 mol is defined as amount of substance containing exactly 6.02214076×10^{23} elementary entities.

Some derived units

Name	Notation	Quantity	Expression in basic units
hertz	Hz	frequency	s^{-1}
newton	N	force	$kg.m. s^{-2}$
pascal	Pa	pressure, stress	$kg.m^{-1}. s^{-2}$
joule	J	energy, work, heat	$kg.m^{2}. s^{-2}$
watt	W	power	$kg.m^{2}. s^{-3}$
coulomb	C	electric charge	A.s
volt	V	voltage	$kg.m^{2}. s^{-3}.A^{-1}$
ohm	Ω	resistance	$kg.m^{2}. s^{-3}.A^{-2}$

Multiples and fractions

	deca	hecto	kilo	mega	giga	tera	peta	exa	zetta	yotta
Notation	da	h	k	M	G	T	P	E	Z	Y
	10^{1}	10^{2}	10^{3}	10^{6}	10^{9}	10^{12}	10^{15}	10^{18}	10^{21}	10^{24}

	deci	centi	milli	micro	nano	pico	femto	atto	zepto	yocto
Notation	d	c	m	μ	n	p	f	a	z	y
	10^{-1}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}	10^{-21}	10^{-24}

Measuring instruments

- *Measuring instrument* – a technical device that clearly changes it’s state in response to the quantity to be measured.

Examples:

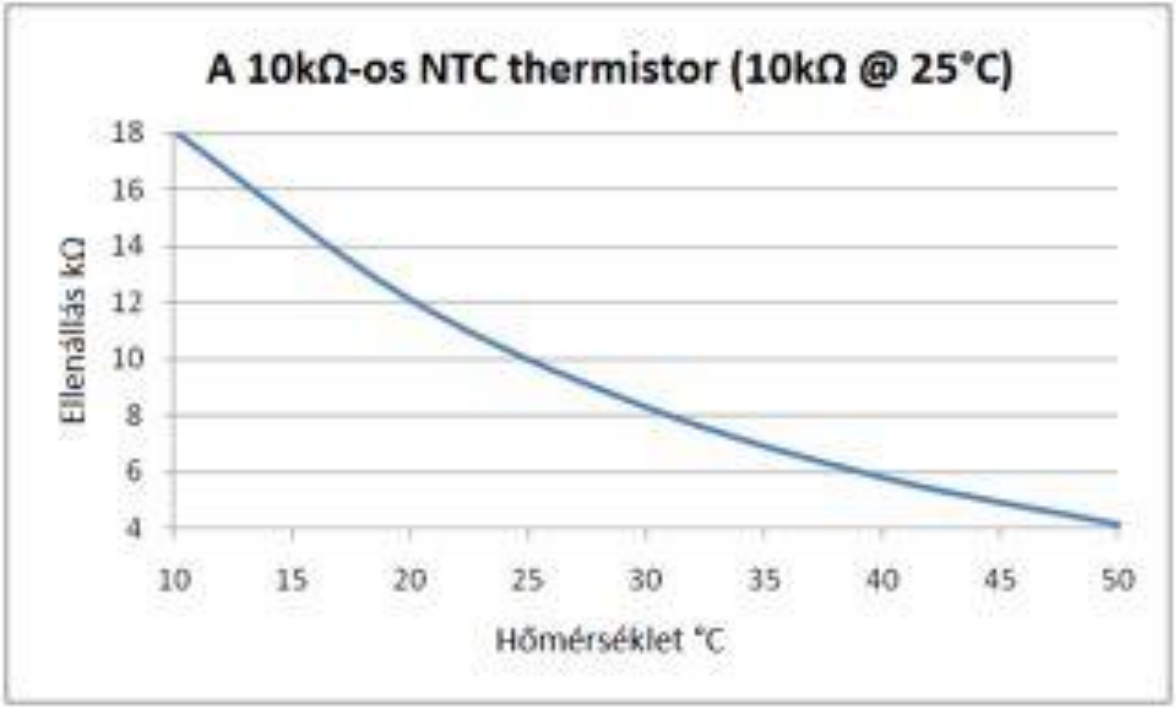
- the linear dimensions of solid bodies change clearly as a result of temperature.
- as a result of the voltage, the analog voltmeter's indicator clearly moves.

Accuracy of measuring instruments

- An instrument can only react clearly within a specific range of the quantity to be measured without malfunctioning. This range is called the *measuring range* of the instrument.
- If the uncertainty of a measurement with an instrument is divided by the maximum of the measurement range of the instrument, we get the "*accuracy*" of the instrument.
- Manufacturers classify instruments into *„accuracy classes”* based on their accuracy, and this must be indicated in the instrument's documentation!

Calibration of measuring instruments

- The *unequivocal change* in the state of the measuring instrument caused by the measured quantity is called the *calibration function*, and the graph representing it is called the *calibration curve*.
- The calibration curve is taken during a *calibration measurement*.
- For calibration, we use etalons or instruments already calibrated based on etalons to determine the measured value!



Calibration curve of a thermistor