Measurement and Uncertainty

- The SI-System
- Units and Conversion
- Significant figures
- Uncertainty

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The SI-System

- Length: meter
- Mass: kilogram
- Time: second
- Temperature: kelvin

Prefixes:

tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

Historical 18th century standard-meter at 36, rue de Vaugirard in Paris
[Photo by LPLT from Wikimedia Commons
https://commons.wikimedia.org/wiki/File:M%C3%A8tre-%C3%A9talon_Paris.JPG

The SI System vs. the US System

SI: International System of Units

US: United States customary units
(similar in most cases to the old Imperial System)

	SI		US		Conversion
Length:	Meter	[m]	foot	[ft]	1.000 ft= 0.3048 m
Force:	Newton	[N]	Kilo-pound	[kip],[kips]	1.00 kip = 4450 N

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Unit Conversion (Unit analysis)

→ Also see https://youtu.be/dumXDlANJA8

$$\text{New Unit} = \text{Old Unit} \times \frac{\text{New Unit value}}{\text{Old Unit value}}$$

Example 1: Convert 300 m to km

$$300\ \text{m} \times \frac{1\ \text{km}}{1000\ \text{m}} = 300 \times 1 / 1000\ \text{km} = 0.3\ \text{km}$$

Example 2: Convert 5.0 km/h to m/s

$$5.0\,\frac{\text{km}}{\text{h}} \times \frac{1000\ \text{m}}{1\ \text{km}} \times \ldots$$

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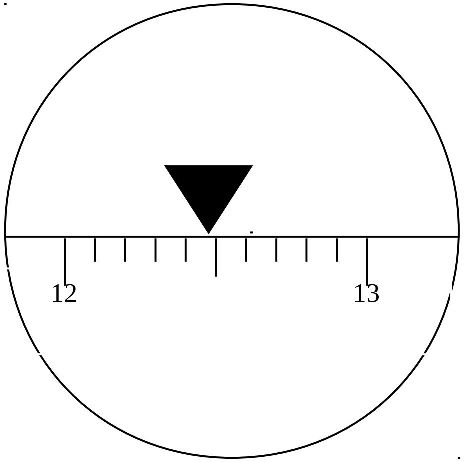
→ Also see
https://youtu.be/Kfy_Sd3jSCk

… why 2 cm and 2.0 cm is not the same



- It is not possible to make an exact measurement.
- The last written digit is the estimated digit

→ 2 cm :   Anything between 1 and 3 cm
→ 2.0 cm: Anything between 1.9 and 2.1 cm

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Uncertainty

→ Also see https://youtu.be/Kfy_Sd3jSCk

Similar to significant figures, uncertainty is used to specify how “uncertain” a measurement is.

Uncertainty specifies, how much the measurement could be off.

Goal: Report an accurate measurement (meaning the „real“ value is within the specified range)

Examples of stating uncertainty:

Range:	*7.02-7.06 cm*
Absolute Uncertainty:	(7.04 ± 0.02) cm
Relative Uncertainty:	(5 ± 1%) cm

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Uncertainty is influenced by:

- the tool -> The influence of the tool is often OVERESTIMATED
- the method used -> There are methods, that, using the same tool, improve precision dramatically
- the experimenter -> Often referred to „the human error“. It should be accounted for when specifying the uncertainty
- the object -> Irregular shape, constantly moving...
- etc.

Precision, Accuracy and Uncertainty

→ Also see https://youtu.be/e-Eb2wdZ-Qk

Precise: Repeated measurements give similar (not necessarily correct) values

Accurate: Repeated measurements produce values around the correct value

Goal: Being precise AND accurate

Worst case scenario: Being precise but not accurate

Example: a hockey player that always shoots the puck exactly 3 meters left of the goal

Why is this the worst case scenario?

- It is often difficult to detect
- High precision (for example of a digital scale with 20 digits) will make us think that our measurement is necessarily also accurate.
- Most (statistical) methods for determining the uncertainty are based on precision, thus we will report an incorrect uncertainty (by increasing the uncertainty, we would increase the accuracy of the measurement, while sacrificing precision)

Absolute vs. Relative uncertainty

→ Also see
https://youtu.be/Kfy_Sd3jSCk

Absolute Uncertainty

- *Uncertainty stated in the same unit as the value*
- *Example:* *10 ± 2 m*

$$\frac{absolute\, uncertainty}{value} \cdot 100$$

Relative Uncertainty

- *Uncertainty stated as a percentage of the value*
- *Example:* *10 m ± 20%*

$$\frac{relative\, uncertainty \cdot value}{100}$$

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How to determine uncertainty

Uncertainty from a measurement can be determined through:

- Estimation -> See https://youtu.be/9YriBMqMx7c
- Statistics
  - Min-Max method -> See https://youtu.be/gHLzzzDohdE
  - Average and standard deviation -> See https://youtu.be/2ld3uFfRVt0

Calculations with uncertainties

Resulting uncertainties based on calculations with values with uncertainties:

Addition/Subtraction	Add absolute uncertainties
Multiplication/Division	Add relative uncertainties
More complex operations	Use the min-max method

→ Also see https://youtu.be/7Q-zuT9cbeo and https://youtu.be/Lrkd6yHjTRI