HyDEX

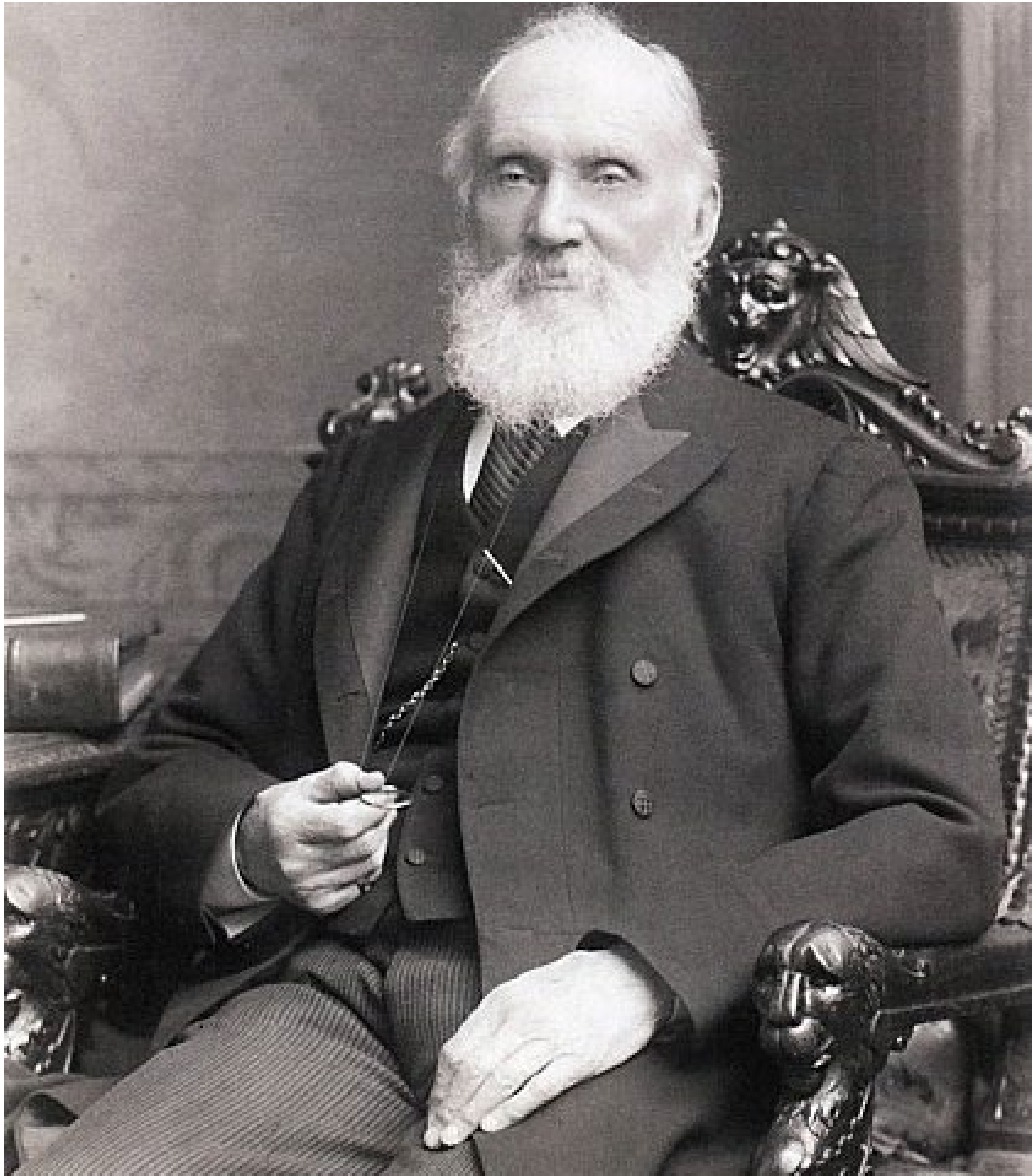
Prof. Paul Holland

If you can't measure it, you can't improve it!

An introduction to hydrogen metrology

Funded by UKRI Research England

Lead academic partners ERA ENERGY RESEARCH ACCELERATOR Keele UNIVERSITY

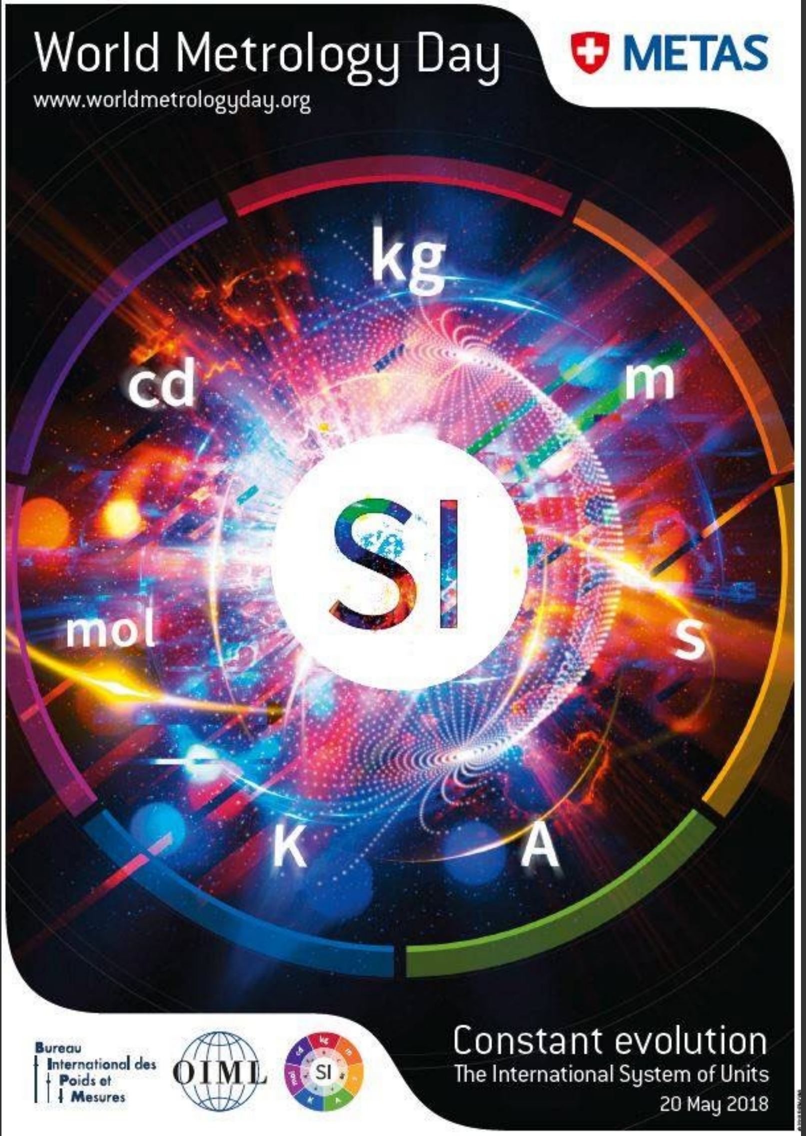


If you can't measure it, you can't improve it

An introduction to hydrogen metrology

Metrology?

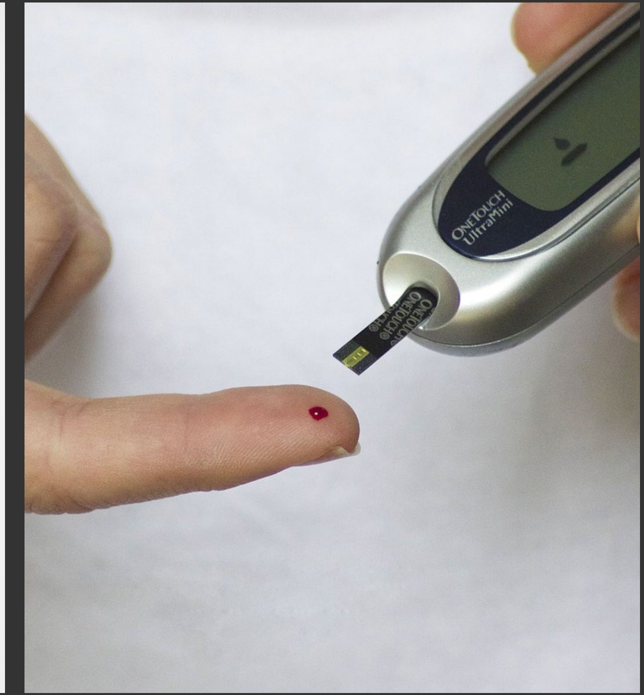
No




WEIGHT IN POUNDS
WEIGHT IN KILOGRAMS
TOLEDO


YR-ATA


REITLING
WED 2
superOcean
CHRONOMETER
SWISS MADE

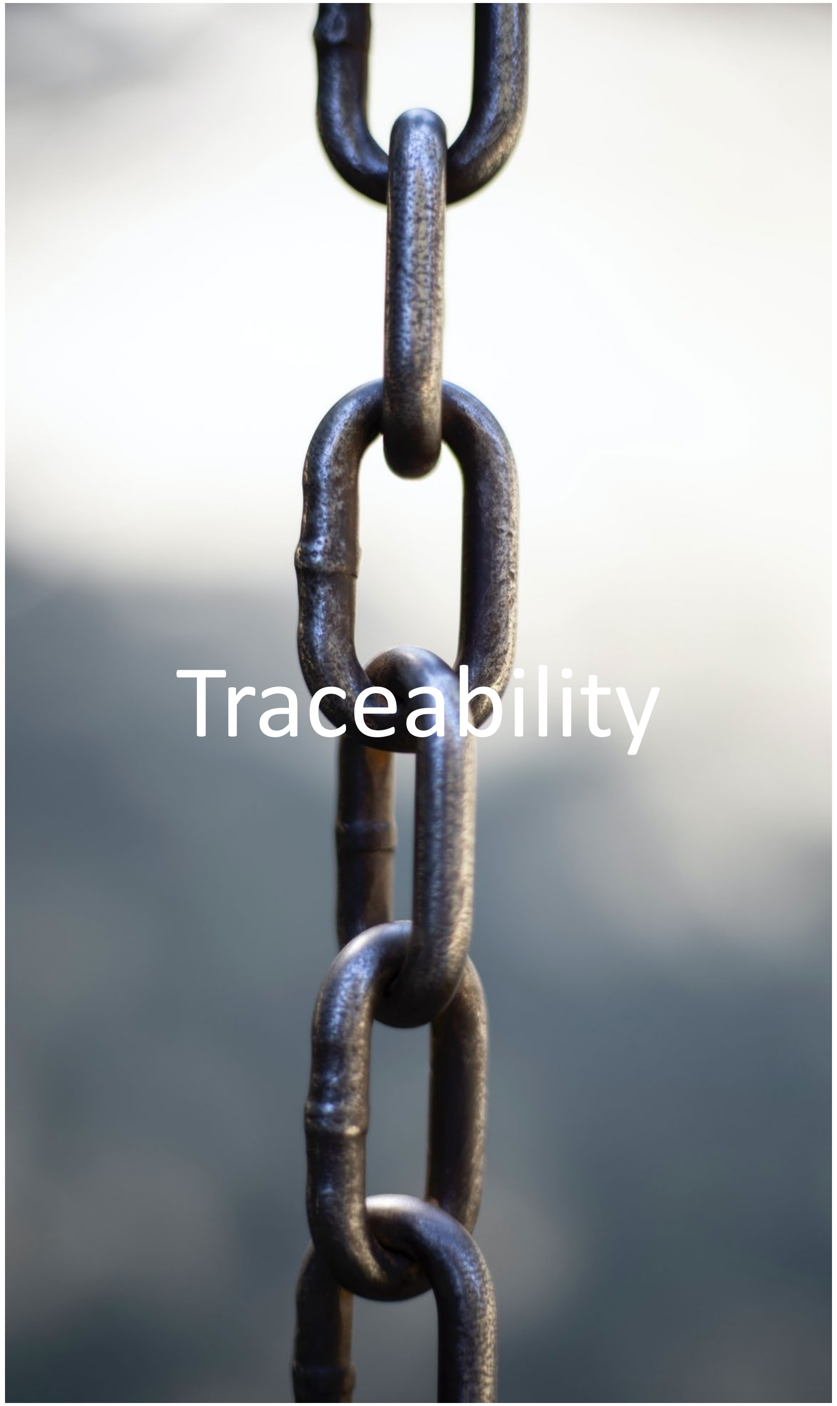

OneTouch UltraMini

Accuracy & Precision

Traceability

Uncertainty

Accuracy & Precision

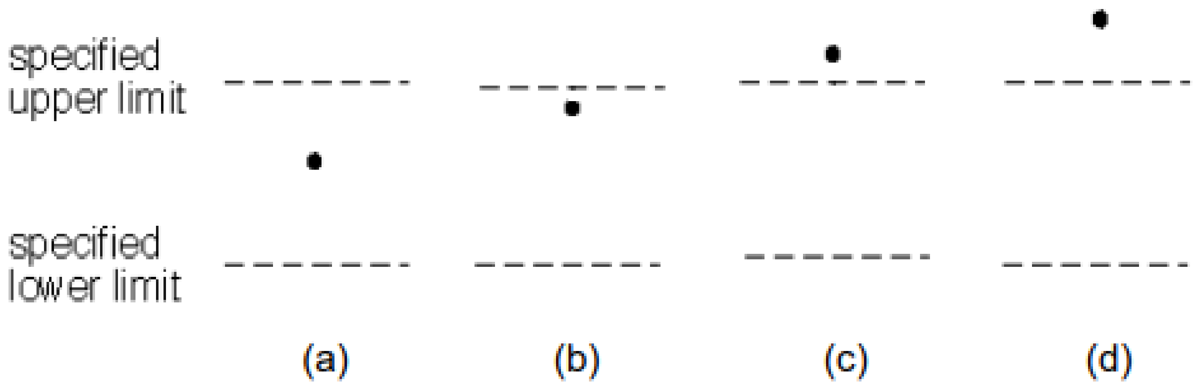


Uncertainty

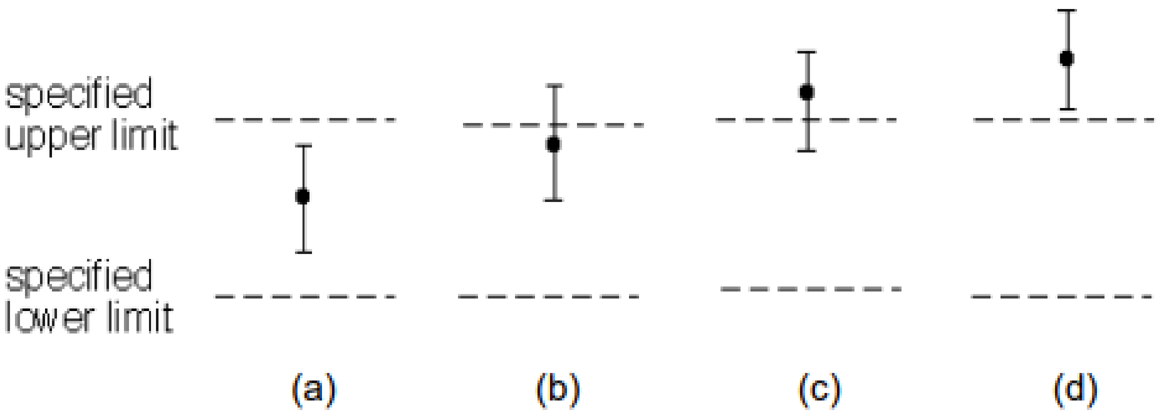
Accuracy & Precision

Traceability

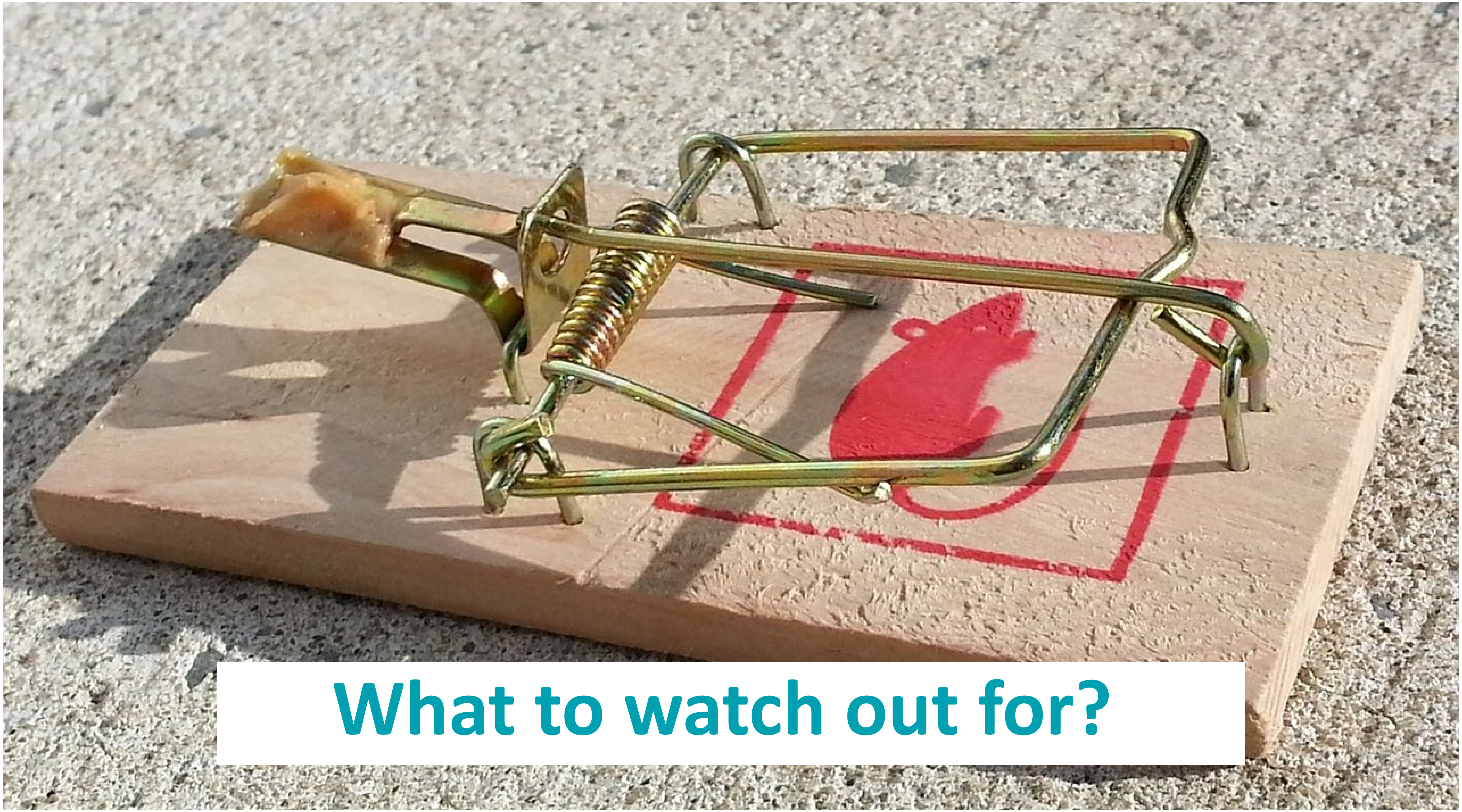
Uncertainty



Compliance?



Compliance?



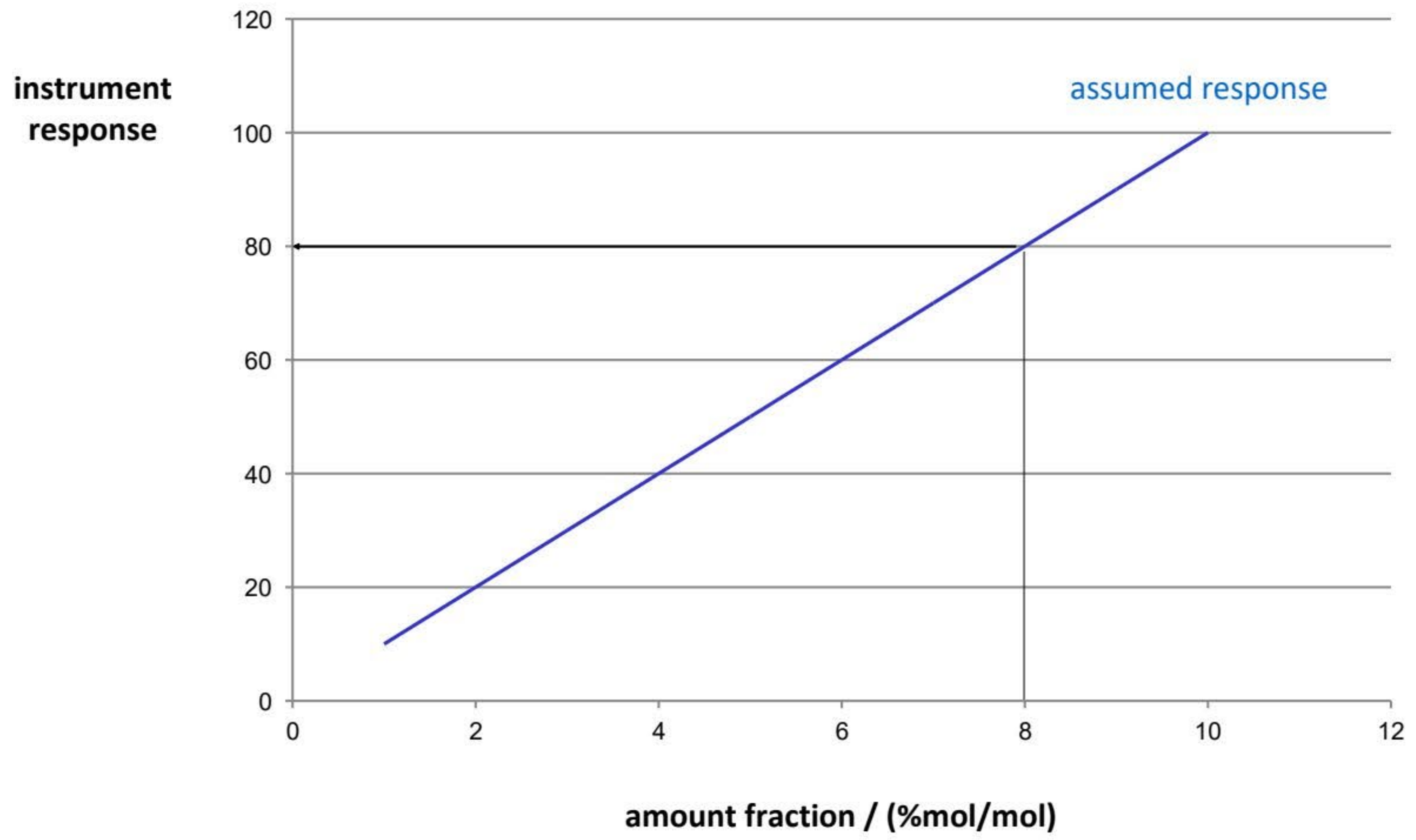
What to watch out for?

Traceable Calibration

Know your instrument

- Linearity
- Repeatability
- Matrix effects and cross sensitivity

Errors caused by non- linear response



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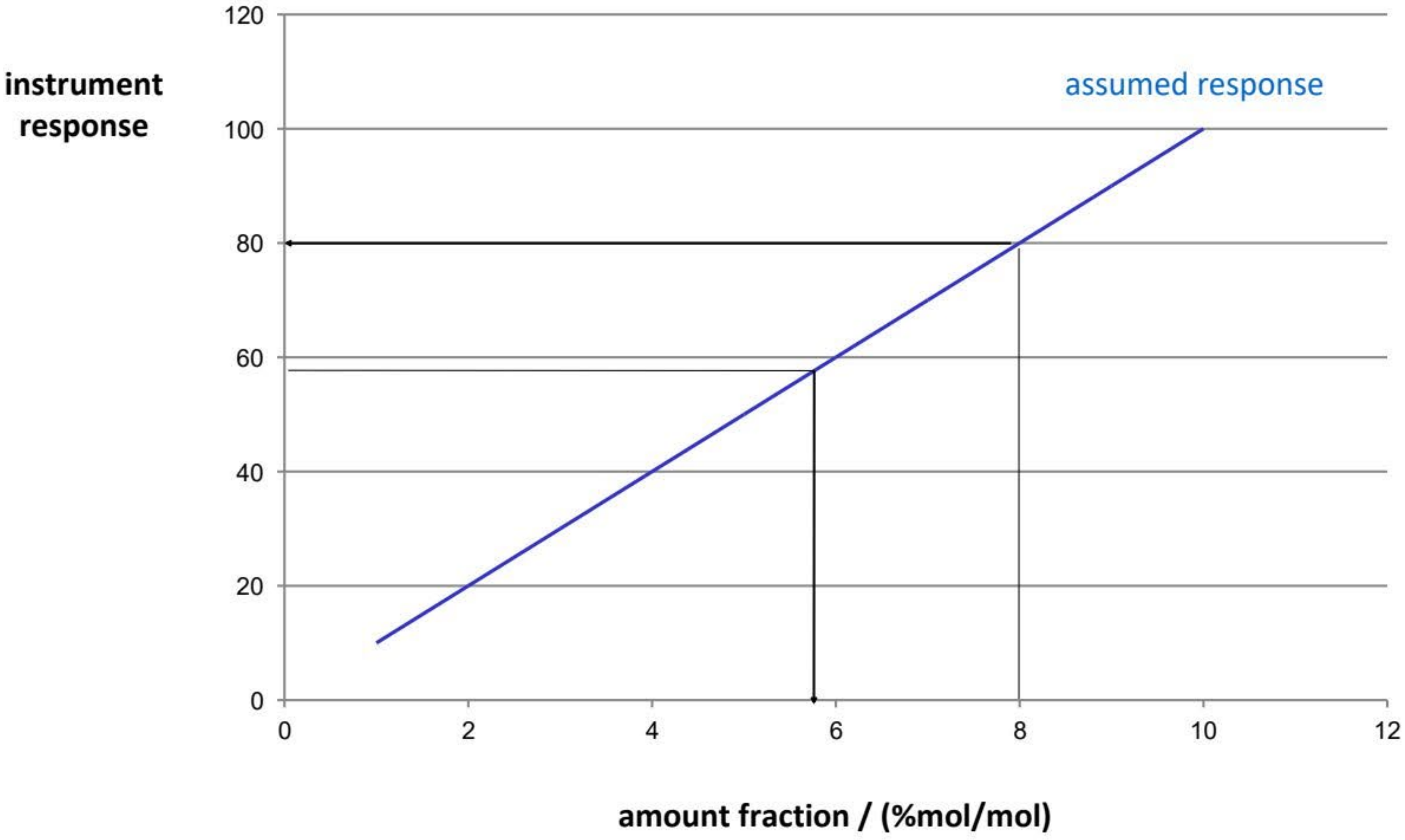

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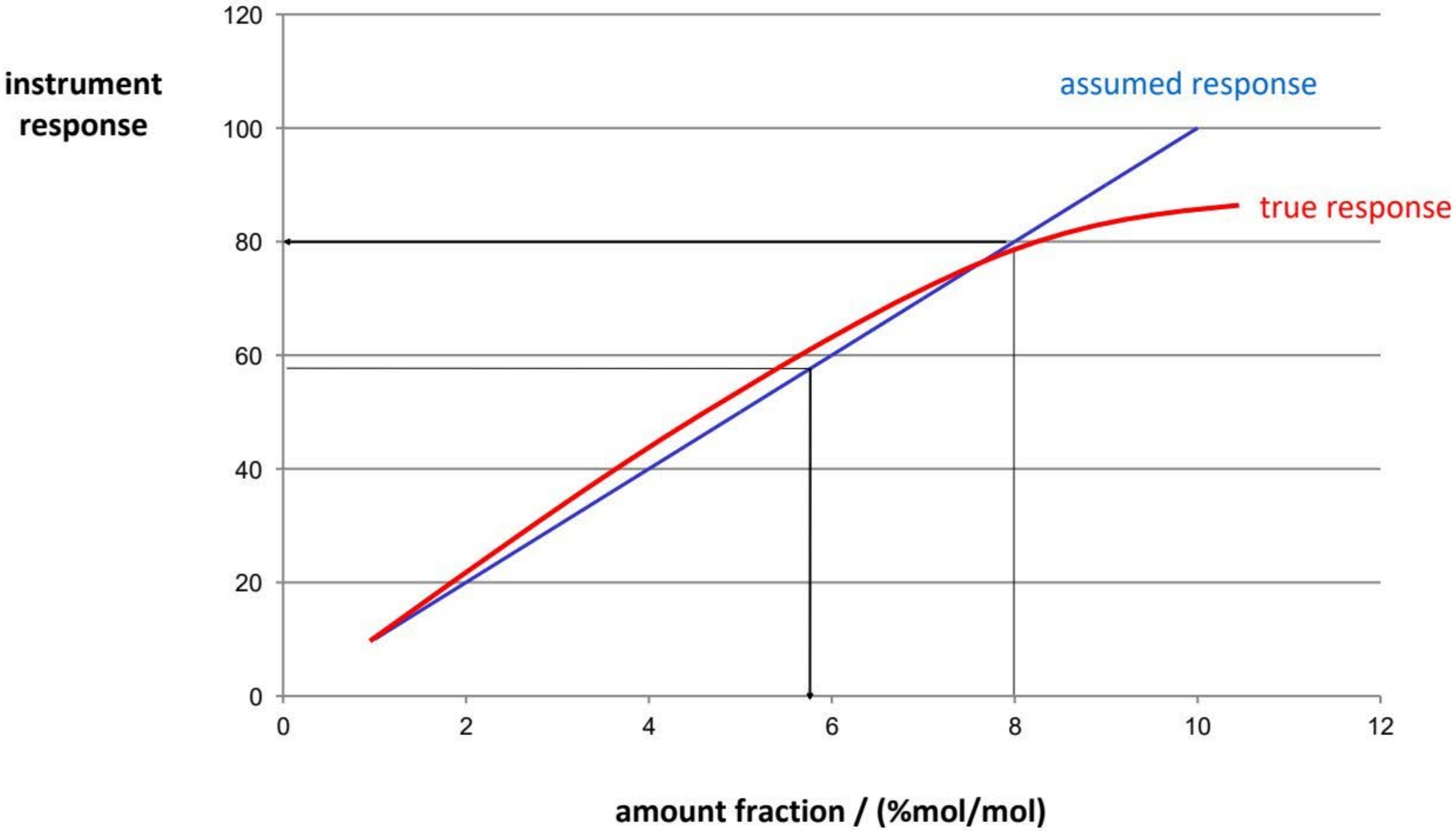

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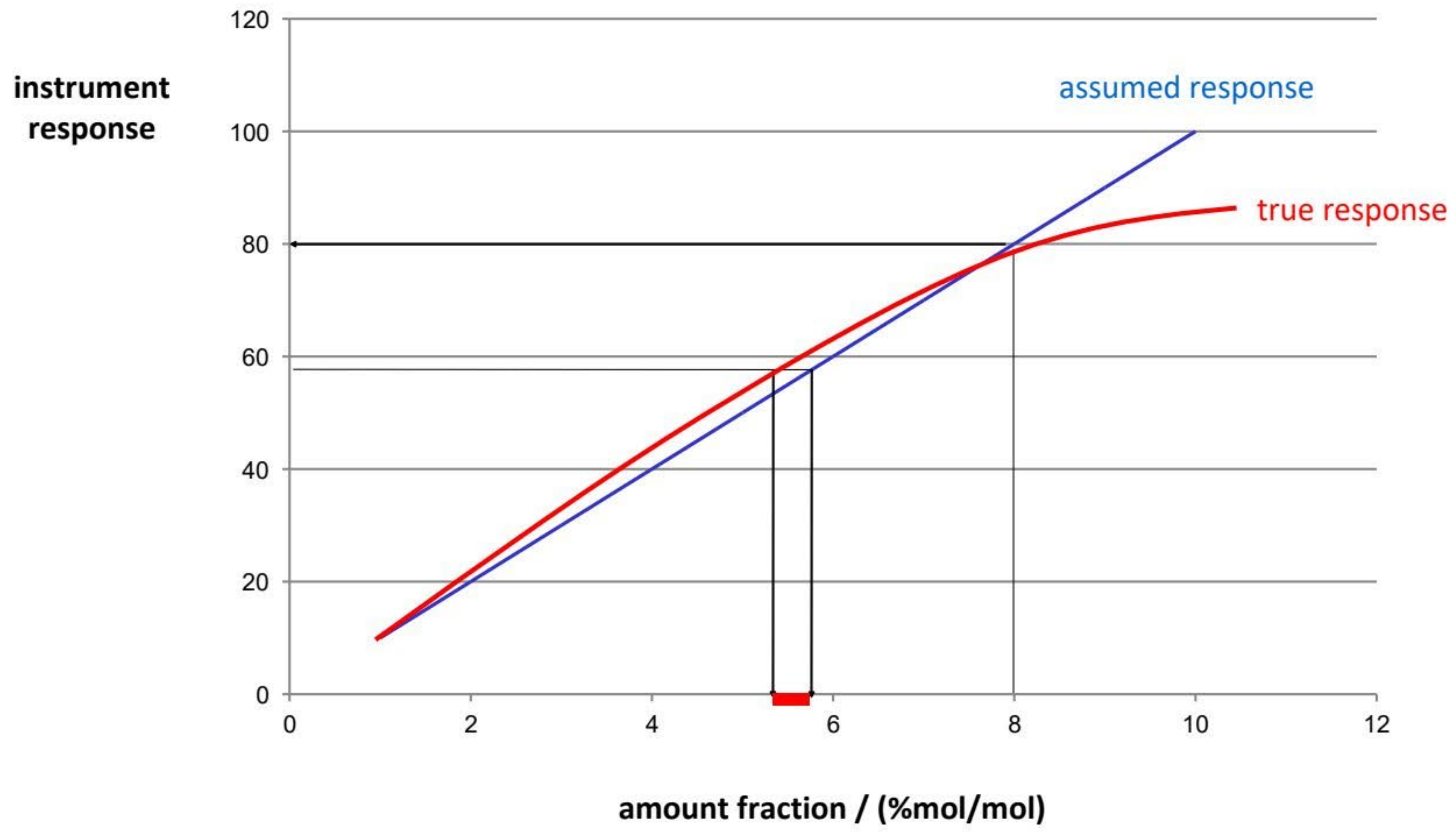

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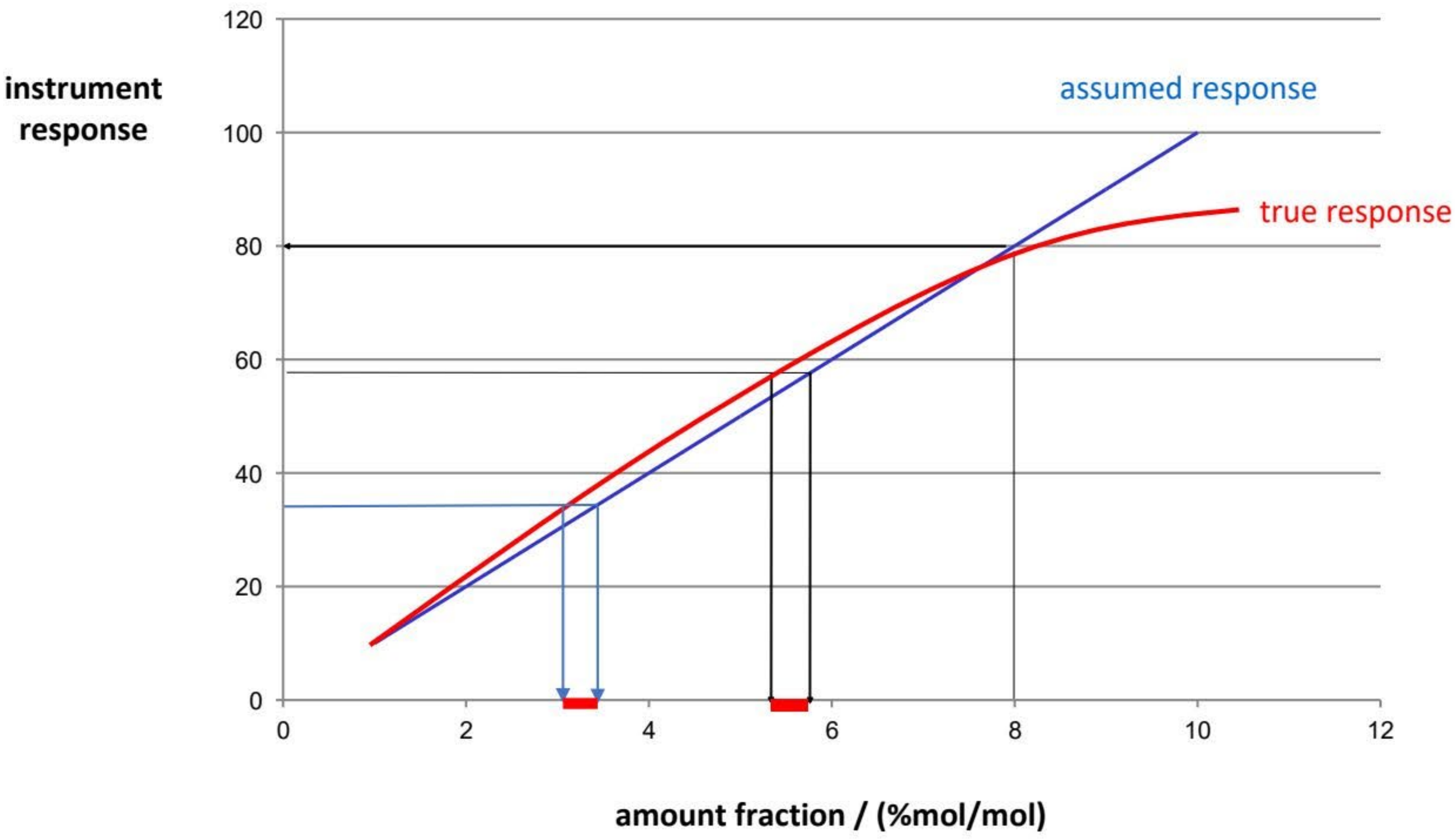

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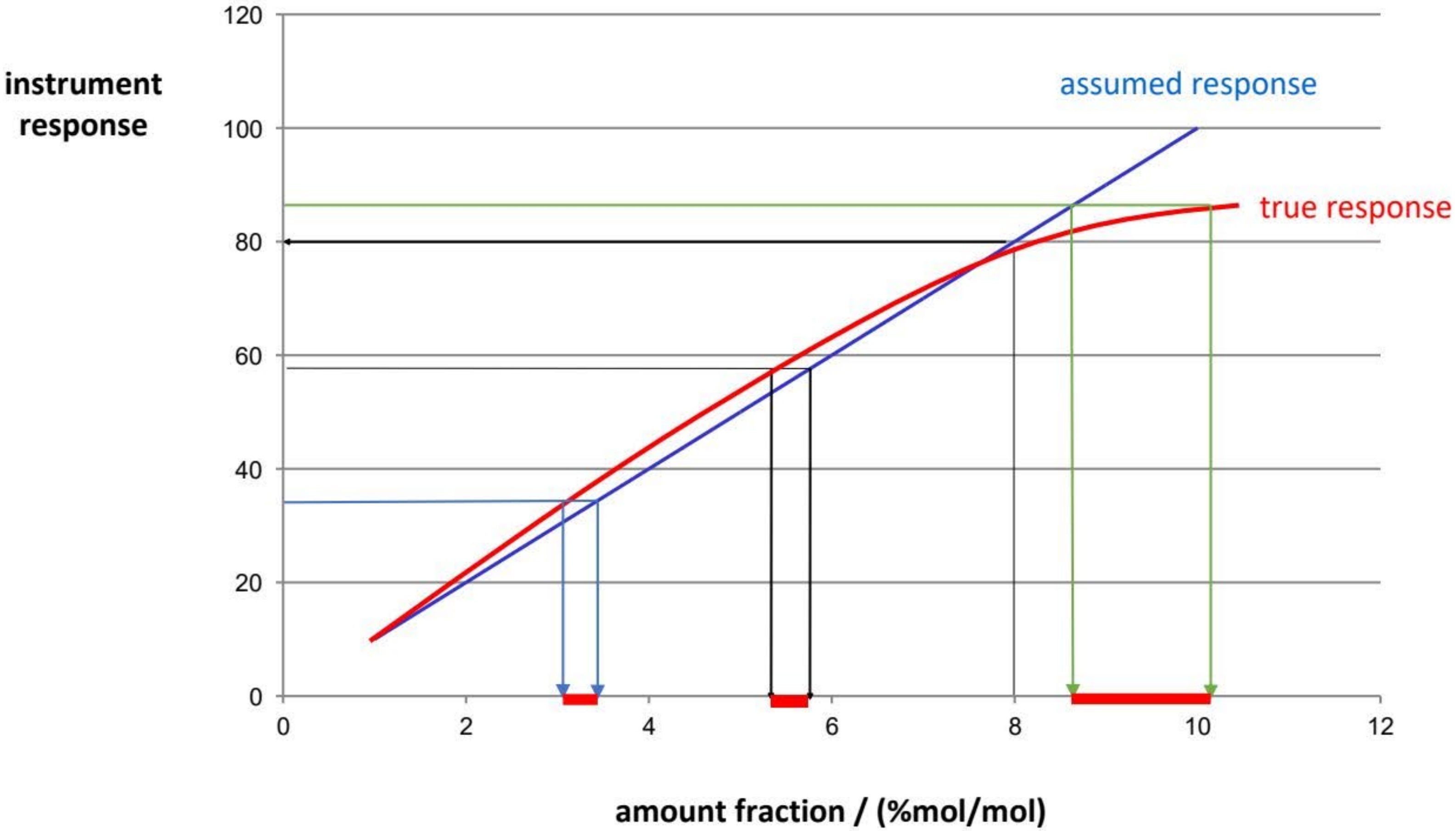
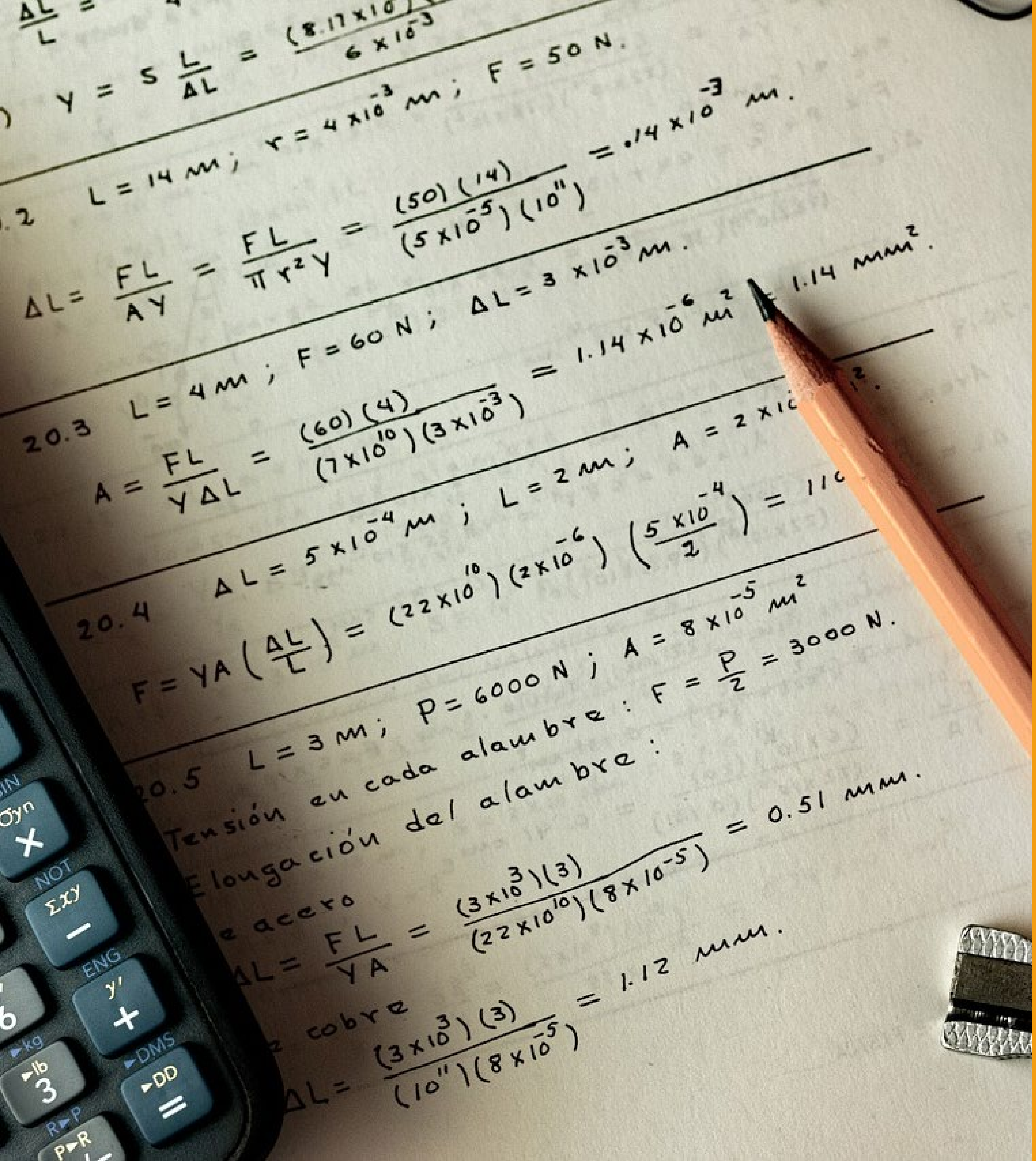
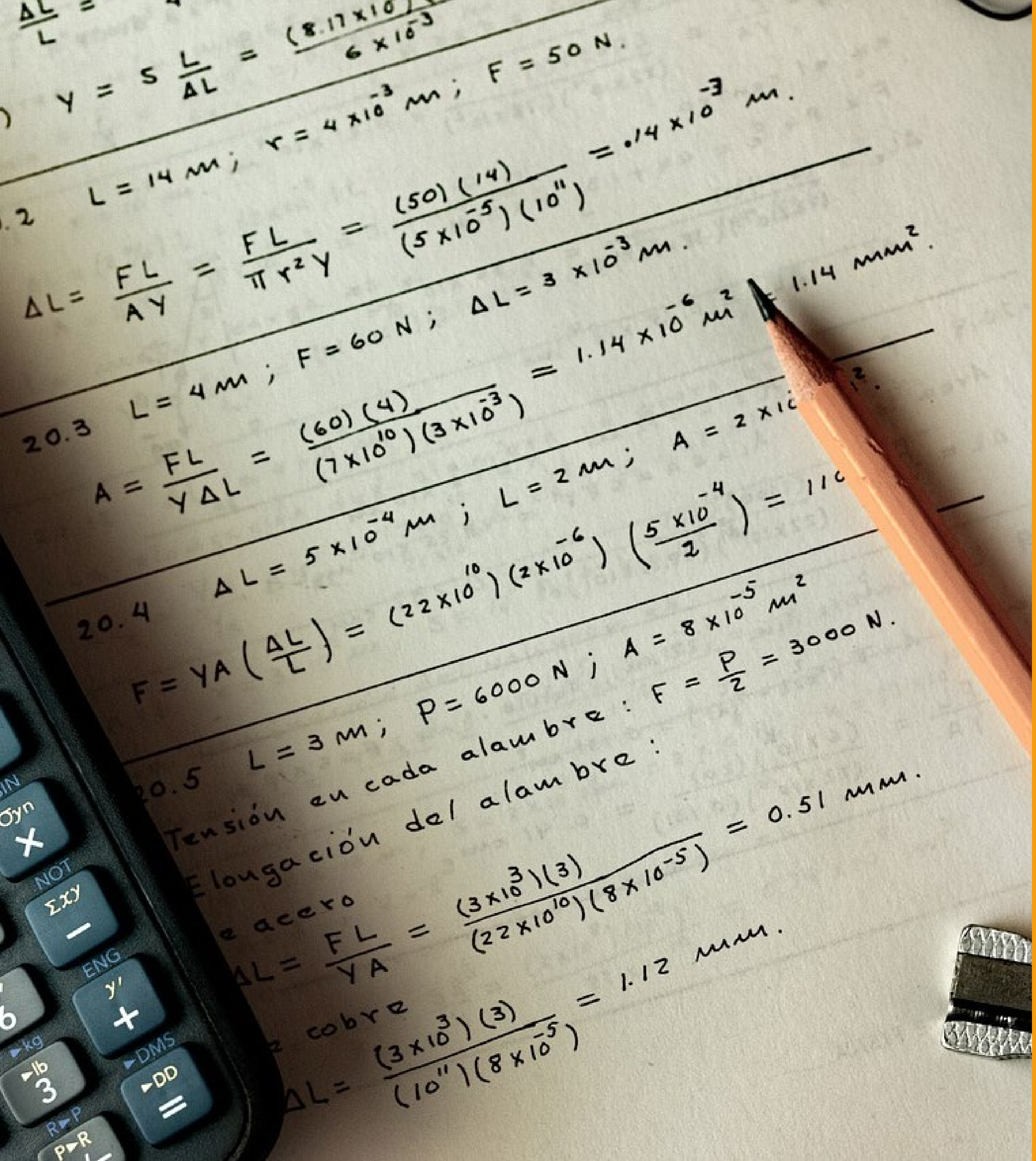




Mathematical Errors

Rounding

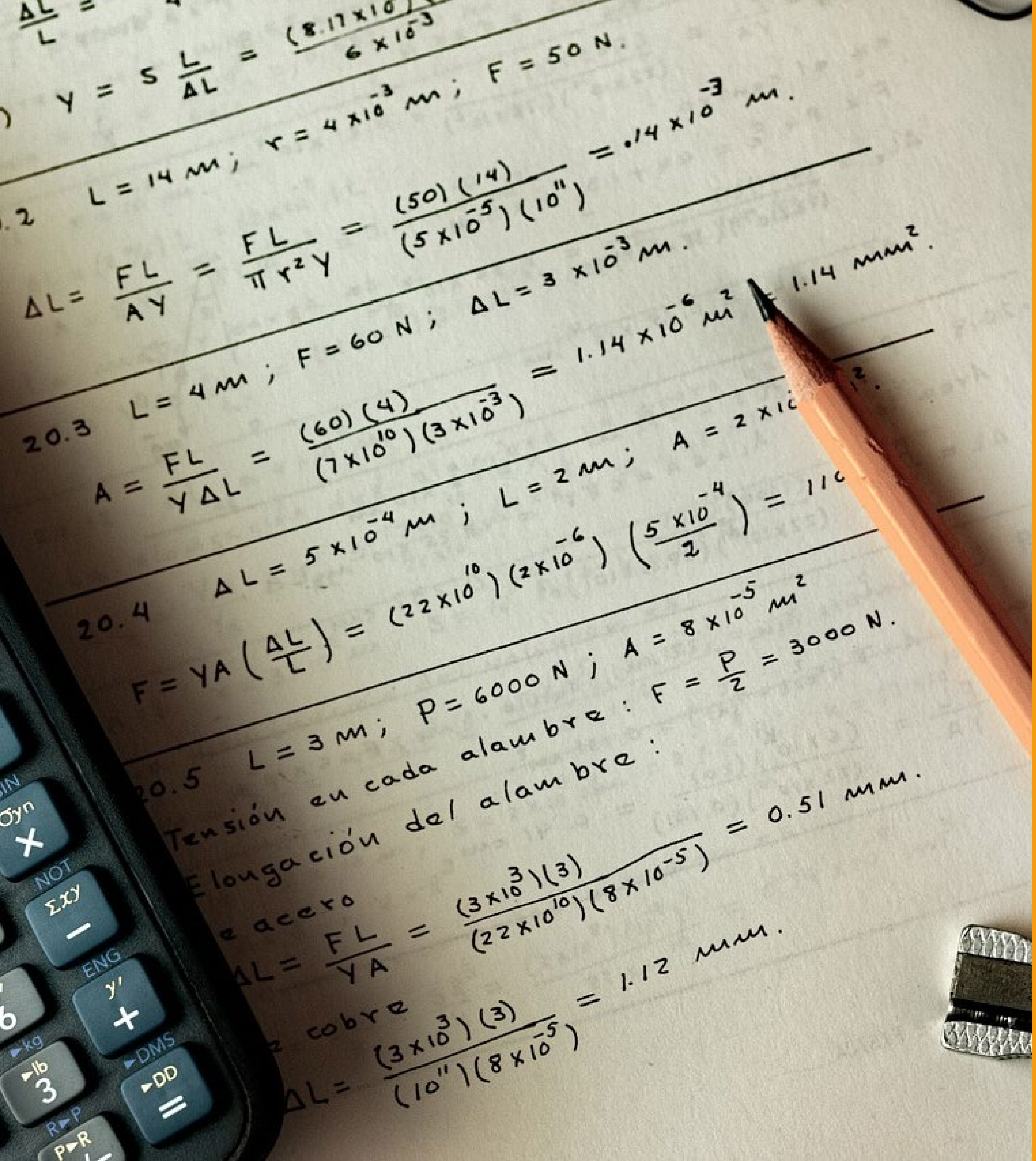
2.346



Mathematical Errors

Rounding

2.346 = 2.35



Mathematical Errors

Rounding

2.346 = 2.35 =2.4

2.346 = 2.3

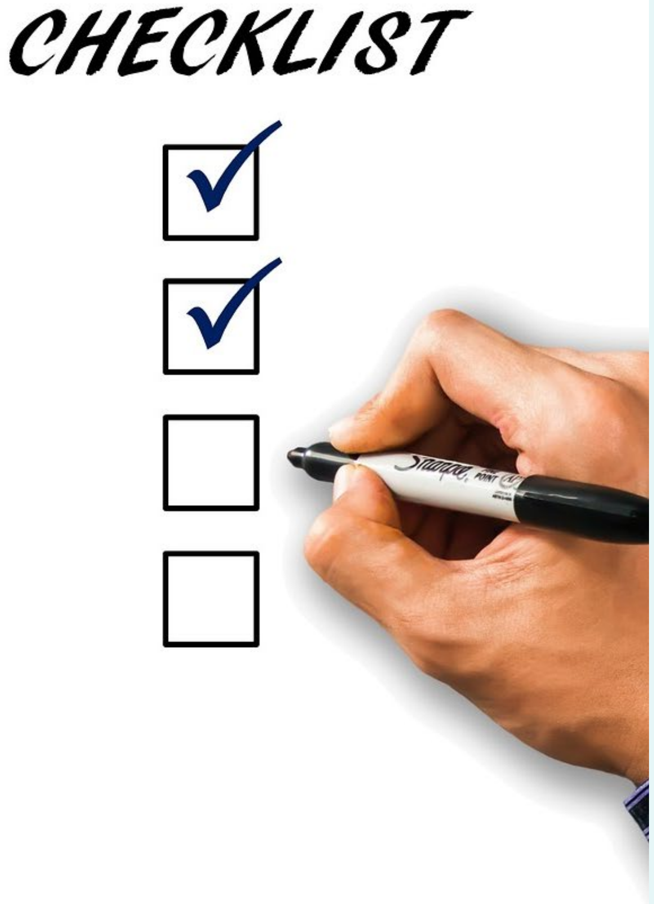
Errors

Paralax

Top Tips

Is there already a standard method? ISO standards, literature review. **Don't reinvent the wheel.**

wheel.



Experimental Design

Define Objective

Outline the purpose and goals of the experiment.

What do you need to measure?

How accurate?

Ranges?

Difficulty?

Setup

Plan and outline the procedures, variables and controls.

Understand the pros and cons of the measurement and design the method maximising the pros and minimising the cons

Data Collection

Implement experiment according to procedures, ensuring accuracy and consistency in the measurements.

Traceable calibration with appropriately sized datasets for calibration and sample

Interpret & Conclude

Check for Outliers, instrument linearity and uncertainties before concluding

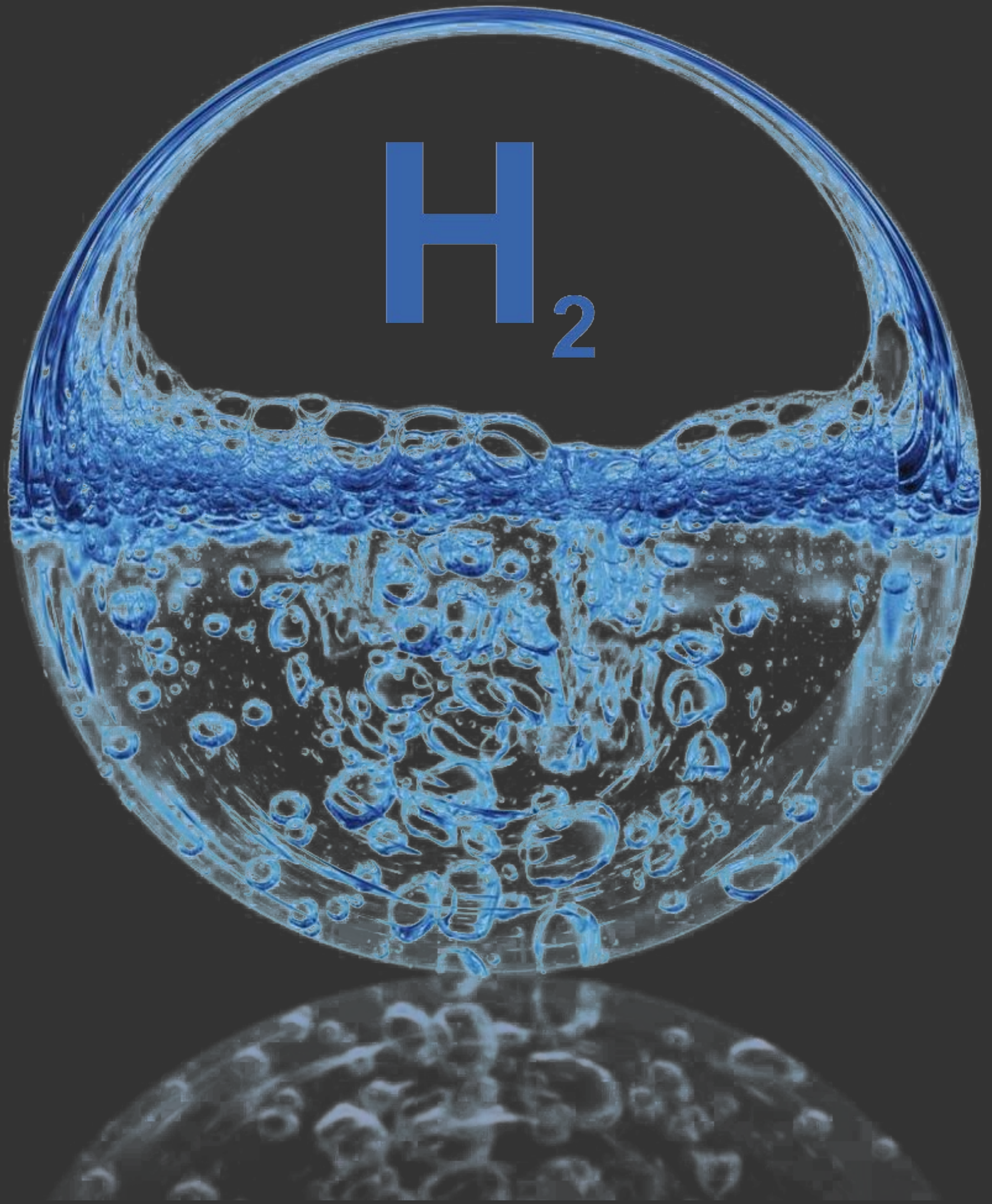
Analyse the data, drawing conclusions based on results. How confident are you in the results?

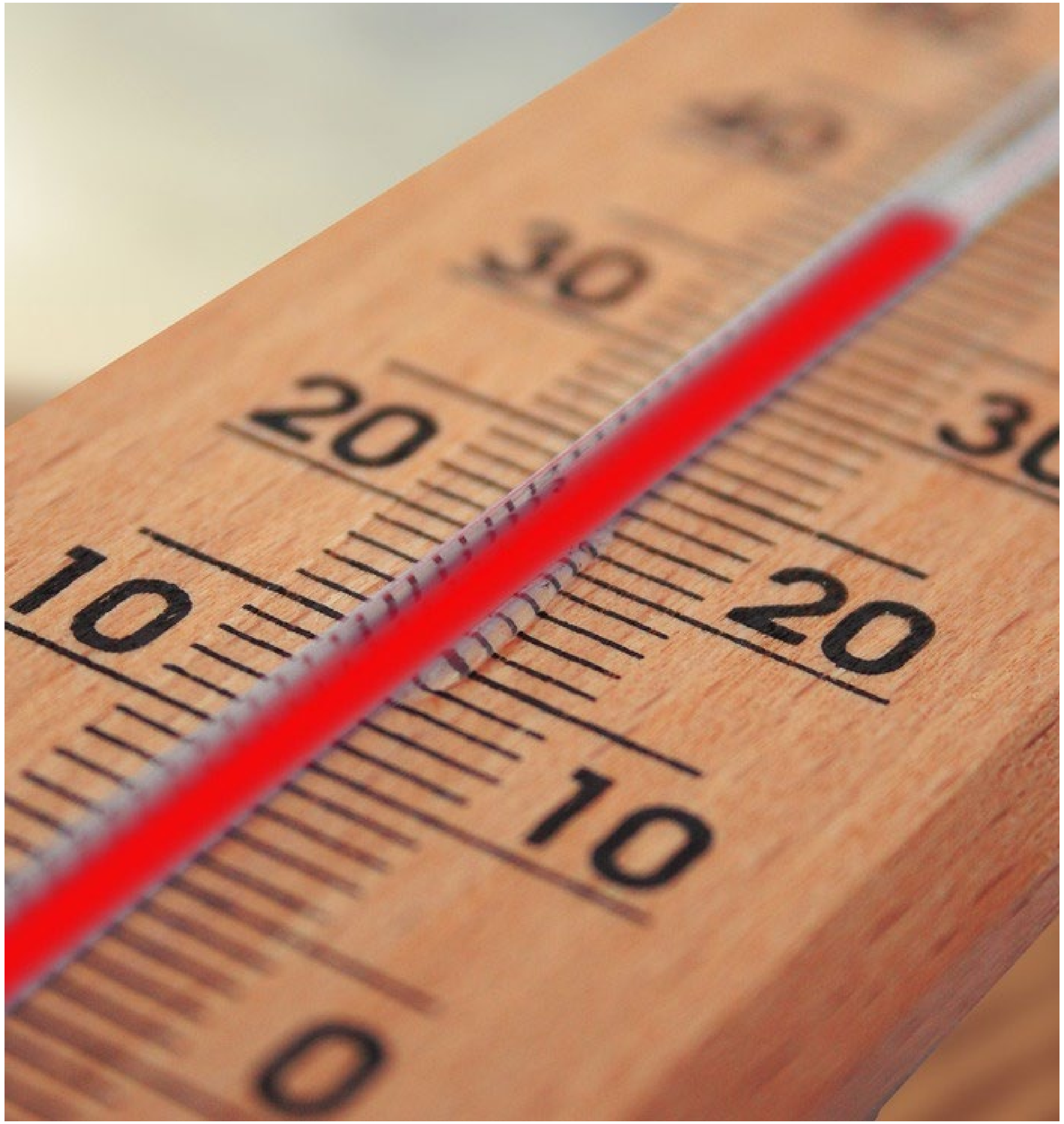
How many measurements?

Taylors Mantra

Measure thrice cut once?
once?

Hydrogen

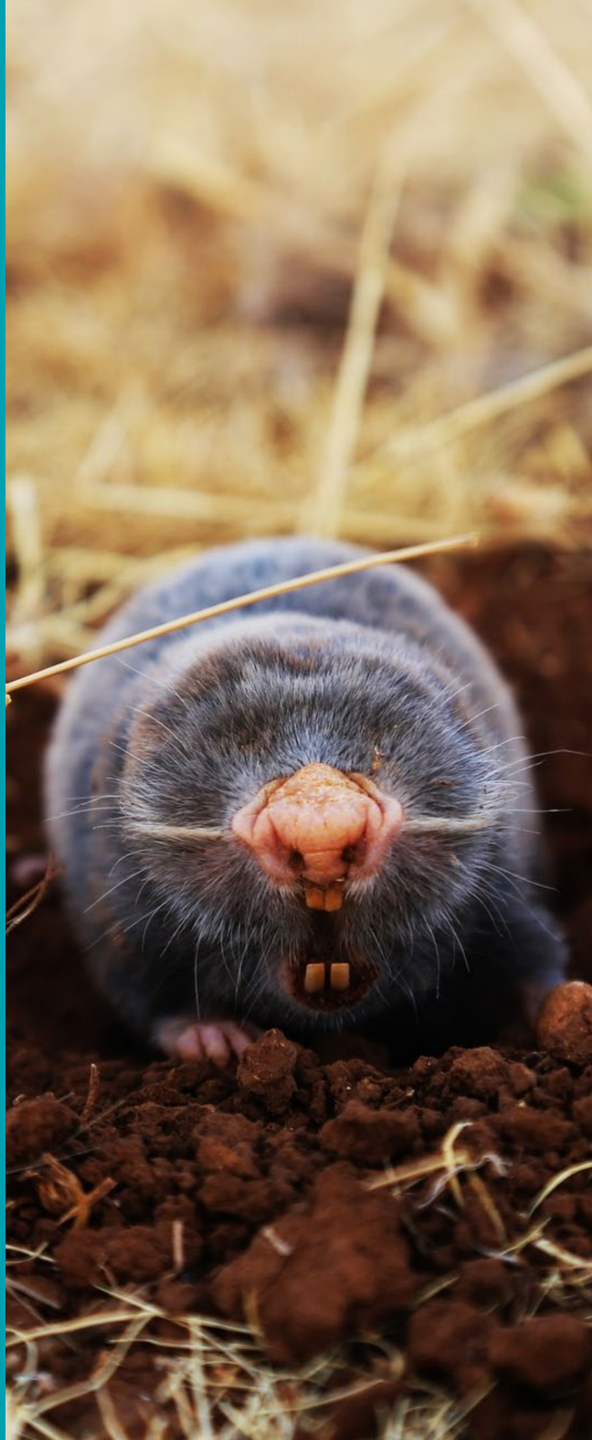


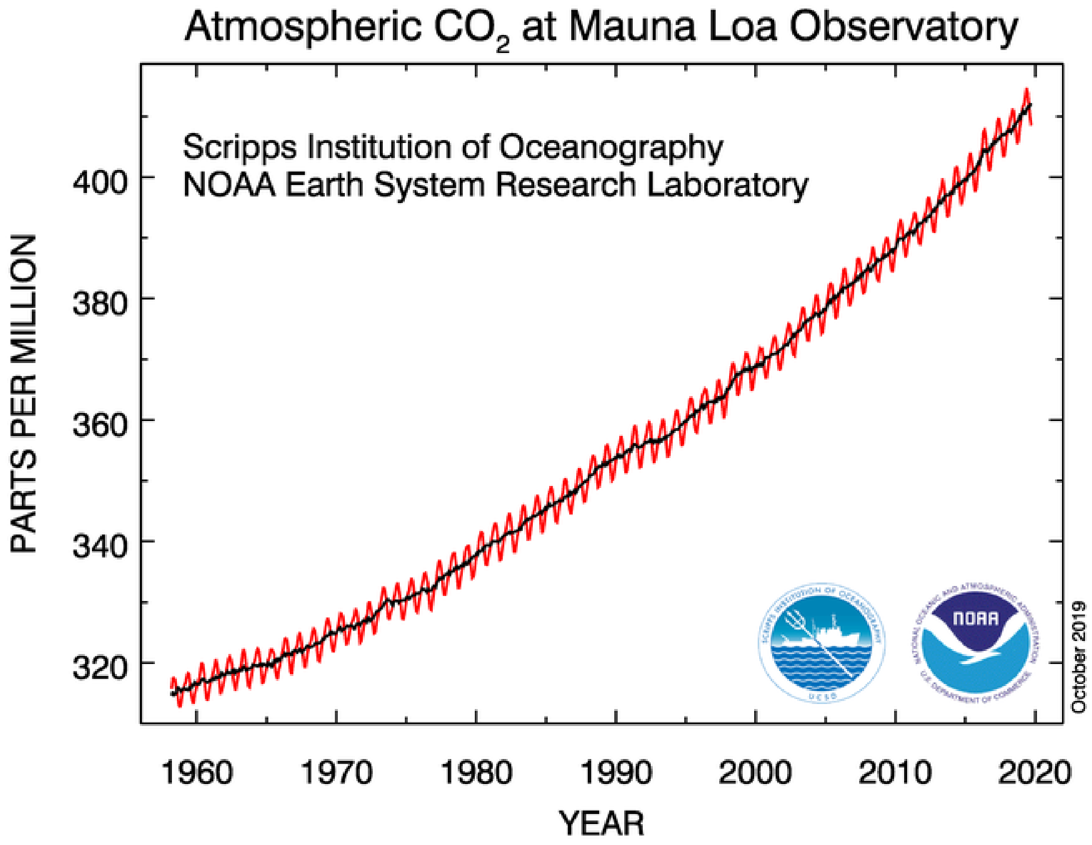

30
20
10
0
20
10

SI Unit - Amount of Substance

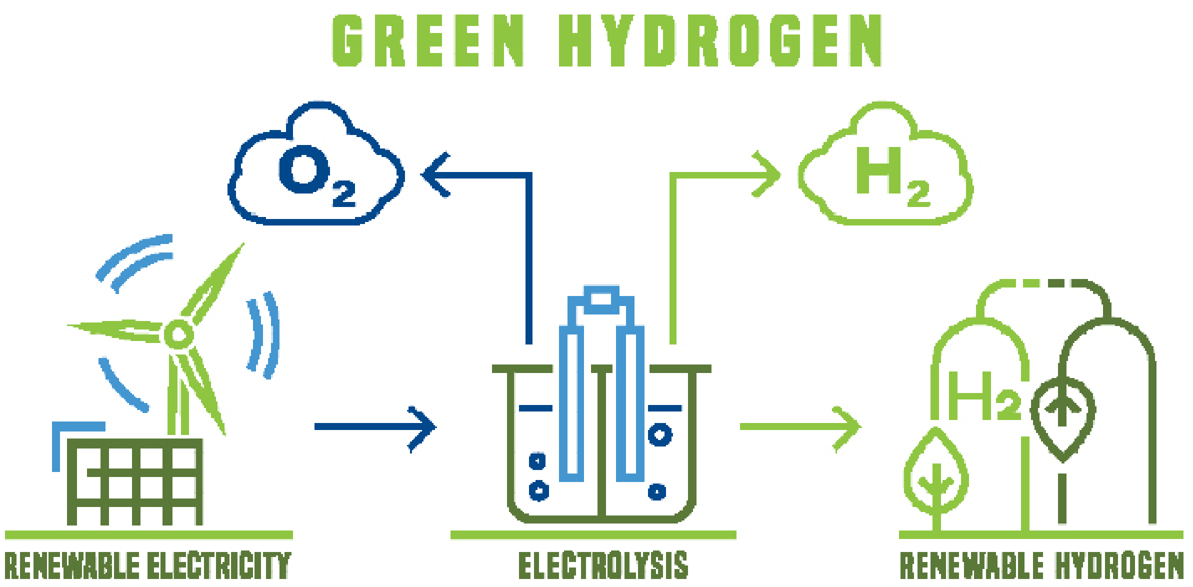
The Mole

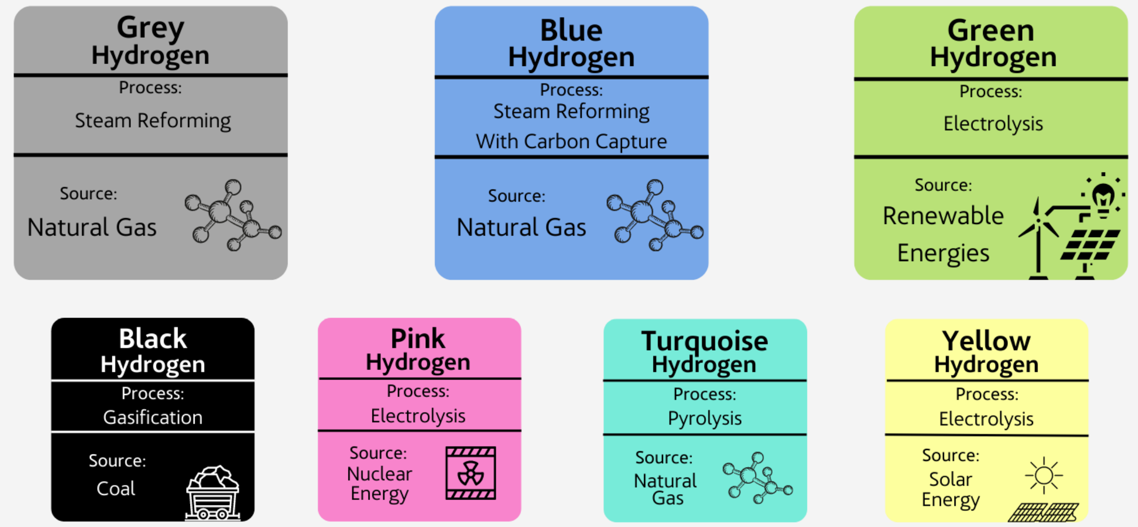
1. Similar concept to a dozen, a dozen is 12 things, a mole is 602214085700000000000000 things
2. Allows ratios of atoms and molecules to be compared
3. 1 mole of a substance = molecular mass in grams
4. 1 mole of Carbon Dioxide = 44.01g
5. Used because gas composition expressed in moles is independent of temperature and pressure.....unlike volumetric units per m3





Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
400
380
360
340
320
1960
1970
1980
1990
2000
2010
2020
YEAR
October 2019


GREEN HYDROGEN
O_2
H_2
H_2
RENEWABLE ELECTRICITY
ELECTROLYSIS
RENEWABLE HYDROGEN


Grey Hydrogen
Process:
Steam Reforming
Source:
Natural Gas
Blue Hydrogen
Process:
Steam Reforming
With Carbon Capture
Source:
Natural Gas
Green Hydrogen
Process:
Electrolysis
Source:
Renewable Energies
Black Hydrogen
Process:
Gasification
Source:
Coal
Pink Hydrogen
Process:
Electrolysis
Source:
Nuclear Energy
Turquoise Hydrogen
Process:
Pyrolysis
Source:
Natural Gas
Yellow Hydrogen
Process:
Electrolysis
Source:
Solar Energy

Hydrogen Measurement Challenge

Hydrogen for Vehicles

1 Hydrogen Quality - High purity for PEM fuel cells

2 Hydrogen Quantity - Limited traceability

3 Hydrogen Safety - 700 Bar pressure

1 - Hydrogen Quality - High Purity for Fuel Cells

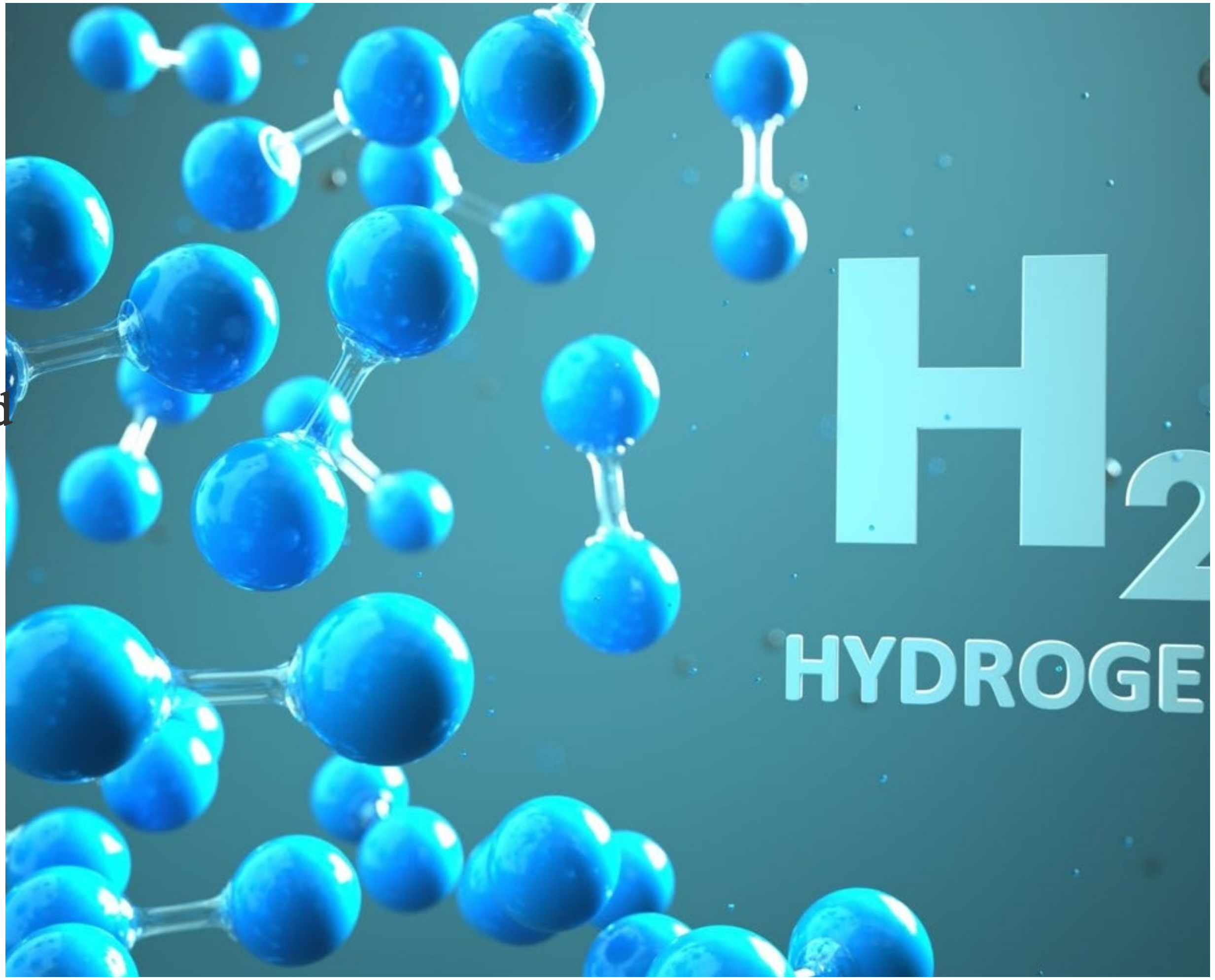
ISO 14687 - Grade D - PEM Fuel Cell for vehicles

Impurity	Amount fraction/µmol mol^{-1}
Helium	300
Nitrogen	100
Argon	100
Water	5
Oxygen	5
Carbon dioxide	2
Total hydrocarbon	2
Formic acid	0.2
Carbon monoxide	0.2
Ammonia	0.1
Total halogenated	0.05
Formaldehyde	0.01
Total sulphur	0.004

- **Appropriate analysis methods**
- **On and off-line sampling**
- **Traceable calibration artifacts**

2 - Hydrogen Quantity - Limited Traceability

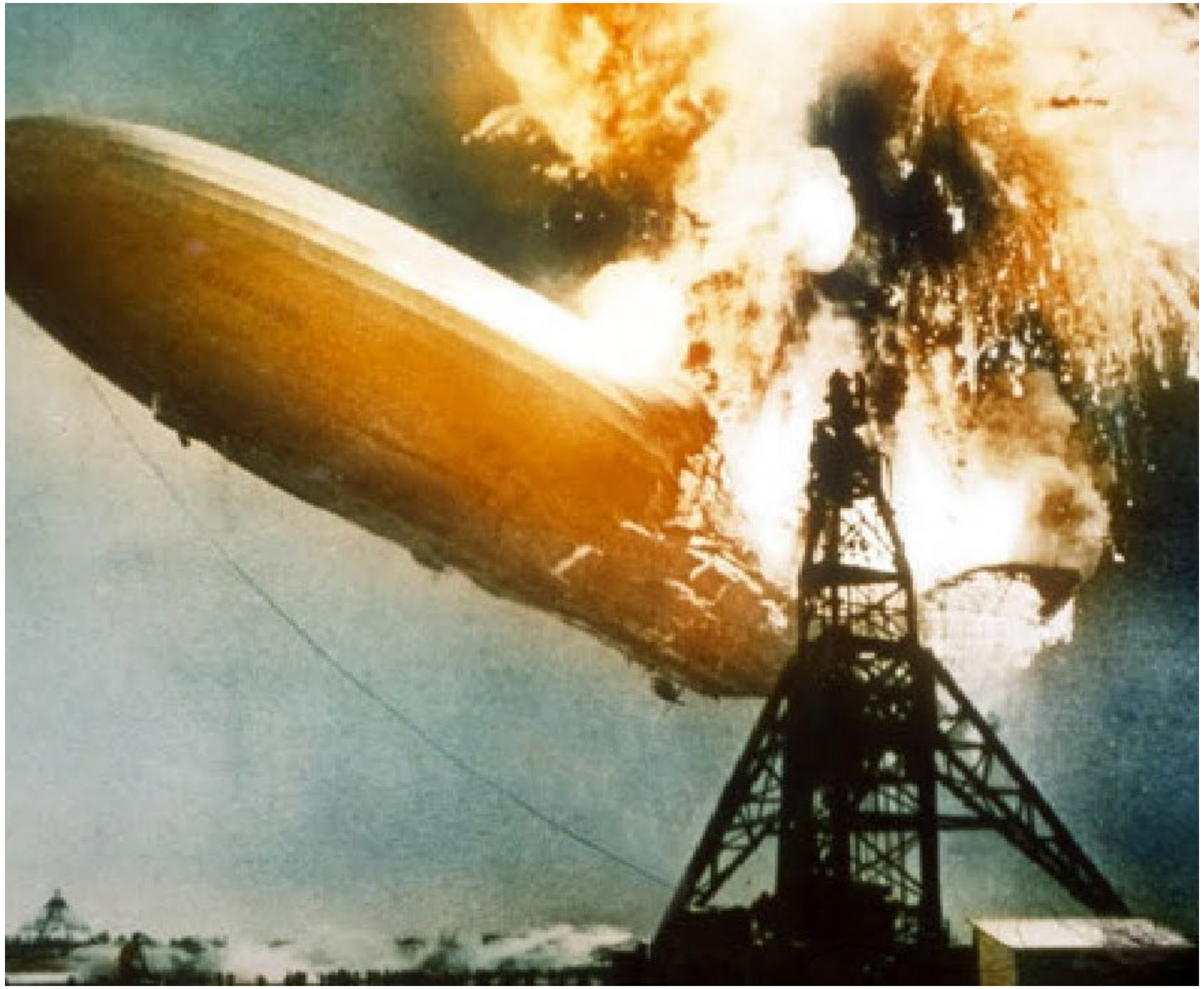
- Properties - low density & high compressibility make measurements difficult
- Leakage - small molecule, easily leaks, losses difficult to quantify
- High pressure filling ~ 700 Bar, flow meters and thermodynamic models not validated at these pressures
- Real time measurements - Variations in flow rates, pressure, and temperature make it difficult to obtain accurate and instantaneous measurements.



3 - Hydrogen Safety

Hindenburg Disaster 1937

- Wide flammability range 4% - 74% in air c.f. natural gas 5% - 15%
- Low minimum ignition energy 0.02 mJ c.f. natural gas 0.29 mJ, propane 0.26 mJ
- No smell
- Almost invisible flame
- More buoyant than air
- 700 Bar storage



What's your challenge?

In the beginning I made a measurement..

Truth

The measurement was not true because the truth rests only with the almighty and he's not telling.

So I compared the measurement with what I thought was the truth.

Correction

And, lo, there was a correction. In assessing this correction, many things went wrong. The temperature kept changing, the operator had forgotten their glasses and there were corrections to the test equipment that I forgot.

Uncertainty

So uncertainty was declared! But you know how it is, I had to cram the whole thing into five minutes, I couldn't take many readings and I wont swear to it.

Confidence

So there was a limit to my confidence. Thus, although I stand corrected, uncertain and lacking in confidence, I may not have made a good measurement but at least I know how bad it is.

Thankyou