Introduction to Laboratory
-
Treatment of Uncertainties

Lecture Outline

1. Introduction to Physics Laboratory
2. Errors / Uncertainties in Measurements
3. Random and Systematic Errors
4. Estimating Random Experimental Errors
5. Combining Experimental Errors

1. Introduction to Labs

- Your lab book must be submitted at the end of the lab session.
- Your report must be *structured*
  - Introduction / Aim of the experiment
  - Apparatus
  - Experimental results (including tables and graphs)
  - Answers to the questions in the lab instructions
  - Uncertainty analysis
  - Conclusion

2. Error / Uncertainty in Measurements

- In experimental Physics, EVERY measurement must be stated with an estimate of its error (or uncertainty)

- An error in not a mistake but a measure of how good your measurement is

- A measurement and its error must have the same number of decimal places

- $Correct$: $L = (56.41 \pm 0.20)\ cm$, $L = (56.400 \pm 0.200)\ cm$
- $Incorrect$: $L = (56.41 \pm 0.2)\ cm$, $L = (56.40 \pm 0.200)\ cm$

Why are errors important?

Consider two measurements of body temperature before and after a drug is administered to a patient

$$T_{before} = 38.2\ °C$$
$$T_{after} = 38.6\ °C$$

Question: Is the temperature rise *significant*?

Answer: It depends on the measurement error

$T_{before} = (38.2\ \pm 0.1)\ °C$ and $T_{after} = (38.6\ \pm 0.1)°C$

$\Rightarrow$ *Significant rise*

$T_{before} = (38.2\ \pm 0.5)\ °C$ and $T_{after} = (38.6\ \pm 0.5)°C$

=> Not significant rise

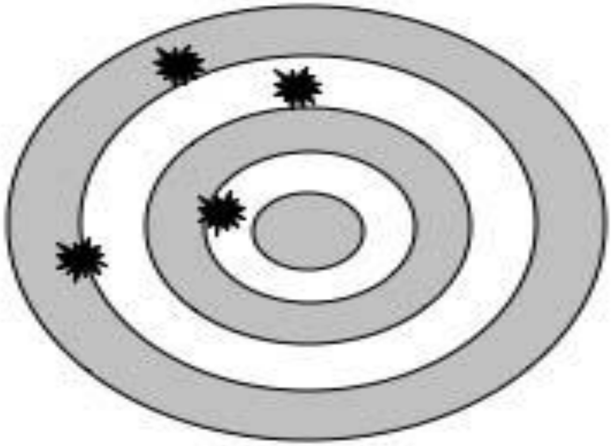
Accuracy and precision

- Accuracy: The degree to which the result of a measurement, calculation conforms to the correct value or a standard

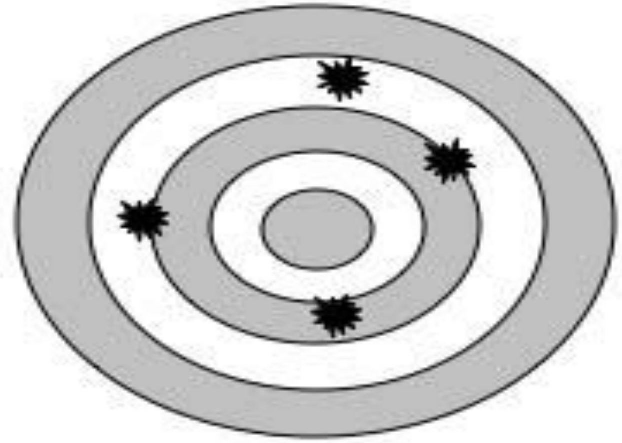
  => *accuracy is the measure of exactness*

- Precision: Refinement in a measurement, calculation, as represented by the number of digits given

  => *precision is the measure of reproducibility or consistency*



Not Accurate
Not Precise



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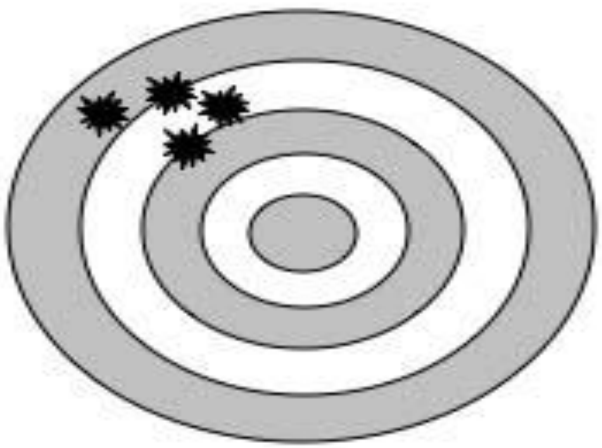

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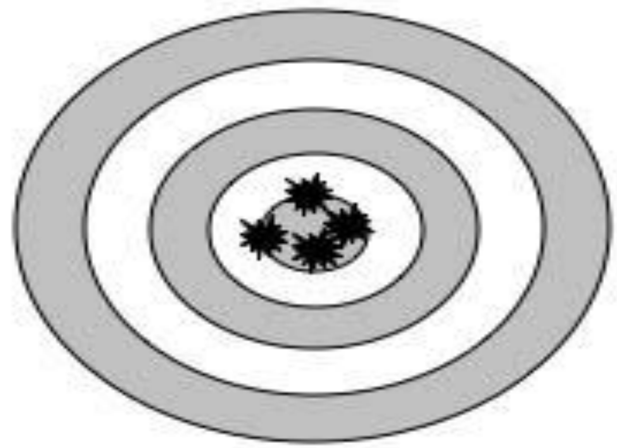


Accurate
Precise

3. Random and Systematic Errors

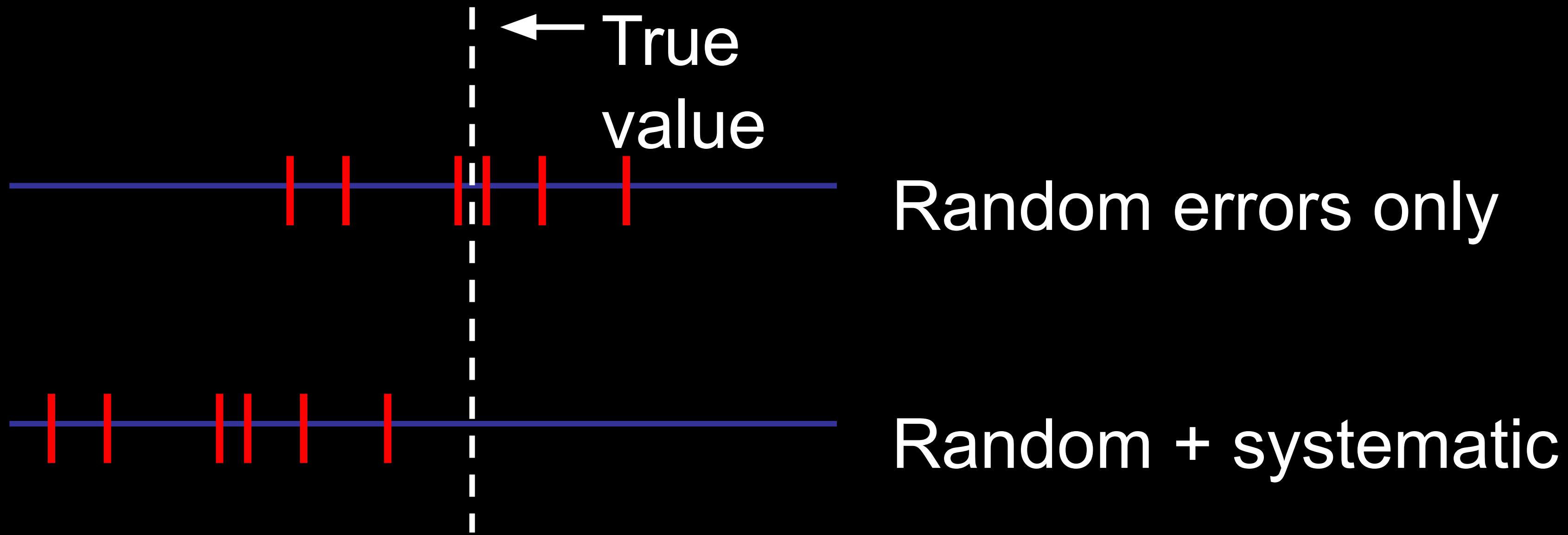
Random Error

- Varies between successive measurements of the same quantity
- Is equally likely to be positive or negative
- Can be reduced by measuring the same quantity several times and taking the average (or the mean)

Systematic Error

- Affects each reading in the same way
- Can result from incorrectly calibrated equipment
- Cannot be reduced by repeating the same measurement
- Difficult to identify → you can suggest a possible source

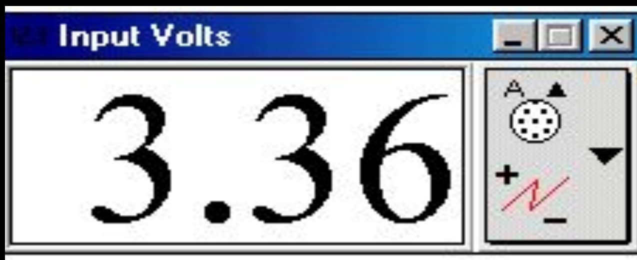
Random and systematic errors - example



- A result is said to be accurate if it is relatively free from systematic errors
- A result is said to be precise if the random error is small

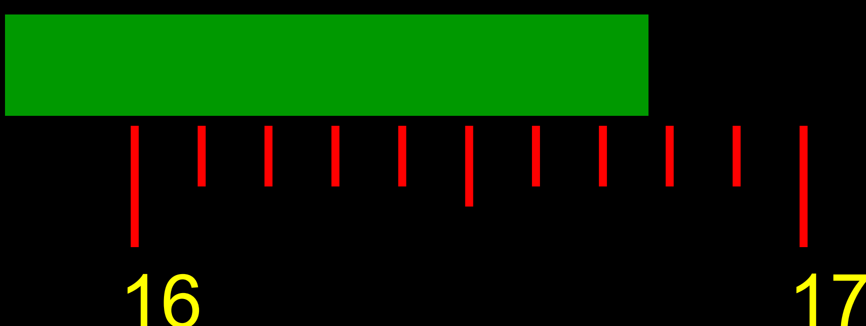
4. Estimating Random Errors (Single Reading)

- Digital meter: reading error is usually taken as

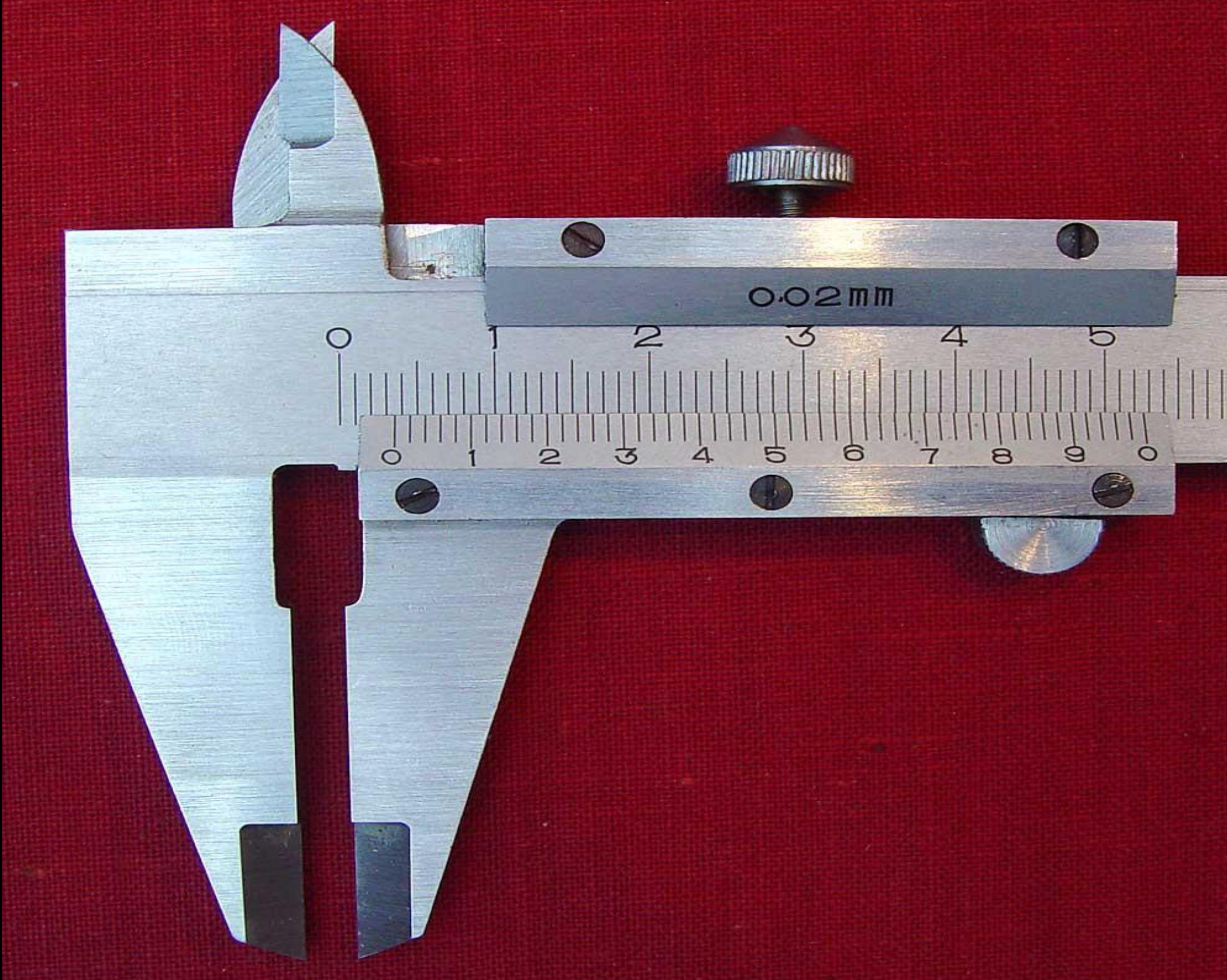


$V = (3.36 \pm 0.01)\ V$

- Linear / Vernier Scale: reading error is usually taken as the smallest scale division



$L = (16.7 \pm 0.1)\ cm$


0.02mm
0 1 2 3 4 5
0 1 2 3 4 5 6 7 8 9 0

Estimating random errors (multiple readings)

- When you have several measurements of the same quantity, the best estimate is the average (mean)

- The random error can be estimated from the minimum and maximum value

Estimating random errors (multiple readings)

T (s)
1.853
1.861
1.831
1.842
1.854
1.847
1.859
1.850
1.852
1.833

Best estimate is the average of the 10 readings of T which gives $T = 1.848$ s

The uncertainty, ΔT, can be found from

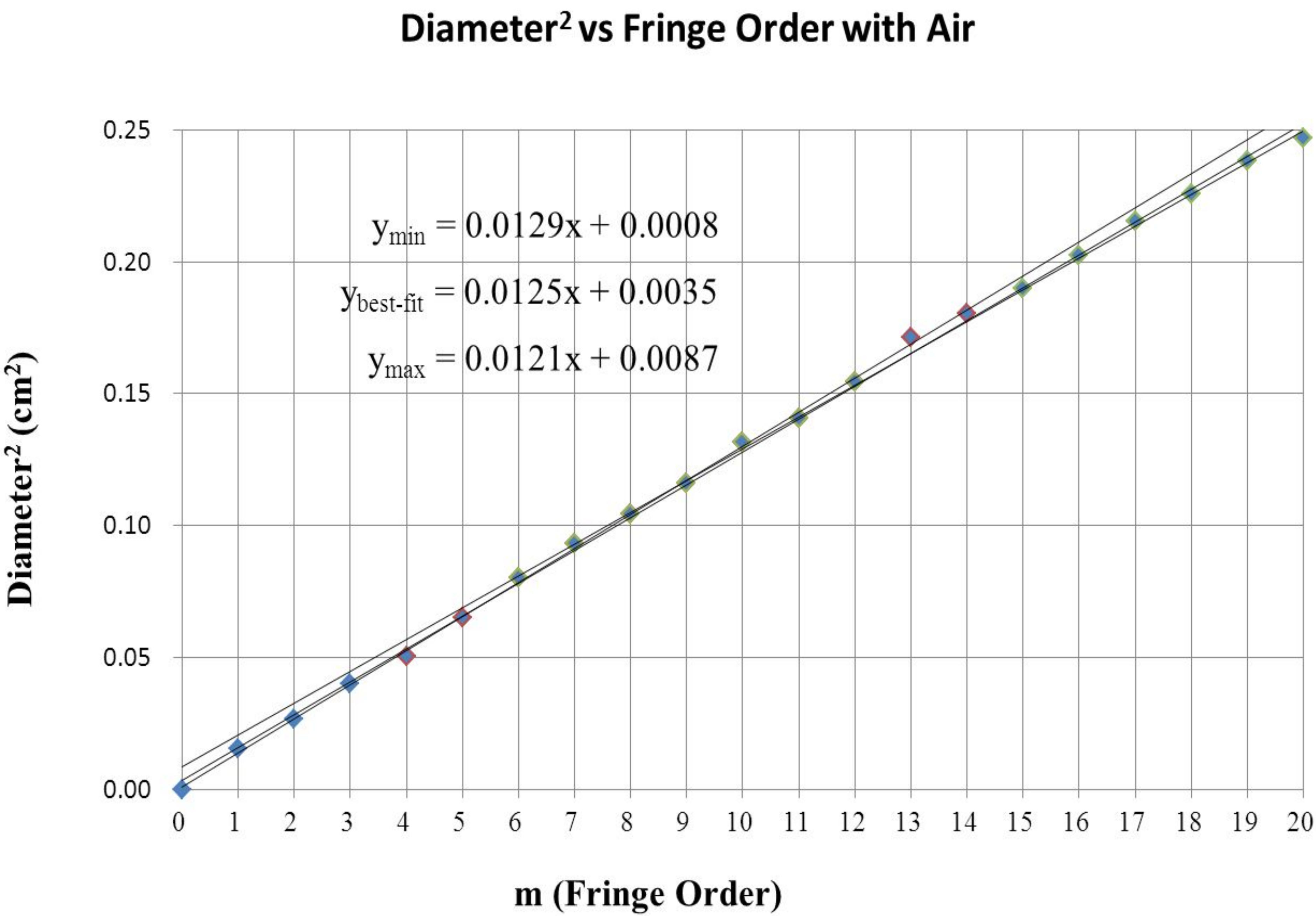
Hence, $\boldsymbol{T = (1.848 \pm 0.015)}$ **s**

Estimating random errors from a graph

- When two quantities are proportional, you can estimate (visually or using Excel) the random error of the gradient of the best-fit line as follows:

- 1) Draw a best-fit line and calculate the gradient G
- 2) Draw two lines of minimum (G_{min}) and maximum (G_{max}) gradients
- 3) Estimate the uncertainty in the gradient ΔG as:

- Note that gradients usually have a dimension (hence a unit)



Diameter² vs Fringe Order with Air
$y_{min} = 0.0129x + 0.0008$
$y_{best\text{-}fit} = 0.0125x + 0.0035$
$y_{max} = 0.0121x + 0.0087$
Diameter² (cm²)
m (Fringe Order)
0.25
0.20
0.15
0.10
0.05
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

5. Combining Experimental Errors (1)

- When variables are multiplied or divided, fractional uncertainties are added
- is called the fractional uncertainty in *A*
- It has no dimension

Combining Experimental Errors (2)

- When variables are added or subtracted, absolute uncertainties are added
- is called the absolute uncertainty in *A*
- It has the same dimension as *A*

Example 1 (Simple Pendulum)

- Suppose we want to estimate the acceleration due to gravity, *g*, using a simple pendulum and we estimated:

  - the period $T = (1.848 \pm 0.015)$ s from multiple readings

  - the length $L = (0.95 \pm 0.05)$ m

- Calculate the value of *g* and its estimated absolute random uncertainty

Example 1, cont.

- Knowing the true value of *g* at the Earth's surface, what can you conclude about random and systematic errors?

Example 1, cont.

- You then realized that you did not use the ruler appropriately and that the length should be

  $L = (0.85 \pm 0.05)$ m
- Recalculate *g* and conclude