

Introduction to Laboratory

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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 is 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:* $L = (56.41 \pm 0.20) \text{ cm}$, $L = (56.400 \pm 0.200) \text{ cm}$
- *Incorrect:* $L = (56.41 \pm 0.2) \text{ cm}$, $L = (56.40 \pm 0.200) \text{ cm}$

Why are errors important?

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

$$T_{before} = 38.2 \text{ }^{\circ}\text{C}$$

$$T_{after} = 38.6 \text{ }^{\circ}\text{C}$$

Question: Is the temperature rise *significant*?

Answer: It depends on the measurement error

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

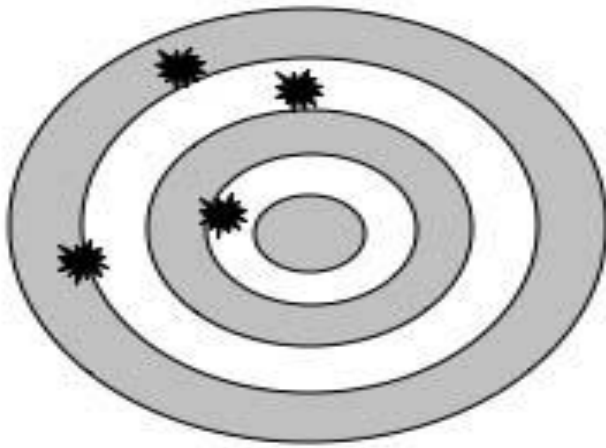
\Rightarrow *Significant rise*

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

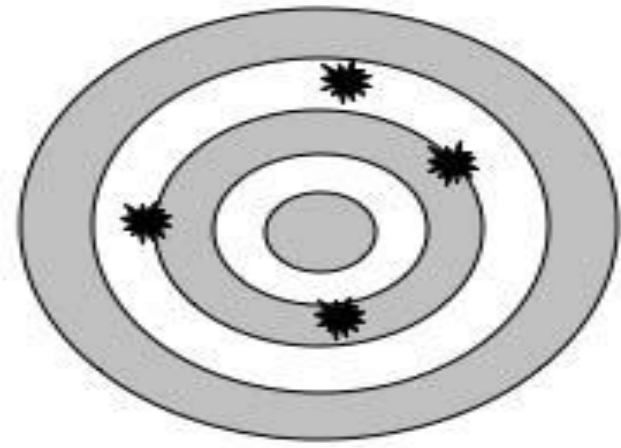
\Rightarrow *Not significant rise*

Accuracy and precision

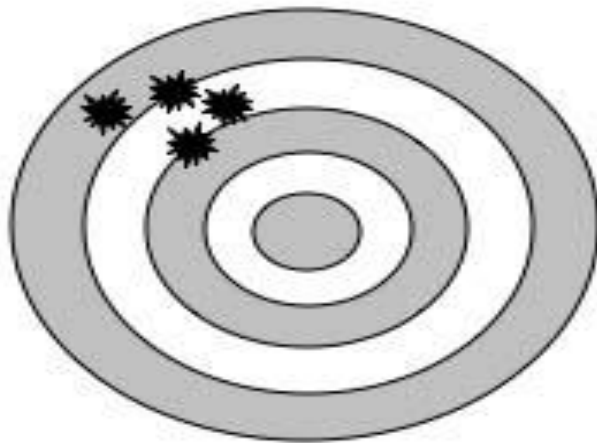
- **Accuracy:** The degree to which the result of a measurement, calculation conforms to the correct value or a standard
=> *accuracy is the measure of exactness*
- **Precision:** Refinement in a measurement, calculation, as represented by the number of digits given
=> *precision is the measure of reproducibility or consistency*



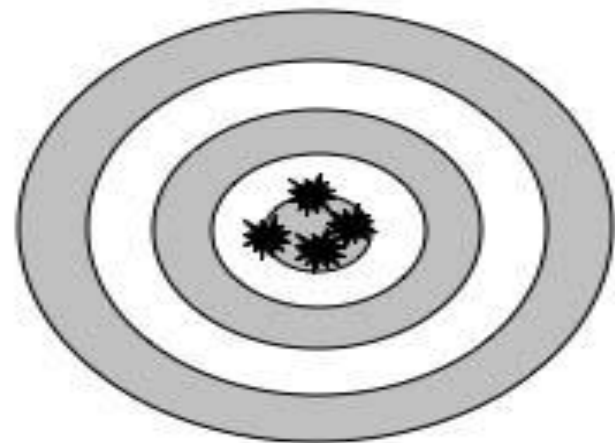
**Not Accurate
Not Precise**



**Accurate
Not Precise**



**Not Accurate
Precise**



**Accurate
Precise**

3. Random and Systematic Errors

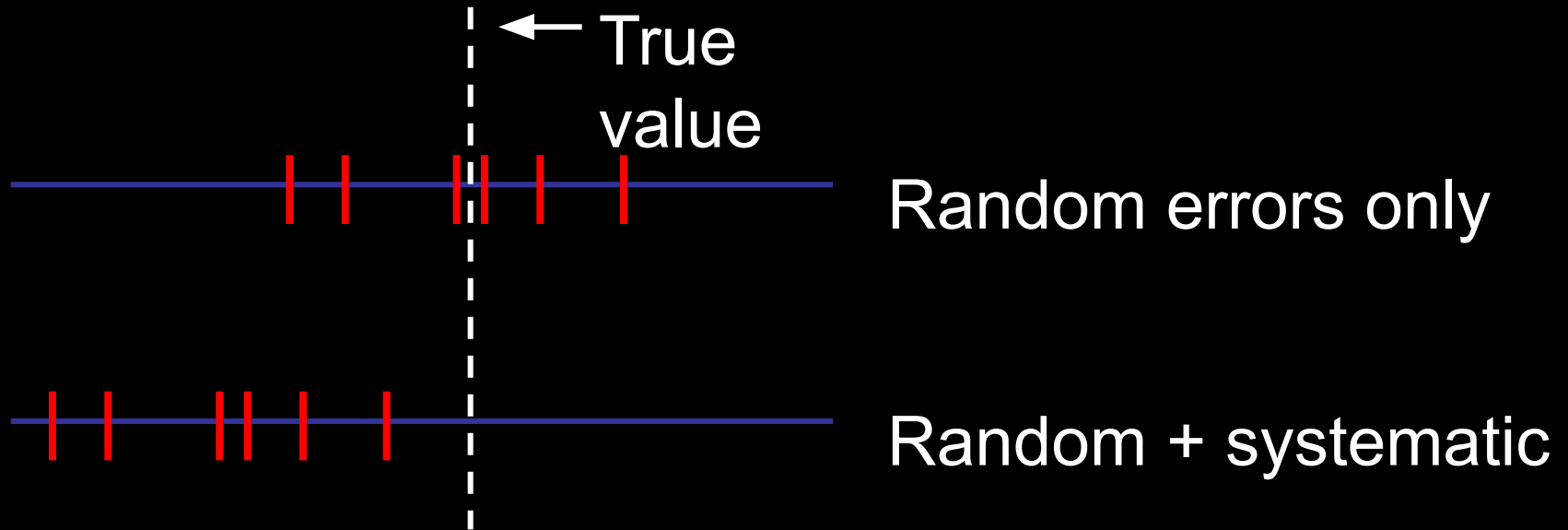
Random Error

- 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

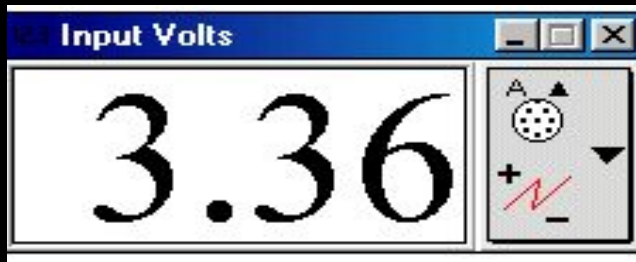
Random and systematic errors - example



- 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

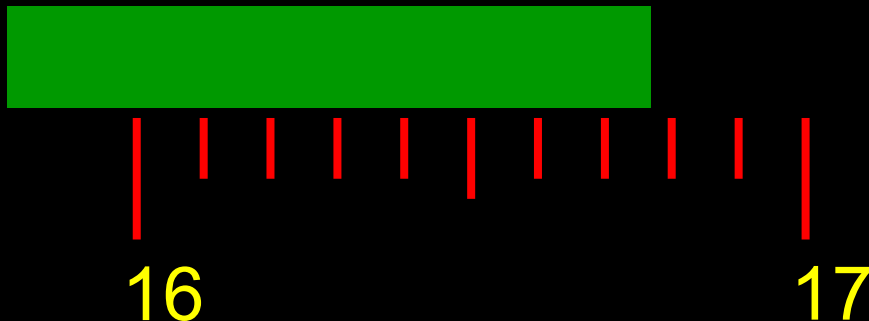
4. Estimating Random Errors (Single Reading)

- **Digital meter:** reading error is usually taken as

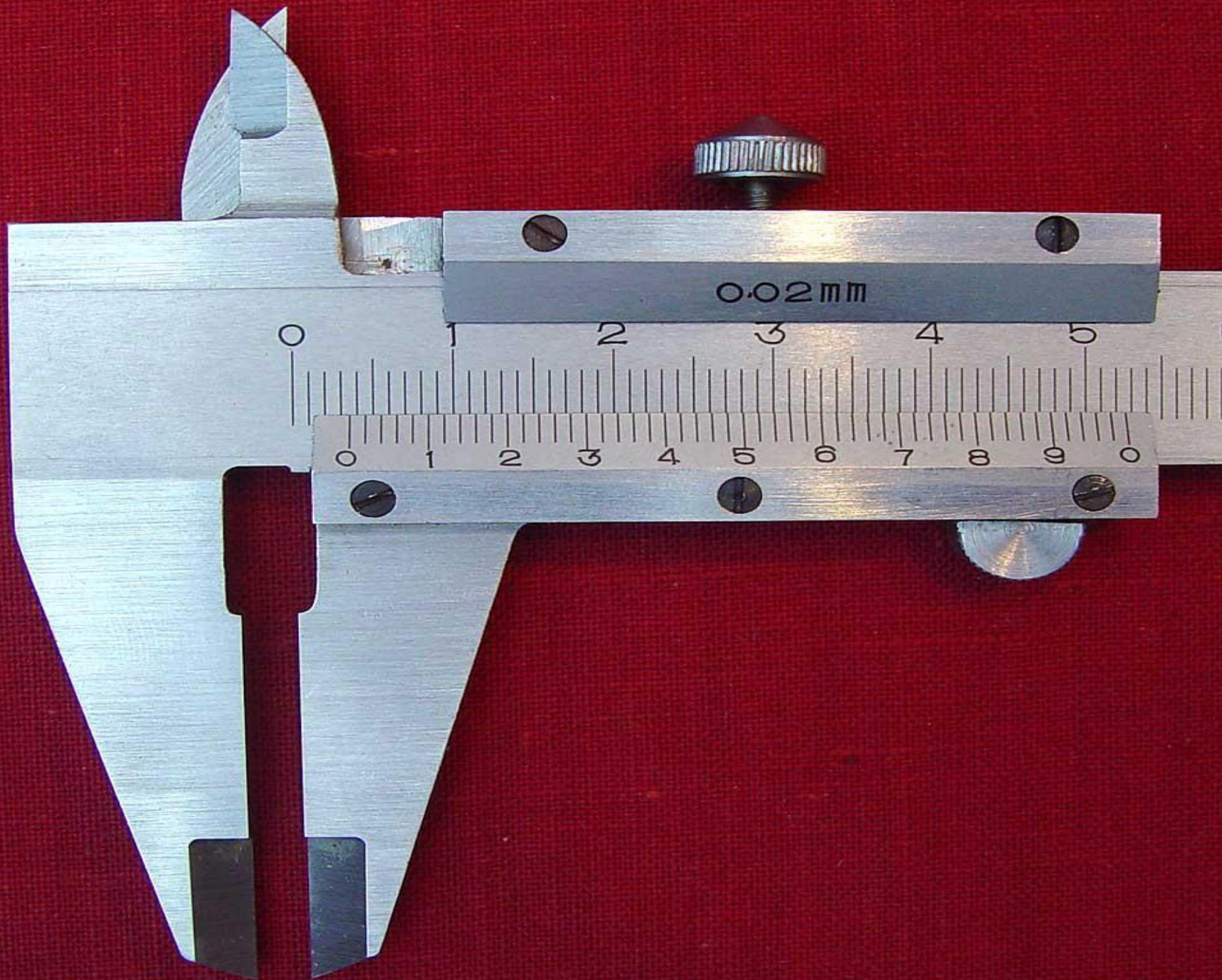


$$V = (3.36 \pm 0.01) \text{ V}$$

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



$$L = (16.7 \pm 0.1) \text{ cm}$$



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

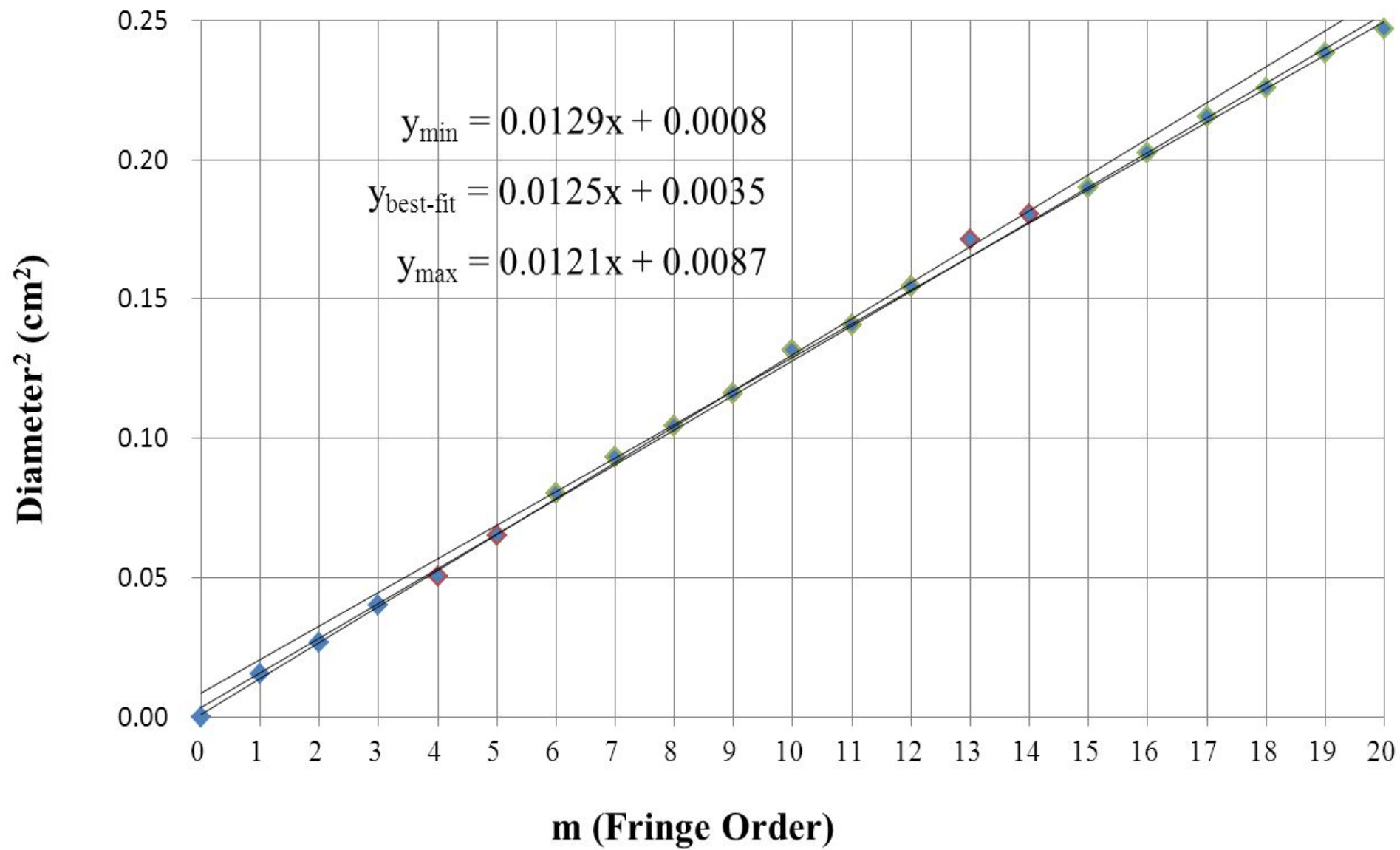
Estimating random errors (multiple readings)

T (s)	Best estimate is the average of the 10 readings of T which gives $T = 1.848$ s
1.853	
1.861	The uncertainty, ΔT , can be found from
1.831	
1.842	
1.854	
1.847	
1.859	
1.850	Hence, $T = (1.848 \pm 0.015)$ s
1.852	
1.833	

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



5. Combining Experimental Errors (1)

- When variables are multiplied or divided, **fractional** uncertainties are added

- $\frac{\Delta A}{A}$ 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

- ΔA 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
 $L = (0.85 \pm 0.05) \text{ m}$
- Recalculate g and conclude