PHYS 500: Research Methodology

General Remarks

Before starting the experiment

- Before starting your experiment inspect carefully your instruments. Try to find the manufacturer's error as well as possible reading errors.
- Try to find possible systematic errors and think how you can dispose them.

Multiple errors-a

- Normally in a measurement we may have different types of errors. For example, if we repeatedly measure the same physical quantity we have, normally three types of errors:

a. Manufacturer’s error
b. Reading error
c. Average value error

- In such a case we may ask which error are we going to keep. Let’s see the following example:

Multiple errors-b

- Let's assume that we measure the length of a rod (in mm) and we have the following recordings:
- 324, 323, 324, 322, 324, 323, 323, 323, 324, 322, 323, 323
- The average value is $\bar{L} = 323.166$ mm and the error of the average value is $\delta L = 0.21mm$. So we can say that the result is

$$L = (323.17 \pm 0.21)mm$$

- But we have not taken into account the manufacturer's error as well as the reading error.
- Assume that the manufacturer's error is 0.1 mm.
- Assume that the reading error is 0.5 mm.
- Then you can see that the manufacturer's error does not play any role since it is very small.

Multiple errors-c

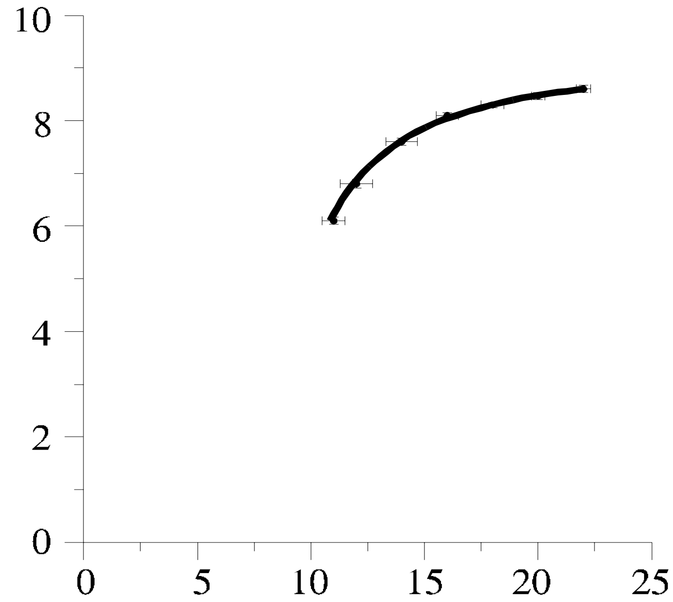
- The average value error has to be dropped. This is because is smaller than the reading error and we cannot make it smaller.
- **Question:** What we have to do if all our recordings were, for example, 323 mm?
- **Rule:** ***In case where in one measurement we have multiple errors we keep always the larger one.***
- Mathematically speaking if in the measurement of a physical quantity *x* we have the errors $\delta x_1,\ \delta x_2,\ \delta x_3,\ \ldots$ then the total final error is given by

$$\delta x = \sqrt{(\delta x_1)^2 + (\delta x_2)^2 + (\delta x_3)^2 + \ \ldots}$$

- (which if $\delta x_1 > \delta x_2,\ \delta x_1 > \delta x_3$, and recalling that normally we keep one significant digit then we could say that $\delta x \approx \delta x_1$)

Data processing-Graph plotting

- Always calculate the involved errors. Do not forget the rounding.
- The final result **must be given** with its error. If you do not include the error your answer is wrong!
- Always graph your plots on graph paper.
- Chose a proper scale such that the graph is extended in the whole area of the diagram.
- When you scale the axes do not include all the possible subdivisions only the basic ones and at equal distances.
- The axes must be labeled with the relevant physical quantities and their units.
- Never write on the axes the recorded values.
- In any plot, if the scale allows you, and for any point draw the error bars.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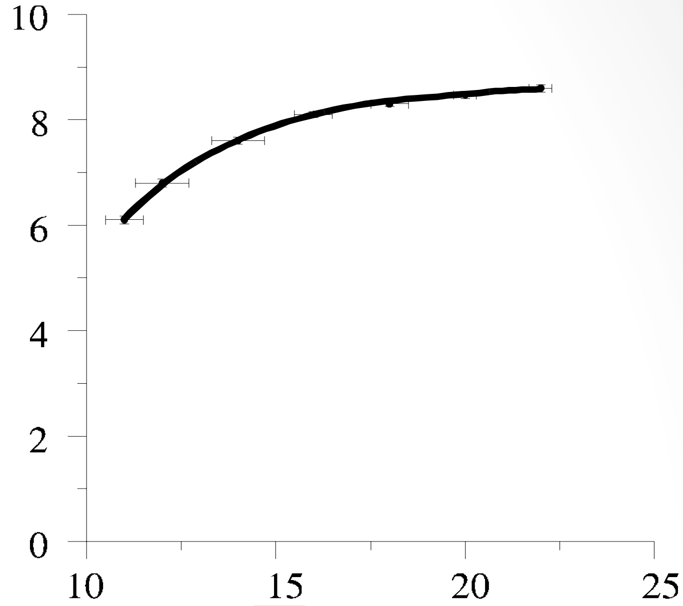
a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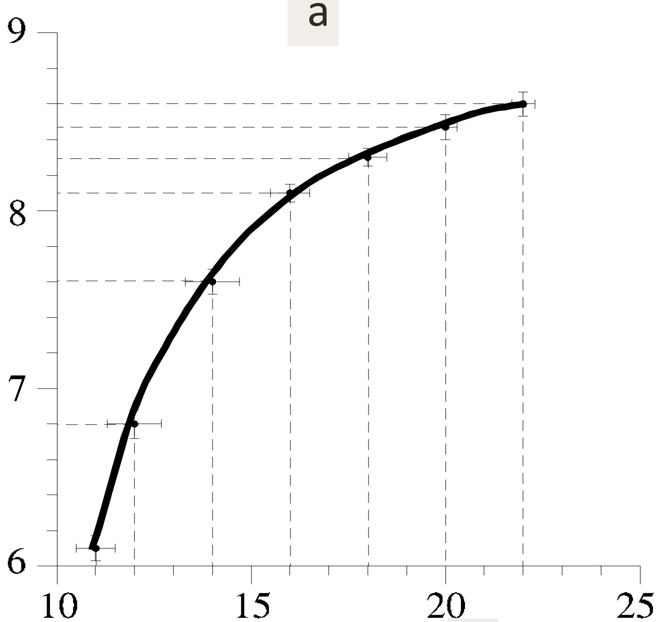
b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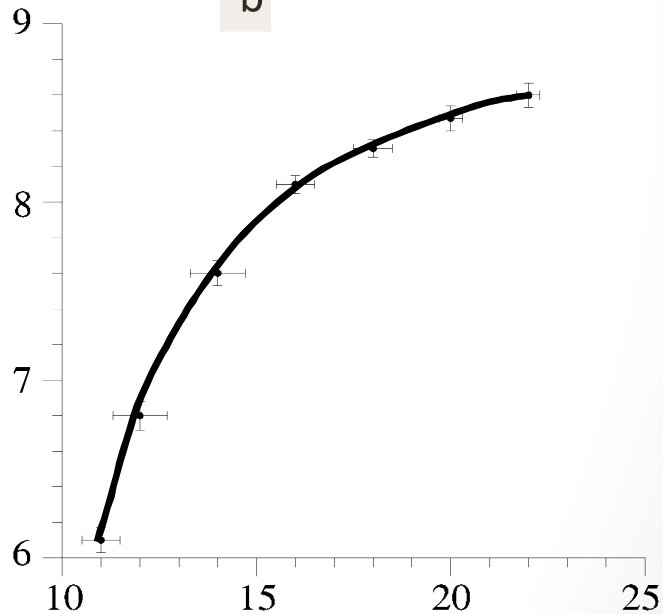
c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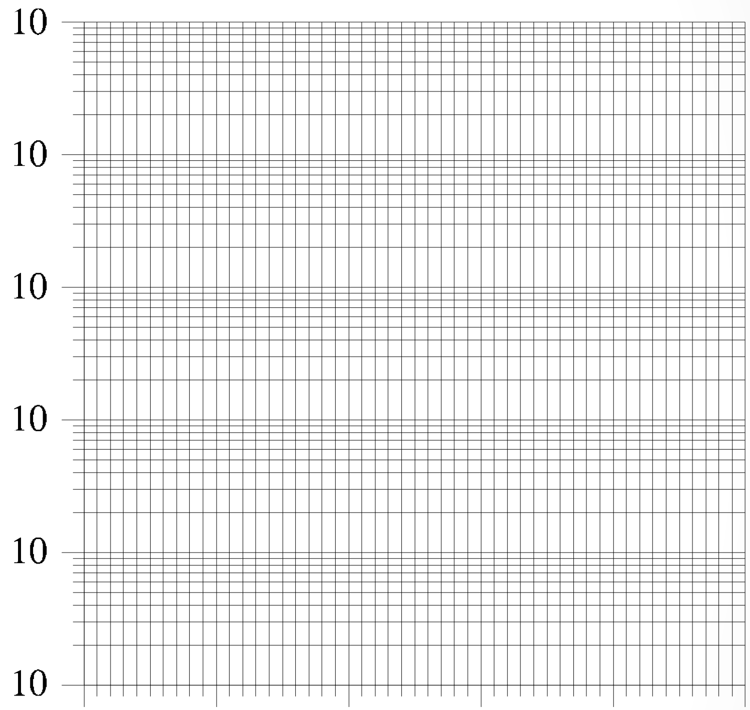
d

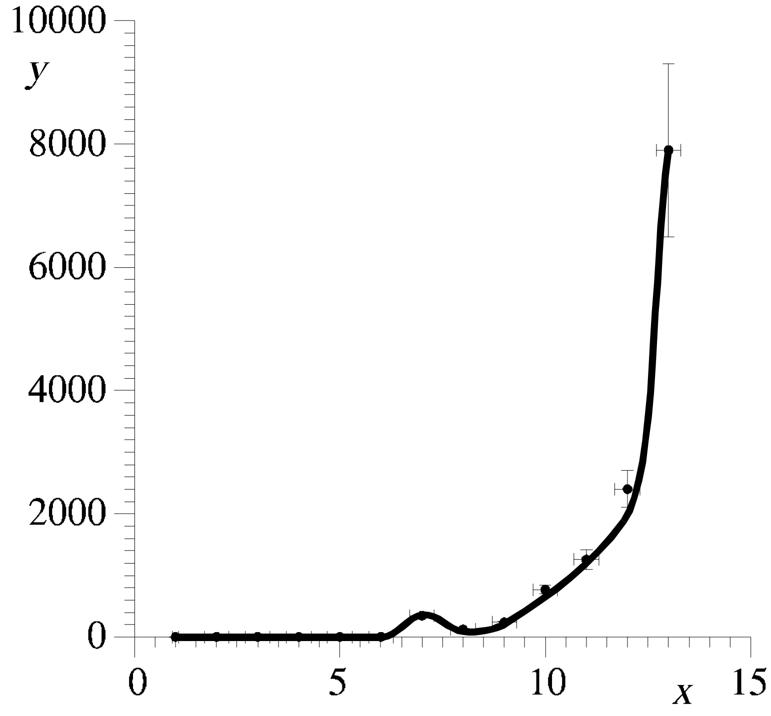
Graph plotting-Semilog paper

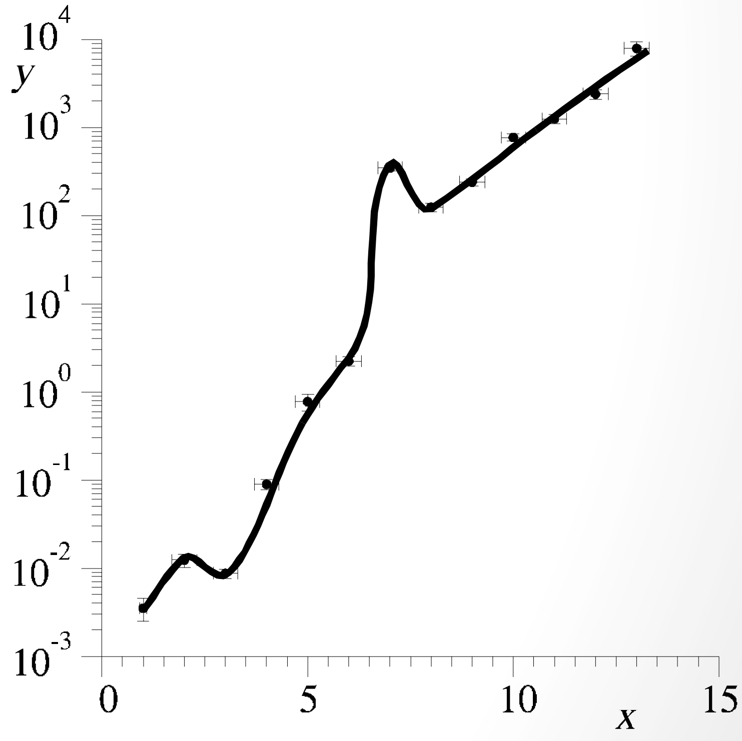
- Except from the usual graph paper we have two other graph papers. The first one it the so called semi-log paper presented in the picture. We use this when the recordings for the y-axis are extended in a very large range.



Graph plotting-Semilog paper

x	1.00	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0
y	0.0035	0.0123	0.0087	0.089	0.77	2.23	34,6	124	240	770	1260	2400	7900
δx	0.08	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
δy	0.001	0.0021	0.0011	0.012	0.16	0.26	28	13	21	70	160	300	1400





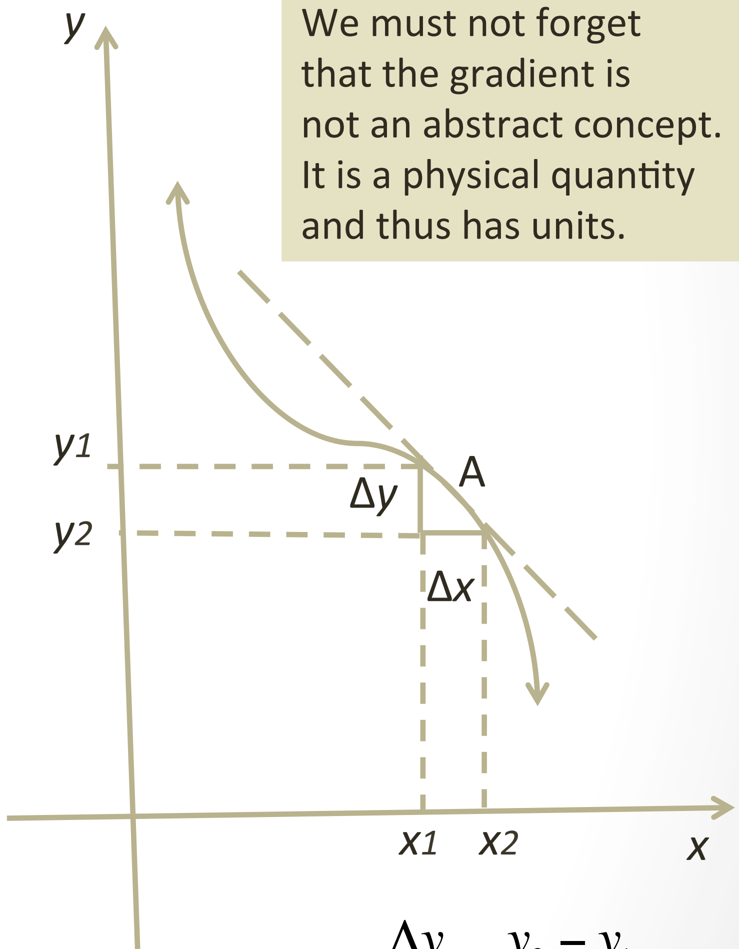
The gradient of a curve-a

- From mathematics we know that the gradient of a curve is associated with the derivative of the function which is represented by the curve.
- But in an experiment we have curves that are taken from experimental data and an analytical calclulation of the derivative is not possible.
- In this case we use the well known rule: **The gradient at a given point of a curve is the tangent of the angle between the horizontal axis and the tangent line to the curve at the point under consideration.**
- But this has nothing to do with taking a protactor, measuring an angle and finding a tangent with a calculator. We rather apply the following procedure:

The gradient of a curve-b

- We draw a line tangent to the curve at the point (A) we are interested in. Then we draw an orthogonal triangle which has the tangent line as its hypoteneuse and its perpendicular sides are parallel to the two axes of our coordinate system. Then the gradient is given by the formula: *K=Δy/Δx.* With Δ*x* we denote the length of the triangle side which is parallel to the x-axis and with Δ*y* we denote the length of the triangle side which is parallel to the *y*-axis.
- The length of Δ*y* and Δ*x* is defined from the relevant scales of the axes.

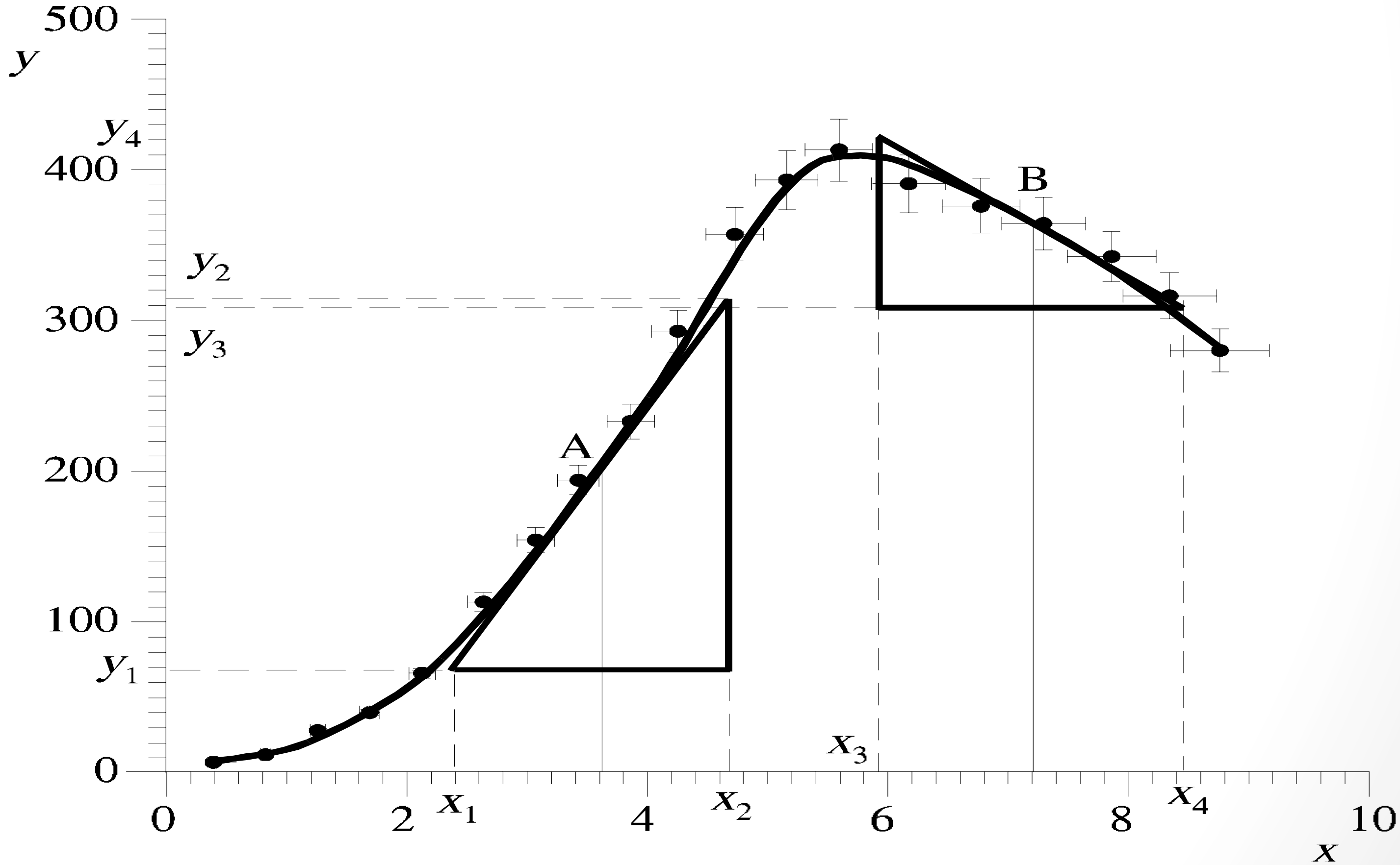
We must not forget that the gradient is not an abstract concept. It is a physical quantity and thus has units.



$$K = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1}$$

The gradient of a curve-c

- Example: Calculate the gradient of the curve at the points A and B.



Account of results of different experimental methods

- Sometimes we can measure the **same physical quantity but with different methods**. So we get different results with different errors. In this case the question is what is the correct answer.
- Let's assume that we use *N* different methods and we get the results: $x_1,\ x_2,\ ...,\ x_N$ with relevant errors $\delta x_1,\ \delta x_2,\ ...,\ \delta x_N$
- Then the result which "combines" all the measurements in the optimum way is:

$$x = \left(\sum_{i=1}^{N} w_i x_i\right) / \left(\sum_{i=1}^{N} w_i\right) \qquad \delta x = \sqrt{1 / \left(\sum_{i=1}^{N} w_i\right)}$$

$$w_i = 1/\left(\delta x_i\right)^2$$