



UNIVERSITÀ DI PISA



Centro E. Piaggio  
bioengineering and robotics research center

# INGEGNERIA DEI TESSUTI BIOLOGICI: STRESS-STRAIN TEST

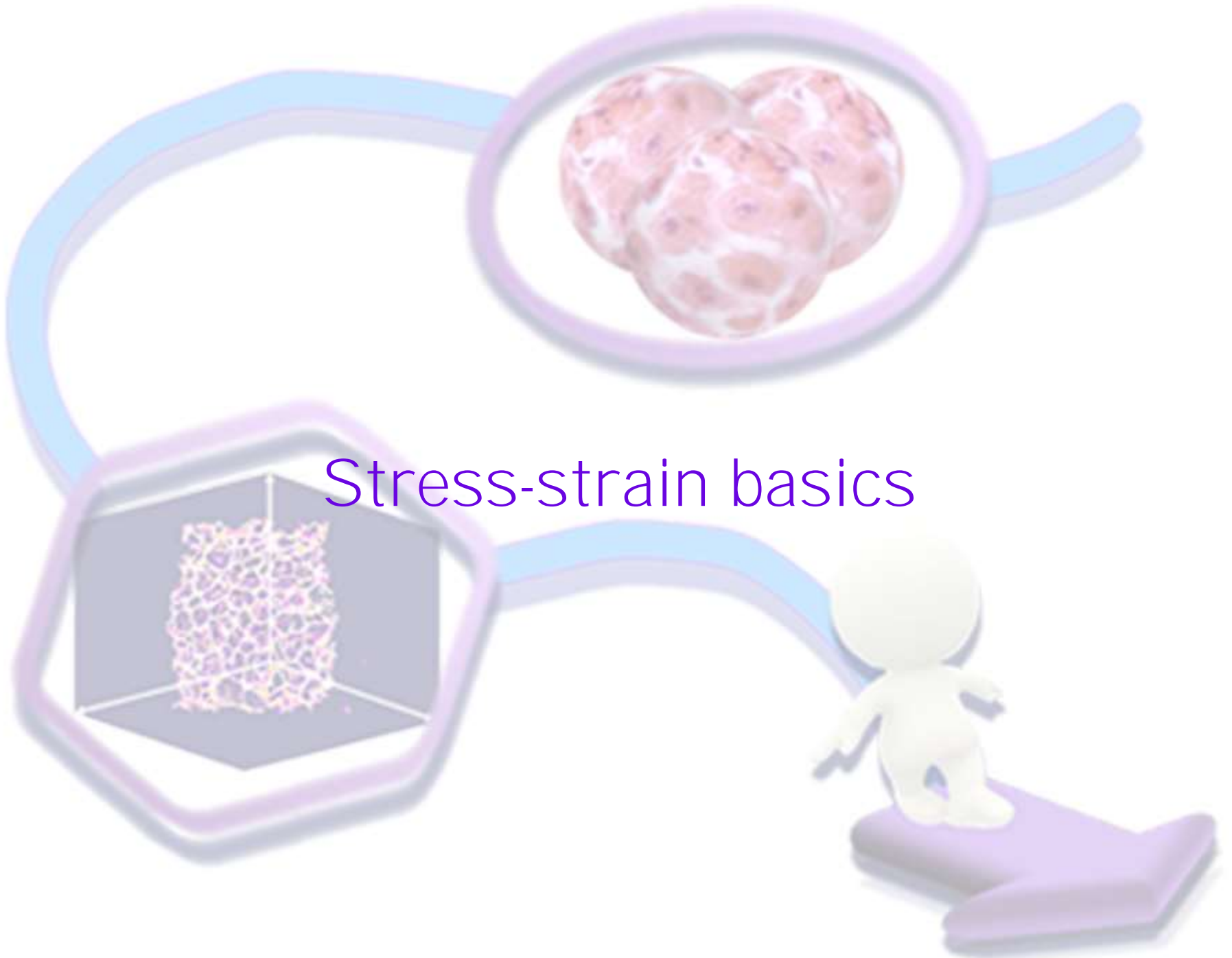
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*14 April 2015*



# Stress-strain basics



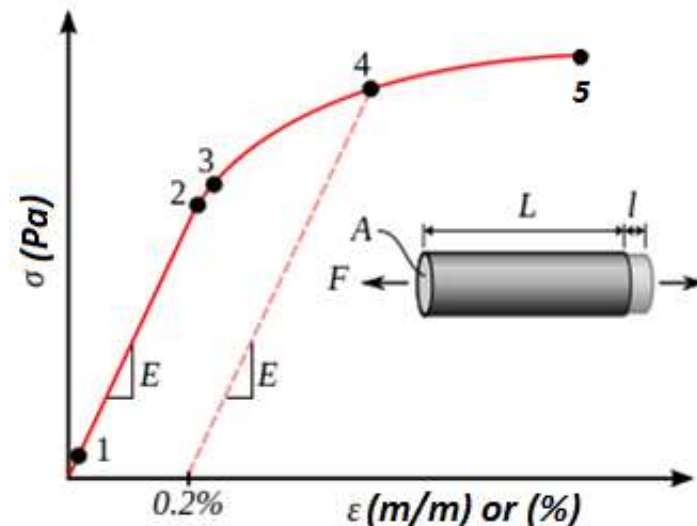


# Stress-Strain curve: *definition*

**Stress-Strain curve** is the relationship between the stress and the strain that a particular material displays. It is *unique* for each material and is found by recording the amount of deformation (strain) at distinct intervals of tensile or compressive loading (stress). [Wikipedia]

$$\sigma = \frac{F}{A}$$

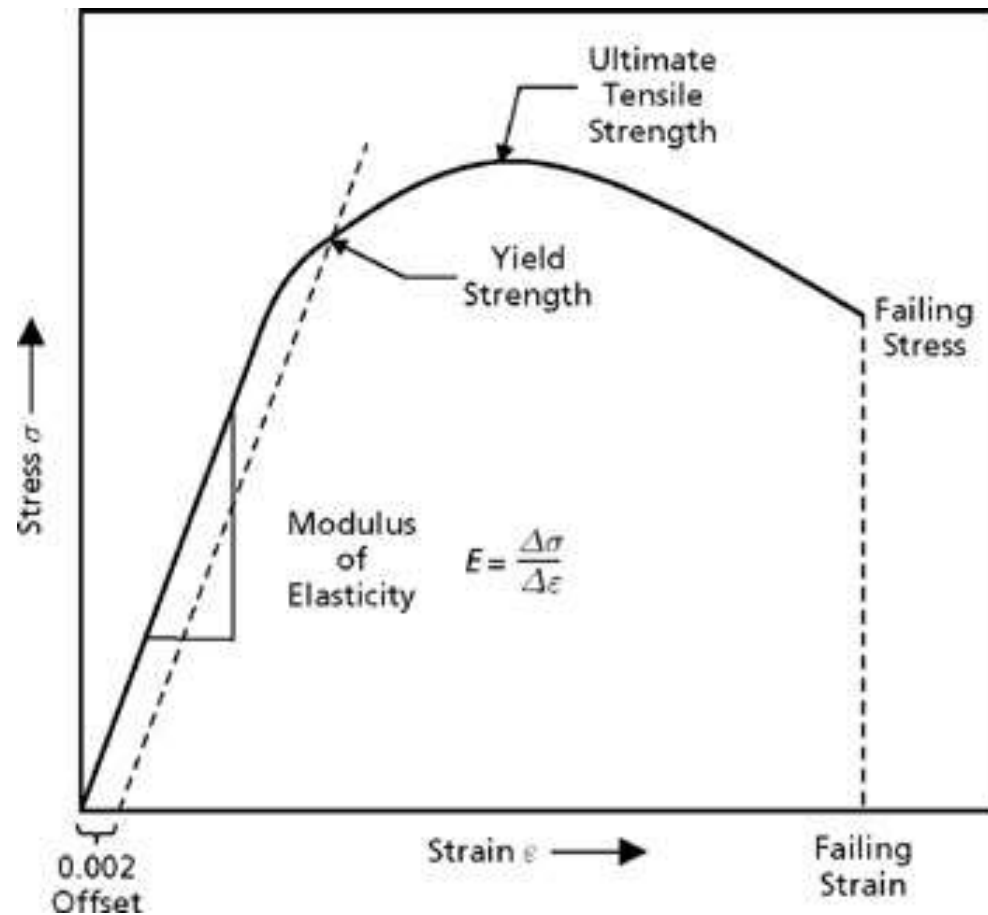
$$\varepsilon = \frac{\Delta l}{l_0}$$





# Stress-Strain curve: *utility*

*Evaluate material mechanical properties*

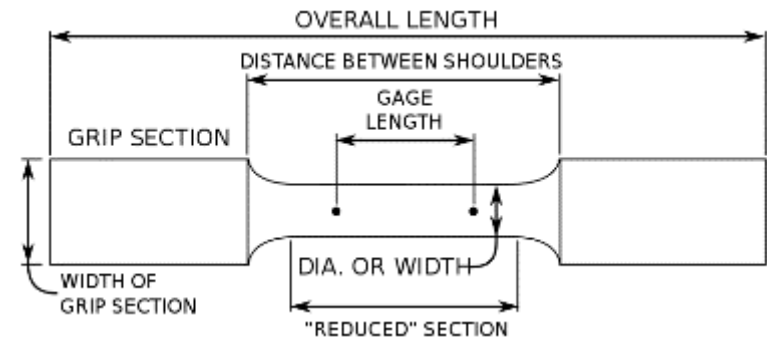




# Stress-Strain: *standard vs real sample*

## Standard «dog-bone» shaped sample

*“...It has two shoulders and a gauge (section) in between. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area...” [J. R. Davis, Tensile testing (2<sup>nd</sup> ed.), ASM International, 2004]*

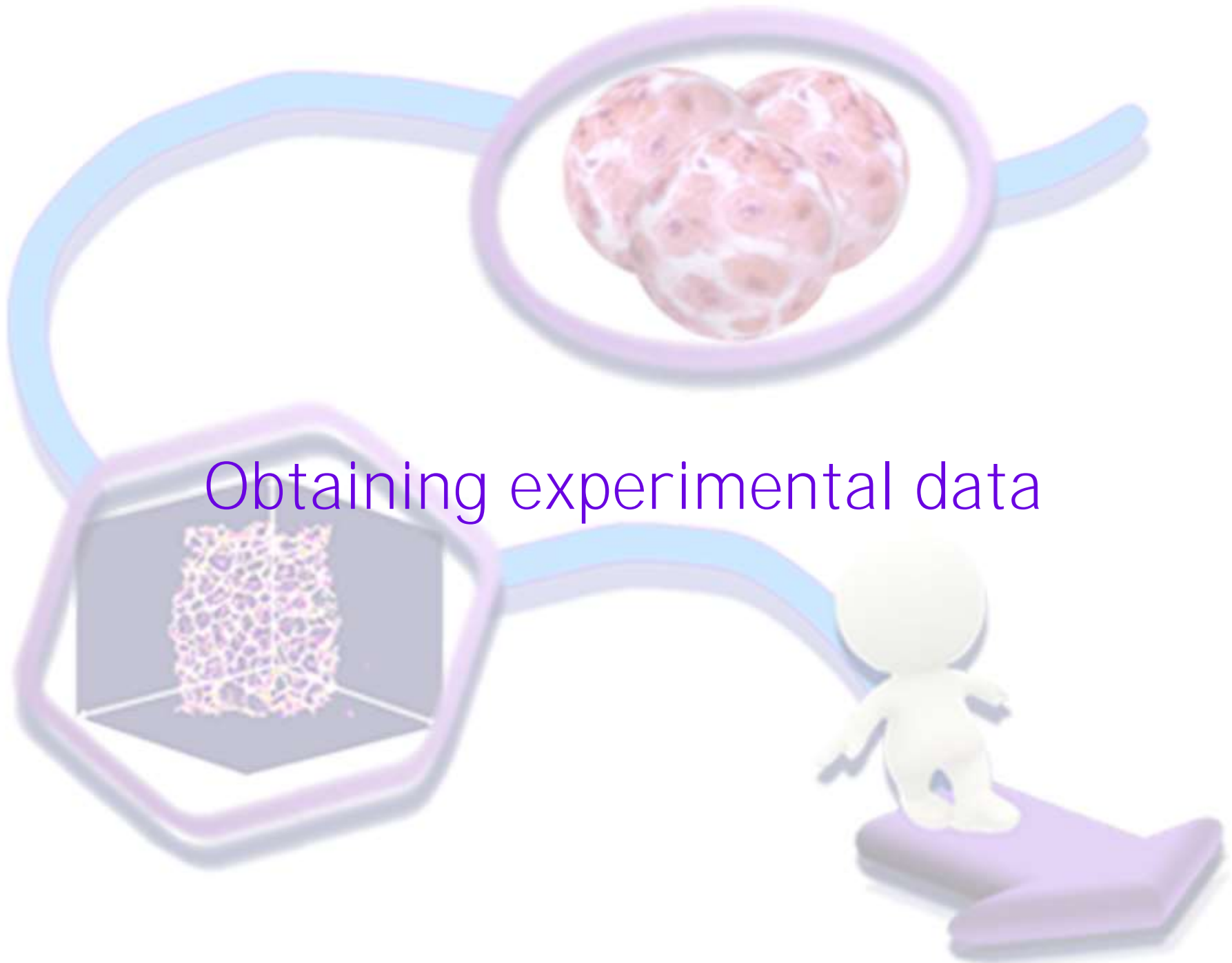


## Real Sample

*Depends on what you are testing and typically it is **NOT standard!***

- *No sufficient material*
- *Heterogeneous (especially tissues or natural materials)*





Obtaining experimental data



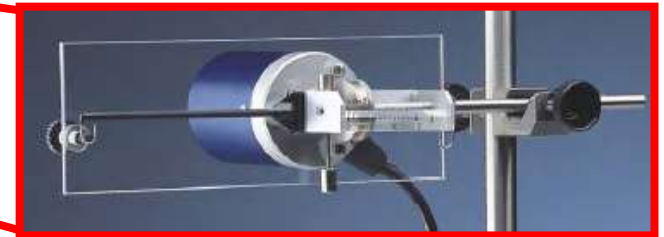
# Biopac

## *How to obtain experimental data*

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Ugo Basile Isotonic Transducer is specially designed for investigating isotonic contractions in isolated organs, particularly smooth muscle, amphibian hearts, etc.

Biopac



Ugo Basile  
Isotonic Transducer

An Isotonic Transducer is basically a ***displacement meter under constant load***, whereas an isometric transducer measures changes in force at constant length



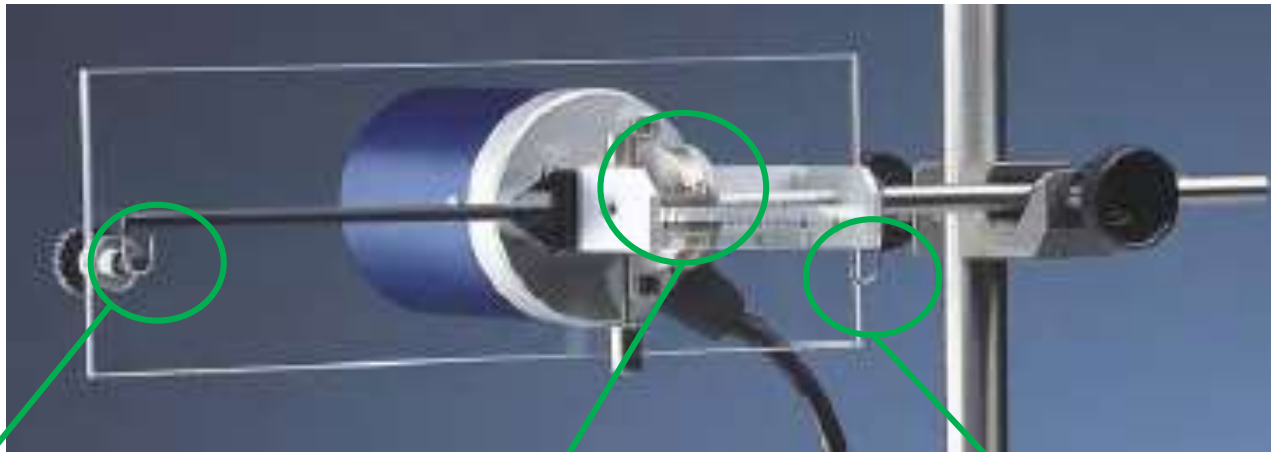


# Biopac

## *Ugo Basile Isotonic Transducer*

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- Based on Hall Effect Transducer



Sample hooking point

Preload

Load hooking point



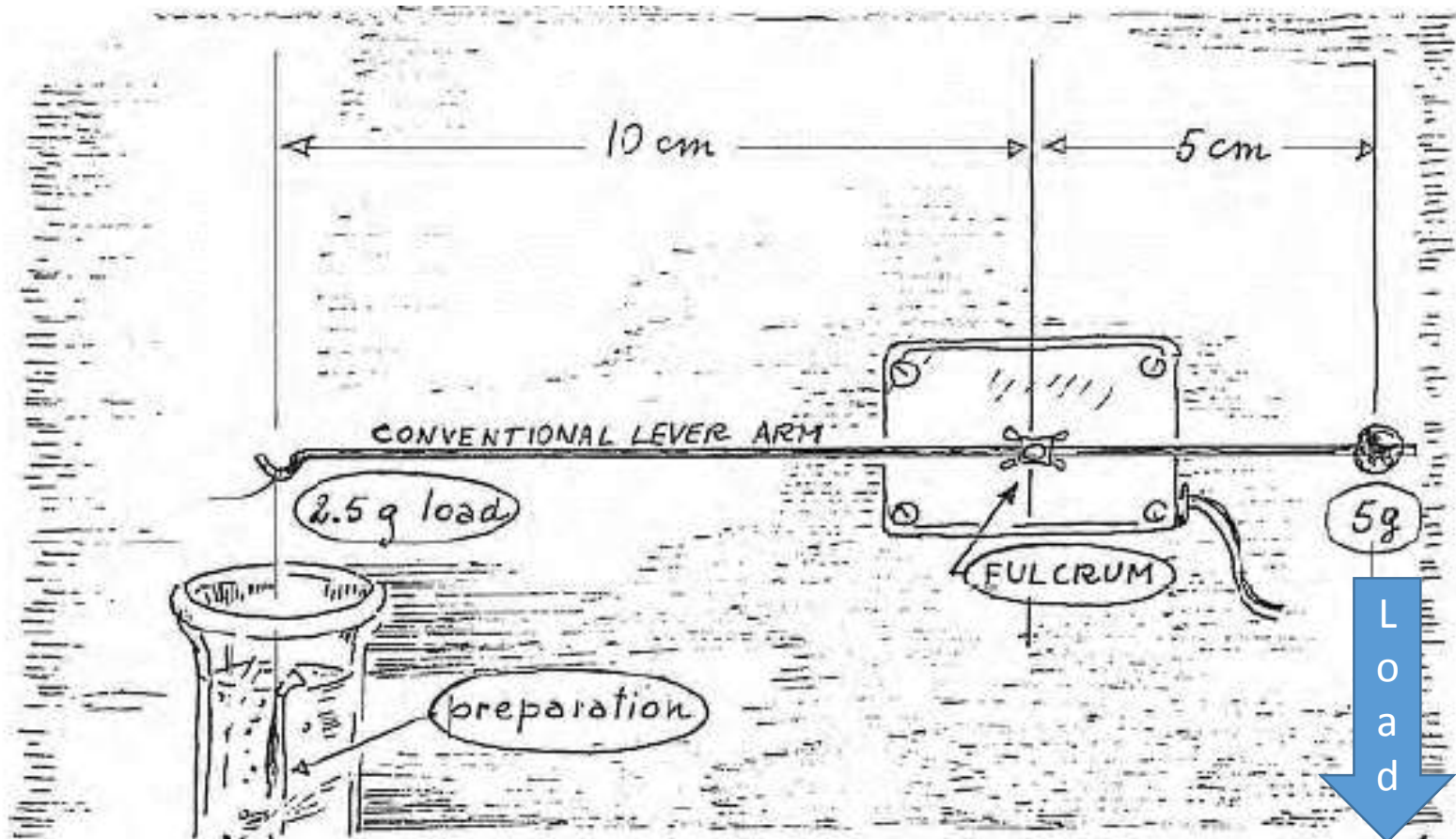


# Biopac

## *Test protocol*

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**N.B.** load on sample =  $\frac{1}{2}$ (applied load)



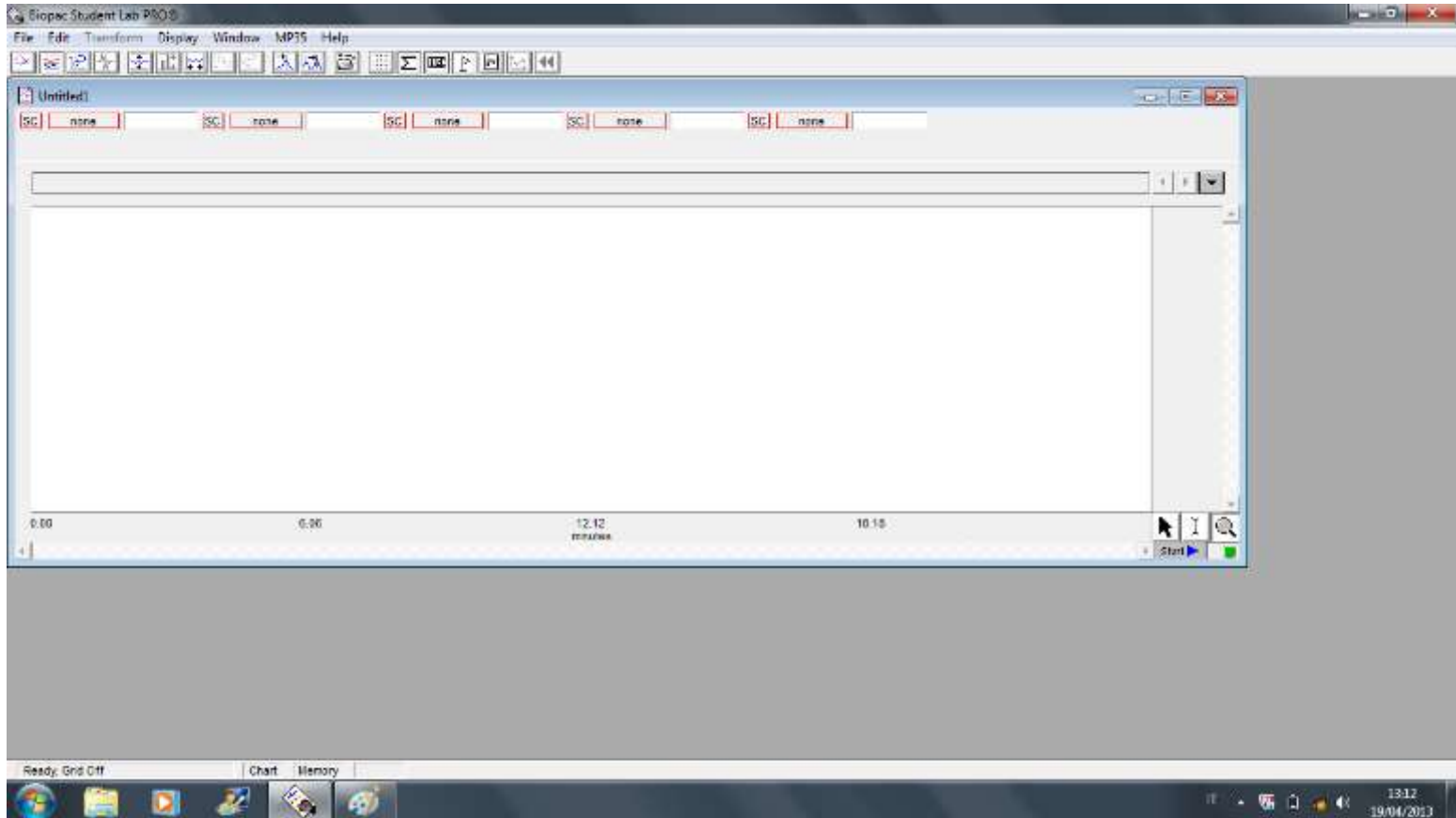


# Biopac

## *Test protocol*

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- Connect Ugo Basile Isotonic Transducer to the *Biopac's* channel 1 (CH1)
- Double-click on *BSL 3.7* icon





# Biopac

## *Test protocol*

- MP35 → *Set up Channels...* → Set «Displacement (cm)» for channel 1 (CH1)

The screenshot shows the Biopac Student Lab PRO software interface. The 'Set up Channels...' menu is open, and the 'Set up Channels' dialog box is displayed. The dialog box has a table with columns: Channel, Acquire Data, Plot on Screen, Label, Presets, and View/Change Parameters. The 'ANALOG INPUT CHANNELS' section is expanded, showing CH1 with 'Displacement (cm)' selected. The 'DIGITAL INPUT CHANNELS' and 'CALCULATION CHANNELS' sections are also visible.

Channel	Acquire Data	Plot on Screen	Label	Presets	View/Change Parameters
CH1	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	Displacement (cm)		
CH2	<input type="checkbox"/>	<input type="checkbox"/>	CH2 Input		
CH3	<input type="checkbox"/>	<input type="checkbox"/>	CH3 Input		
CH4	<input type="checkbox"/>	<input type="checkbox"/>	CH4 Input		

Channel	Acquire Data	Plot on Screen	Label	Presets	View/Change Parameters
D1	<input type="checkbox"/>	<input type="checkbox"/>	D1 - Digital Input		
D2	<input type="checkbox"/>	<input type="checkbox"/>	D2 - Digital Input		
D3	<input type="checkbox"/>	<input type="checkbox"/>	D3 - Digital Input		
D4	<input type="checkbox"/>	<input type="checkbox"/>	D4 - Digital Input		

Channel	Acquire Data	Plot on Screen	Label	Presets	View/Change Parameters
C1	<input type="checkbox"/>	<input type="checkbox"/>	C1 - calculation - OFF		
C2	<input type="checkbox"/>	<input type="checkbox"/>	C2 - calculation - OFF		
C3	<input type="checkbox"/>	<input type="checkbox"/>	C3 - calculation - OFF		
C4	<input type="checkbox"/>	<input type="checkbox"/>	C4 - calculation - OFF		



# Biopac

## *Test protocol*

- MP35 → *Set up Channels...* → *View/Change Parameters* → *Scaling*

The screenshot displays the Biopac Student Lab PRO software interface. The main window shows a data plot area with a video feed of a mechanical setup. Overlaid on the interface are two dialog boxes:

- Set up Channels:** This dialog box is used for configuring the acquisition channels. It includes a table for channel settings:

Channel	Acquire Data	Label	Presets	View/Change Parameters
CH1	<input checked="" type="checkbox"/>	Displacement (cm)		
CH2	<input type="checkbox"/>	CH2 Input		
CH3	<input type="checkbox"/>	CH3 Input		

- Change Scaling Parameters:** This dialog box is used to adjust the scaling for a selected channel. It shows the following settings:

Channel	Input value	Scale value
Displacement (cm)	4.81	-3
Ca2	5.88	3

The 'Change Scaling Parameters' dialog also includes an 'Input value' field set to 4.81, a 'Scale value' field set to -3, and a 'Units label' field set to 'cm'. The 'Ca2' channel is also visible with an input value of 5.88 and a scale value of 3.



# Biopac

## *Test protocol*

- MP35 → *Set up Acquisition...* → set *Sample rate* and *Acquisition Length*

The screenshot shows the Biopac Student Lab PRO software interface. A 'Set up Acquisition' dialog box is open, displaying the following settings:

- Record: Record
- and: Append
- using: PC Memory
- Sample Rate: 1.0 examples/second
- Max acquisition length: 208981 Samples
- Current acquisition requires: 35 Kbytes
- Acquisition Length: 5.000000 hours
- Repeat every: 0 seconds

Two blue arrows point from text labels to the 'Sample Rate' and 'Acquisition Length' fields in the dialog box.

Number of samples per second

Long enough to perform experiment

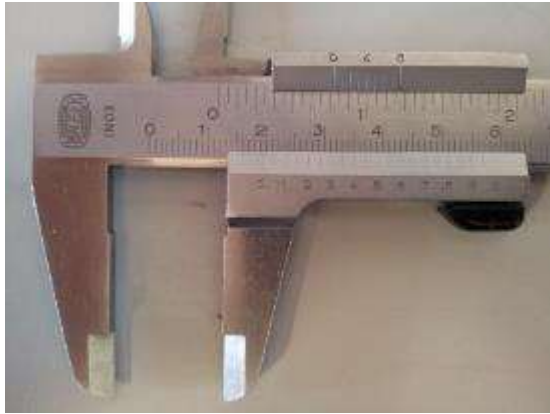
At the bottom of the window, the status bar shows 'Show acquisition settings' and the system tray displays the date and time: 13:16 19/04/2013.



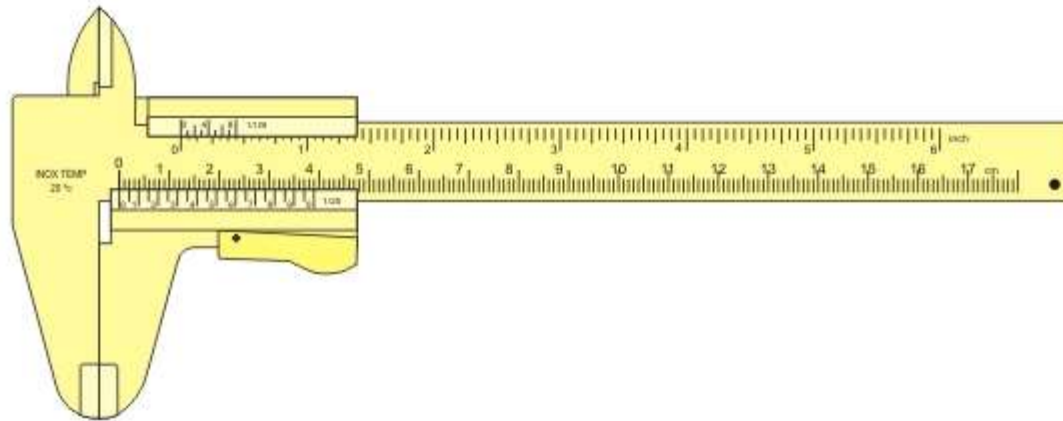
# Calliper

*how to use it*

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- direct reading of the distance measured with high accuracy and precision
- 0.05 mm resolution

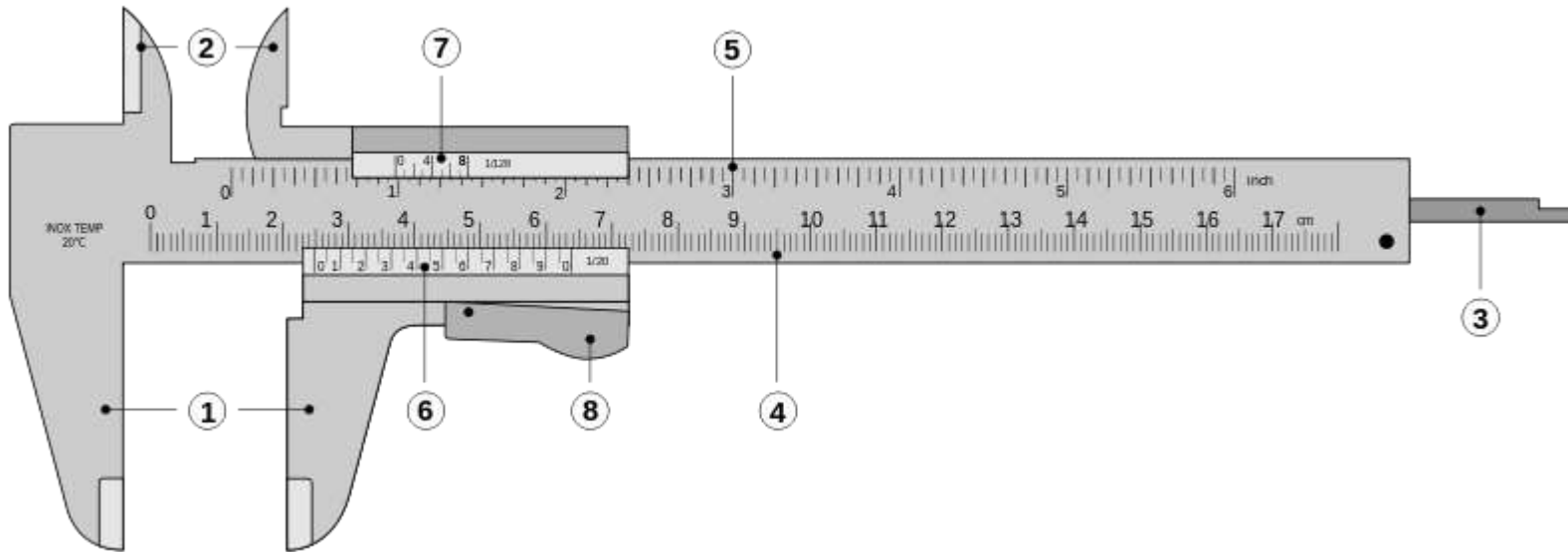






# Calliper

## *how to use it*



- 1. Outside jaws:** used to measure external diameter or width of an object
- 2. Inside jaws:** used to measure internal diameter of an object
- 3. Depth probe:** used to measure depths of an object or a hole
- 4. Main scale:** scale marked every mm
- 5. Main scale:** scale marked in inches and fractions
- 6. Vernier scale** gives interpolated measurements to 0.1 mm or better
- 7. Vernier scale** gives interpolated measurements in fractions of an inch
- 8. Retainer:** used to block movable part to allow the easy transferring of a measurement



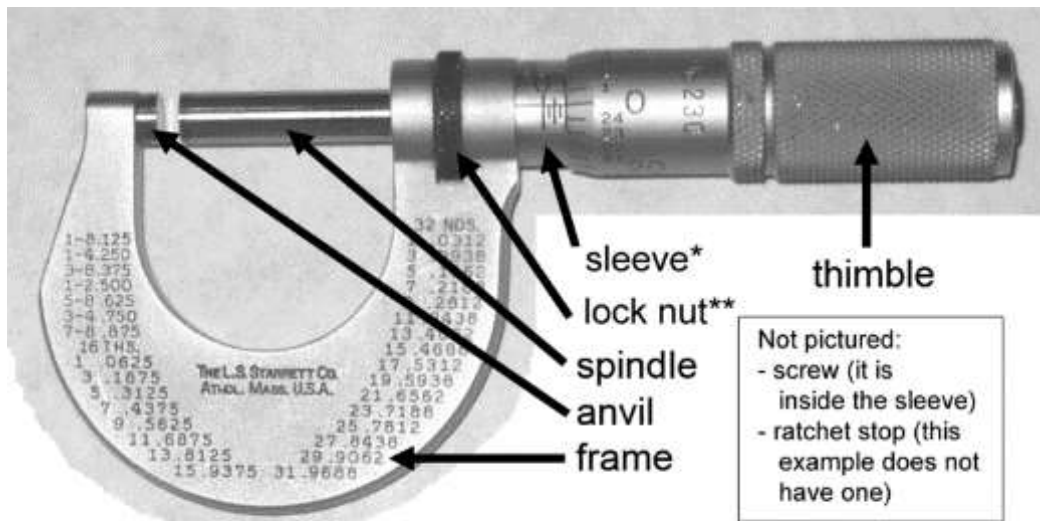


# Micrometer

## *how to use it*



- Micrometers use the principle of a screw to amplify small distances (that are too small to measure directly) into large rotations of the screw that are big enough to read from a scale



- Resolution 0.01mm (10 $\mu$ m)

\*Sleeve is the most prevalent name. May also be called the *barrel* or *stock*.

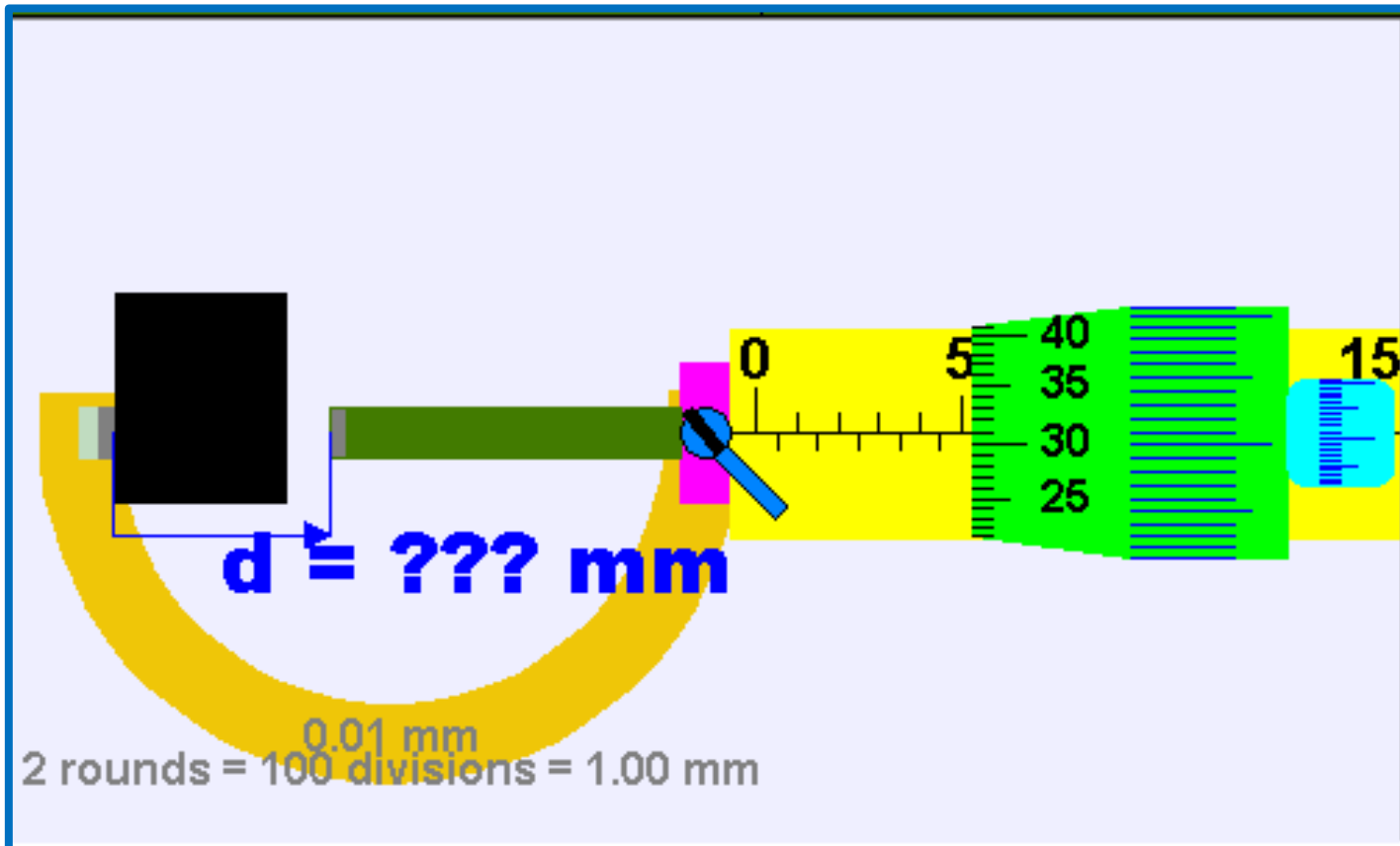
\*\*Aka *lock-ring*. Some mics have a *lock lever* instead.



# Micrometer

*how to use it*

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The image features a light blue path that starts at a magnifying glass in the top right, moves left, then curves down and left to a 3D wireframe model of a cell cluster, and finally curves down and right to a small white figure standing on a purple platform. The text "Modelling the linear response" is centered in purple over the middle of the path.

Modelling the linear response



# Linear Regression: *Definition*

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In statistics, **linear regression** is an approach to modeling the ***relationship*** between a dependent variable  $y$  and one or more independent variables denoted  $x$ .

*In linear regression, data are modeled using linear predictor functions, and unknown model parameters are estimated from the data.*



# Linear Regression

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Relationship between **input** and **output** is assumed as:

$$y = \alpha + \beta \cdot x + e$$

where

- **y** is the experimental output observed in response of an input **x**
- **$\alpha$**  and  **$\beta$**  are the unknown parameters to estimate (i.e. intercept and slope of the linear fit)
- **e** is a random error term such that  $E\{\varepsilon_i\} = 0$   $\sigma^2\{\varepsilon_i\} = \sigma^2$   $\sigma\{\varepsilon_i, \varepsilon_j\} = 0 \quad \forall i, j \ni i \neq j$



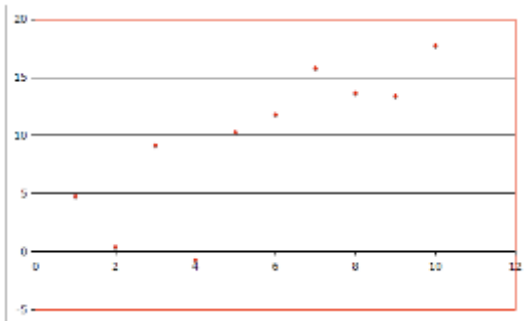


# Linear Regression

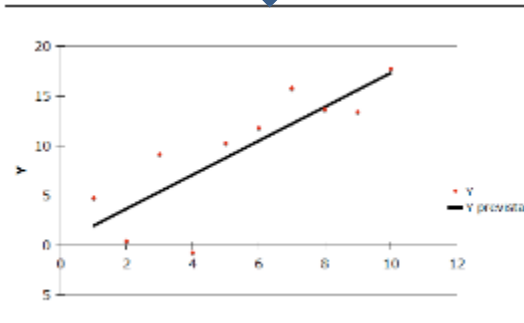
Parameters are estimated by minimizing the of ***sum of squared residual*** ( $SS_R$ )

$$y = \alpha + \beta \cdot x$$

$$SS_R = \sum_{i=1}^n (y_i - a - bx_i)^2$$



*residual = vertical distance between real data and estimated curve*



Assumptions:

- $(x_i, y_i)$  are independent and identically distributed observations
- $x_i$  are random and sampled together with  $y_i$

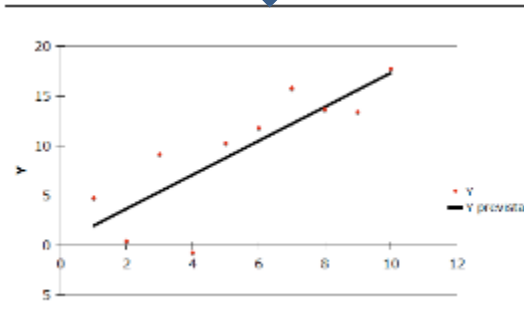
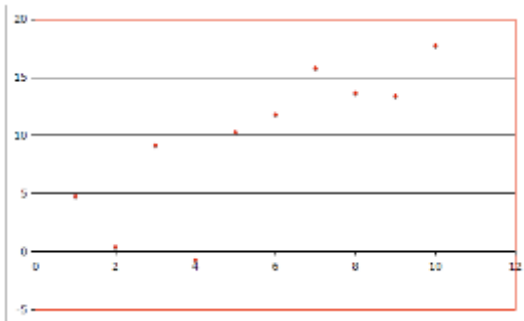


# Linear Regression

Parameters are evaluated by minimizing the of ***sum of squared residual*** ( $SS_R$ )

$$y = \alpha + \beta \cdot x$$

$$SS_R = \sum_{i=1}^n (y_i - a - bx_i)^2$$



The  $SS_R$  is an index of inherent variability, quantifying how much the fitted line differs from the real output due the error (**e**)





# Linear Regression

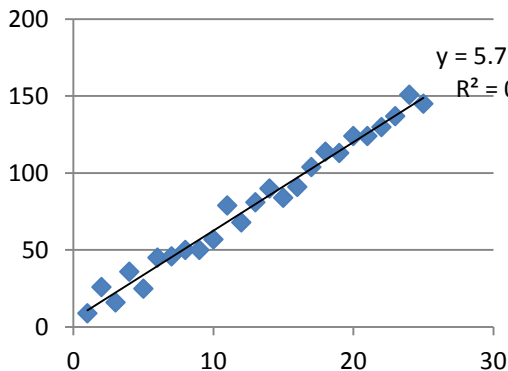
$R^2$ : a measure of goodness-of-fit of linear regression

$$R^2 := 1 - \frac{SS_R}{S_{yy}}$$

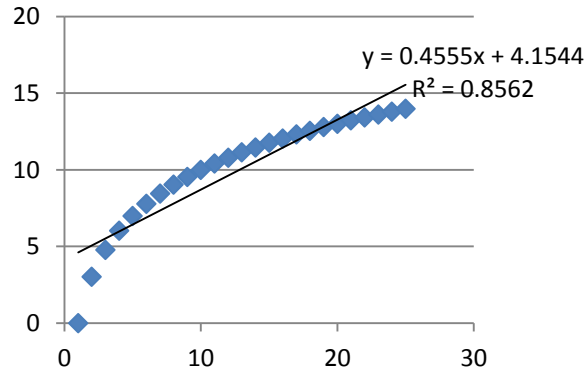
The coefficient of determination ( $R^2$ ) ranges from 0 (model does not fit the data) to 1 (perfect fit)

$$SS_R = \sum_{i=1}^n (y_i - a - bx_i)^2$$

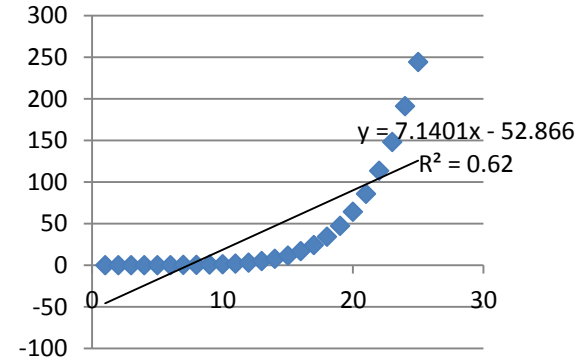
$$S_{yy} = \sum_i (y_i - \bar{y})^2$$



Good fit  
( $R^2 > 0.9$ )



Poor fit  
( $0.9 > R^2 > 0.8$ )



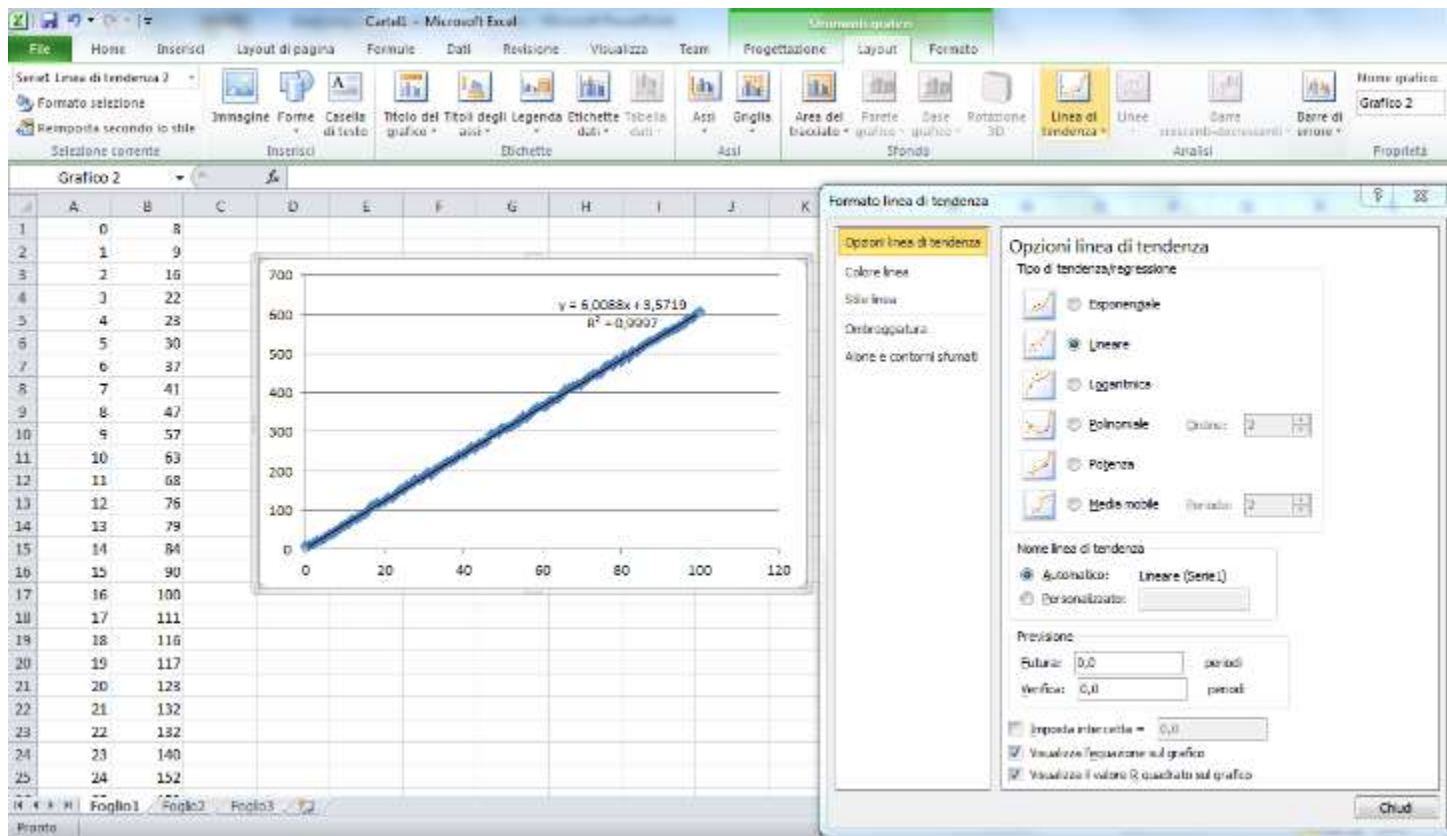
Very bad fit  
( $R^2 < 0.8$ )



# Microsoft Excel: *Linear Regression*

## Two ways to evaluate fit parameters

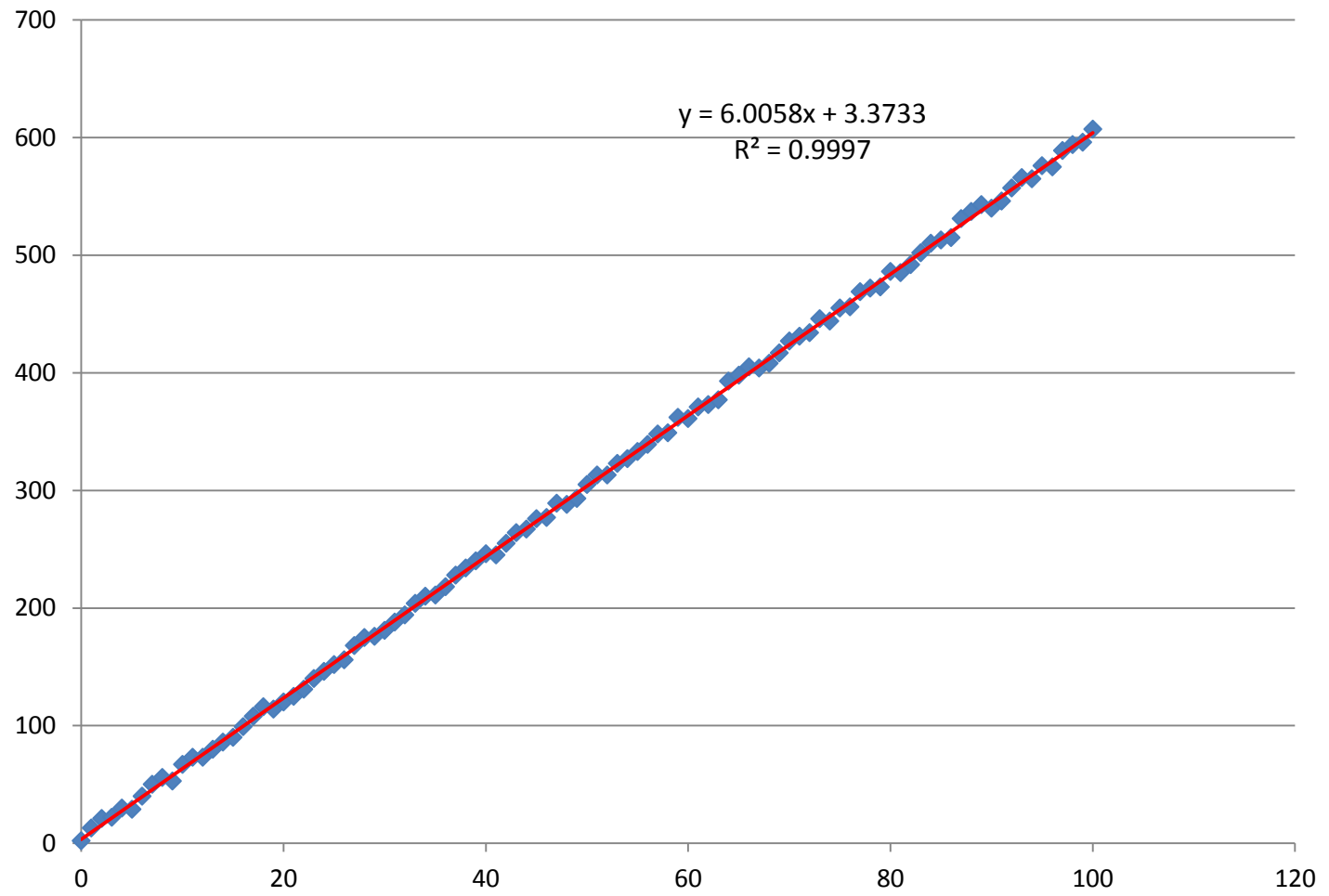
- *Directly on the plot*: add trendline



- Easy method
- Data on plot
- GUI help



# Microsoft Excel: *Linear Regression*





# Microsoft Excel: *Linear Regression*

## Two ways to evaluate fit parameter

- *As a cell function: use linear estimation function*

**Known\_y's:** experimental y values you wish to fit using  $y = ax + b$

**Const:** a logical value to fix line intercept to 0 (const = 0  $\rightarrow$  b=0)

In Italian...

**=REG.LIN**

(known\_y's, known\_x's, const, stats)

**Known\_x's:** experimental x values you wish to fit using  $y = ax + b$

**Stats:** a logical value to specify whether to return additional regression statistics (stats = 1 returns additional regr. statistics)

	A	B	C	D	E	F
1	$m_n$	$m_{n-1}$	...	$m_2$	$m_1$	b
2	$se_n$	$se_{n-1}$	...	$se_2$	$se_1$	$se_b$
3	$r^2$	$se_y$				
4	F	$d_f$				
5	ssreg	ssresid				



Arrangement of fitted parameters in Excel (select the necessary number of cells then press **CRTL+SHIFT+ENTER** to enter an array formula)



# Case of study: the hair

Typical experiment and analysis



# Testing the hair: experimental details

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1. Measure **hair diameter** using the **micrometer** to evaluate the sample **cross sectional area ( $A$ )**
2. **Clamp the hair using acetate sheets**, then measure the **distance between the latter** using the **calliper** to evaluate **sample initial length ( $l_0$ )**
3. Assemble the **testing setup**
4. Acquire displacement in **absence of applied** load for **60 s** (at least) to determine the **displacement offset**
5. **Every 60 s**, apply the following **loads in sequence** until the hair breakage (if reached)
  - Loads in grams: 0.4, 0.4, 0.84, 0.84, 1.96, 1.96, 4, 4, 10, 10, 40, 40, 70, 70
6. Calculate **mean sample displacement in response to each applied load ( $\Delta l$ )** by **averaging displacement measurements over the 60 s** and **subtracting the offset**
7. For each **load-displacement point experimentally obtained**, calculate the **respective stress ( $\sigma = F/A$ )** and **strain ( $\varepsilon = \Delta l/l_0$ )**
8. **Plot stress-strain points together** to obtain the **stress-strain curve of the hair**
9. Evaluate the **elastic modulus of the hair** as the **slope of the stress-strain curve** in the **first linear (elastic) tract**



# Practical exp: hair mechanical test

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**Aula A210** – Dip. Ingegneria dell'Informazione (polo A)

- 15 Apr 2015 – 11.30-14.30
- 22 Apr 2015 – 11.30-14.30







## **Giorgio MATTEI**

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