GDYNIA MARITIME UNIVERSITY
FACULTY OF MECHANICAL
PHYSICS LABORATORY

DEPARTMENT OF PHYSICS

Theoretical Introduction

Experiment “Y O U N G”

Young’s modulus is the so-called modulus of elasticity, which is determined for elements subjected to static stresses, such as rods, ropes or flat bars. Substances and materials have the ability to recover their original shapes and dimensions after the removal of an external force that causes deformation. All solid bodies possess this elastic property within a certain range.
The application of an external force leads to the formation of internal stress in the material.
The relative strain ε, associated with a change in the length of the specimen, is defined as the ratio of elongation x to the initial length L:

$$\varepsilon = \frac{x}{L}$$

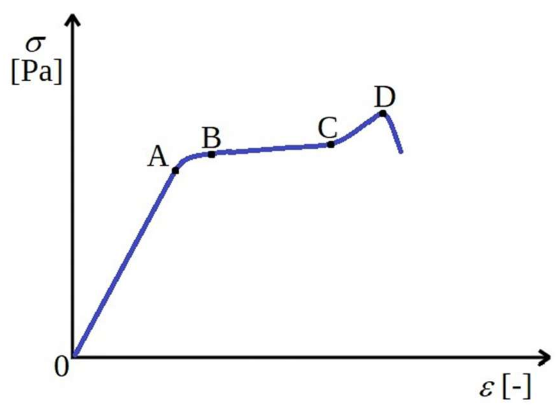
Hooke’s law is the fundamental experimental law of elasticity of bodies and applies to small deformations. This law states that relative strain is proportional to the stress causing the deformation. The proportionality coefficient is a constant value for a given material. This coefficient is called the modulus of elasticity.
Hooke’s law for a material subjected to elongation is defined by the formula:

$$\frac{F}{S} = E \cdot \frac{x}{L}$$

which can be shortened to the form:

$$\sigma = E \cdot \varepsilon$$

where:
σ– normal stress resulting from the action of forces Fperpendicular to the cross-sectional area S,
E– modulus of elasticity in tension, called Young’s modulus.



Graph of internal stress as a function of the relative elongation of a stretched wire:
The range 0–A on the graph is the linear elastic range, in which Hooke’s law applies.
Point B indicates the end of the elastic range.
Exceeding point B means permanent deformation of the specimen.
The range B–C is the plasticity, or yielding, range of the material. The specimen continues to elongate without additional stress.
Point D indicates the strength limit of the material, at which the specimen breaks.

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Preparation Questions:

1. State Hooke’s law and write it as a formula.
2. Explain what the spring constant is and give its unit.
3. Give the definition and unit of Young’s modulus.
4. Within what ranges are the Young’s moduli of common materials, for example steel, copper, aluminium, wood, nylon, etc.?
5. Discuss the classification of solids according to the structure of their molecules and explain the differences in their structure, crystalline and amorphous solids.
6. Give the definition and unit of relative strain.
7. Give the definition and unit of normal stress.
8. Give the definition and unit of force.
9. Draw a graph of internal stress as a function of relative elongation.
10. Describe the characteristic ranges occurring on the graph of internal stress as a function of relative elongation.
11. Draw a graph of internal stress as a function of relative elongation within the range of applicability of Hooke’s law.
12. How will the normal stress change if the tensile force increases twofold?
13. Give the types of stresses occurring in a material.
14. Explain the difference between elastic deformation and plastic deformation.
15. Describe the classification of materials according to their mechanical properties and explain the differences between them, elastic, brittle and plastic materials.

Course of Activities:

1. Measure the diameter of the specimen d using a vernier caliper.
2. Switch on and zero the force meter.
3. Mount the specimen in the holders.
4. By turning the crank, find the initial position at which the force meter indicates 0 N.
5. Measure the initial length of the specimen L, the distance between the holders, using a vernier caliper.
6. Stretch the specimen, measuring the elongation x and the tensile force F. Record the results at intervals of approximately 0.15 mm.
7. After collecting 15 measurements, the elongation x may be increased by 1–2 mm until the specimen breaks.
8. Using a computer, prepare a graph of stress σ as a function of strain ε for all measurement points.
9. Initially determine the limit of applicability of Hooke’s law, that is, the coordinates of point A: $\varepsilon_{\text{limit}}$ and σ_{limit}

10. **Student 1:** Prepare a graph, on graph paper, for 10 points from the 0–A range. Determine Young’s modulus as the slope coefficient of this graph.

    Student 2: Prepare a graph, on graph paper, for selected points including measurements in the 0–B range, including at least two consecutive points beyond the limiting point A. Determine the strain range in which Hooke’s law is satisfied, that is, the largest range in which a straight line can be drawn through the uncertainty areas.

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Methodological Template:

Student 1: Determination of Young's modulus for a specimen made of ABS or PETG.
Student 2: Determination of the strain range in which Hooke's law is satisfied.

Theoretical Basis

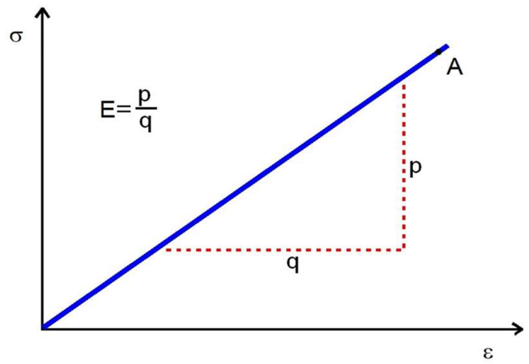
Hooke's law applied to the stretching of a specimen:
Within the elastic limits of the material, the elongation x is directly proportional to the applied external force F, which causes this elongation:

$$\frac{F}{S} = E \cdot \frac{x}{L}$$

Using the definitions of stress $\sigma$and strain ε:

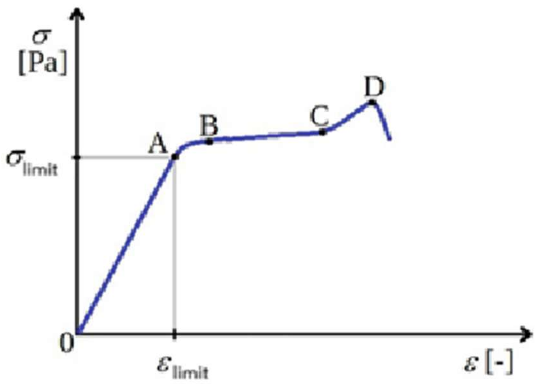
$$\sigma = E \cdot \varepsilon$$

Relative elongation, strain, is directly proportional to the stress that causes it.
The proportionality coefficient is **Young's modulus *E***.



Therefore, in order to **determine Young's modulus**, one should:

- perform measurements of the dependence of stress σ, caused by stretching, on strain ε,
- prepare a graph of stress σ as a function of strain ε within the linear range of variation 0–A:
  σ as a function of ε
- read the value of Young's modulus from the graph.



Therefore, in order to **determine the range of applicability of Hooke's law**, one should:

- perform measurements of the dependence of stress σ, caused by stretching, on strain ε,
- prepare a graph of stress σ as a function of strain ε within the range of variation 0–B:
  σ as a function of ε
- analyse its linearity, that is, specify the initial strain range in which the graph is linear.

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Report Guidelines - Determination

Student 1: Determination of Young’s modulus in tension for a specimen made of ABS or PETG

I. Methodology (conceptual plan of the exercise)
II. **Course of the exercise**
II.1. Course of activities
II.2. Sketch of the measurement setup
III. Results
III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F	[N]																				
x	[mm]																				

L = …   ΔL= …
d = …   Δd= …
Δx= …   ΔF= …
E_{limit}= … σ_{limit}= …

III.2. Calculations (example calculations - referring to measurement no. 2)

$$S = \frac{\pi d^2}{4} =$$

$$\sigma = \frac{F}{S} = \frac{4F}{\pi d^2} =$$

$$\Delta\sigma = \frac{4}{\pi d^2}\Delta F + \frac{8F}{\pi d^3} \cdot \Delta d =$$

$$\varepsilon = \frac{x}{L} =$$

$$\Delta\varepsilon = \frac{\Delta x}{L} + \frac{x}{L^2} \cdot \Delta L =$$

III.3. Calculation Results

		1	2	3	4	5	6	7	8	9	10
σ	[ ]										
Δσ	[ ]										
ε	[-]										
Δε	[-]										

III.4. Graph

- calculation of E, the slope of the best-fit straight line for the 0–A section of the graph,
- calculation of E', the slope of the deviated straight line for the 0–A section of the graph,
- calculation of the accuracy of the method: $\Delta E = | E - E' |$

IV. Summary

The determined value of … is …
The accuracy of the method is …
The tabulated value of … is …
Additional conclusions, observations, causes of measurement uncertainties.

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Report Guidelines - Verification

Student 2: Verification of the strain range in which Hooke’s law is satisfied..

I. Methodology (conceptual plan of the exercise)
II. **Course of the exercise**
II.1. Course of activities
II.2. Sketch of the measurement setup
III. Results
III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F	[N]																				
x	[mm]																				

L = …	ΔL= …
d = …	Δd= …
Δx= …	ΔF= …
E_{limit}= …	σ_{limit}= …

III.2. Calculations (example calculations - referring to measurement no. 2)

$$S = \frac{\pi d^2}{4} =$$
$$\sigma = \frac{F}{S} = \frac{4F}{\pi d^2} =$$
$$\Delta\sigma = \frac{4}{\pi d^2}\Delta F + \frac{8F}{\pi d^3} \cdot \Delta d =$$
$$\varepsilon = \frac{x}{L} =$$
$$\Delta\varepsilon = \frac{\Delta x}{L} + \frac{x}{L^2} \cdot \Delta L =$$

III.3. Calculation results

		1	2	3	4	5	6	7	8	9	10
σ	[ ]										
Δσ	[ ]										
ε	[-]										
Δε	[-]										

III.4. Graph
IV. Summary

On the graph of stress σas a function of strain ε, a straight line can be drawn through the measurement uncertainty rectangles only for the range of $\varepsilon$from … to …, therefore the range of applicability of Hooke’s law is … % of the initial length.
Additional conclusions, observations, causes of measurement uncertainties.