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Oxford Cambridge and RSA

AS and A LEVEL

Delivery Guide

PHYSICS A

H156/H556
For first teaching in 2015

Understanding materials

Version 2

Introduction

AS and A LEVEL PHYSICS A

Delivery guides are designed to represent a body of knowledge about teaching a particular topic and contain:

- Content: A clear outline of the content covered by the delivery guide;
- Thinking Conceptually: Expert guidance on the key concepts involved, common difficulties students may have, approaches to teaching that can help students understand these concepts and how this topic links conceptually to other areas of the subject;
- Thinking Contextually: A range of suggested teaching activities using a variety of themes so that different activities can be selected which best suit particular classes, learning styles or teaching approaches.

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Curriculum content

This module is intended to introduce students to the classification of mechanical properties of materials, the behaviour of materials under forces and to scientific vocabulary that is key to the topic of materials. As well as the qualitative descriptive work, there is quantitative work including Hooke's law, force constant, breaking stress and the determination of Young modulus for a material.

The physics is put into context by linking the properties of materials to their uses in engineering, construction, medical sciences and the manufacture of everyday objects.

Human and cultural issues arise in considering the impact of materials on the environment, technology and society.

It is not intended that students acquire a detailed knowledge of specific individual materials, rather that they should have a command of the technical terms needed to understand the properties of materials when presenting answers.

Students should be given opportunities to discuss and share their understanding of the uses and properties of these materials.

The areas covered in this module are:

- Behaviour of materials and springs under forces, elastic deformation, plastic deformation and breaking stress of materials.
- The appropriate use of the technical terms: tensile stress, tensile strain, tension, compression, breaking stress, elastic, plastic, ductile, brittle and strong.
- Understanding force constant and Young modulus.
- Determining the Young modulus of a material.
- Determining the breaking stress of a material.

Students should be familiar with the following concepts and ideas:

- Hooke's law, $F = kx$
- Elastic potential energy for an elastic material = $\frac{1}{2}kx^2$
- Energy as area under a force-extension graph for elastic materials
- tensile stress = force/cross-sectional area
- tensile strain = extension/original length
- Young modulus E = tensile stress/tensile strain

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Thinking conceptually

Approaches to teaching the content
This module introduces students to the study of materials. Students should be given opportunities to gain confidence in the use of technical terms, making careful measurements, handling numbers in scientific form and interpretation of graphs to analyse data. The goal for the experimental aspect of this module can be seen as making a valid determination of the Young modulus to a sensible degree of precision with a statement of the uncertainty of the result. It is important to encourage the discussion of experimental results and sources of uncertainty in measurements. This discussion should not be limited to experiments performed in the laboratory; students should be encouraged to link their growing understanding of material properties to the use and choice of materials in everyday life.

Common misconceptions or difficulties students may have
Although earlier work will have covered the use of prefixes and numbers in scientific form, many students continue to find conversions difficult; for example converting cross-sectional area from mm^2 to m^2. It is useful practice to use a micrometer to measure diameter in mm and thus calculate cross-sectional area in m^2 as this will build confidence and develop useful practical skills. Similarly the use of a Vernier scale in determining the extension introduces another practical measuring device.

A particular difficulty many students have with this topic is the terminology. This is not because the vocabulary is new, but because the scientific meanings are different from those in everyday use. Words such as elastic and plastic have very precise interpretations in physics, but in everyday conversation these words can take on different meanings. Many objects made of plastic have elastic properties and materials such as steel may be used to make objects which are elastic.

Students find the concept that elastic potential (stored) energy is given by ½ Fx leading to ½ kx^2 rather than kx^2 based solely on "work done = force × distance moved in the direction of the force" conceptually challenging.

Conceptual links to other areas of the specification – useful ways to approach this topic to set students up for topics later in the course
This module gives an opportunity to develop an understanding of the limitations of measurements. These ideas may have been introduced earlier, but it is perfectly possible to begin the course with this module. The possible techniques for considering the spread of results, including error bars on graphs and giving an uncertainty to the final result, will be used consistently throughout the course. Work carried out with tangible data such as lengths and diameters of wires allows students to gain confidence in dealing with uncertainties. This work also gives an opportunity to introduce or develop the good practice of focusing attention on the largest uncertainty in an experiment.

Using logarithmic charts to represent the range of breaking stress of materials helps students develop a familiarity with logarithms which are used in many areas of the course.

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Activities

This module has links to a wide range of contexts. For example:

- Why choose polymers for baby cups whilst adult crockery is usually ceramic?
- Why use reinforced concrete for building projects when concrete is exceptional in compression?
- What properties do artificial joints need in medical uses?
- Why are cables on pylons wound using both aluminium on the outside and a steel core?
- What are the latest materials used in airframes of aircrafts?
- How have polymer developments shaped fashion?

Each student should understand the specific use for which a metal, a ceramic or a polymer is chosen. This will place ideas such as breaking stress firmly into context. It is important for students to realise that the choice of materials always depends on material properties (though not always mechanical properties). We should not restrict our examples to the obvious – material choice is crucial in all areas from fashion to toothbrushes to space-probes.

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Learner Activity 1

Describing materials

The topic can start with either the students themselves experiencing materials hands on, or with demonstrations creating cognitive conflict between the everyday usage and scientific use. Examples of this are the elastic properties of a metre rule, the elastic and plastic properties of a paper-clip and that not all plastics behave in a plastic manner!

An exercise in matching technical terms to definitions is given in Learner Resource 1.

Learner Activity 2

The use of material selection charts

Material selection charts are available from a number of sources including Cambridge University Department of Engineering (http://www-materials.eng.cam.ac.uk/mpsite/interactive_charts/) where a collection of materials data charts use log scales that show the range of properties of commonly used materials. Specific criteria for materials can be given to search, and drop-down menus allow selection for each analysis. A useful introduction to the charts is available at:

http://www-materials.eng.cam.ac.uk/mpsite/physics/overview/

Learner Activity 3

Revision of Hooke's law, elastic potential (stored) energy and force constant

Elasticity is easily observed using a spring. Students will probably have carried out experiments stretching springs a number of times in their prior education. This can be repeated, demonstrated or revised using computer animations (applets) such as those from:

http://www.absorblearning.com/media/item.action?quick=5l

http://phet.colorado.edu/sims/mass-spring-lab/mass-spring-lab_en.html

Learner Activity 4

Elastic potential (stored) energy

Breaking down the incremental extension of a spring as individual masses are added to illustrate that the elastic potential (stored) energy is $\frac{1}{2}Fx$ and hence $\frac{1}{2}kx^2$ overcomes the misconception that the energy stored is the product of final force and extension, making it clear that it is represented by the area under the force-extension graph.

For those studying maths and already familiar with integration this is a possible extension task.

Students can calculate data for energy given final extension and the force constant of the spring. The simple integration on the second page will give mathematically inclined students a chance to check the integral given.

Resource details: http://hyperphysics.phy-astr.gsu.edu/hbase/pespr.html

Learner Activity 5

Modelling Young modulus using springs

In the activity shown in Learner Resource 2, students are challenged to consider the effect of changing the cross-sectional area of a sample or its original length, considering the implications for the force constant (which changes, as the object being investigated has changed dimensions) and the hypothetical Young modulus of the spring material, which should remain constant.

The activity allows students to practice graphical techniques and interpretation of graphs.

Learner Activity 6

Determining the breaking stress of aluminium

A strong material has a larger value of breaking stress. This important quantity can easily be determined in the laboratory using equipment that all students should be familiar with (micrometer screw gauge, slotted masses, etc). The percentage uncertainty in the value of the breaking stress can be used to illustrate how percentage uncertainties add up and which ones dominate. The details of the activity are provided in Learner Resource 3.

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Learner Activity 7

Determining Young modulus

Details of a possible experimental procedure are given here.

https://spark.iop.org/episode-228-young-modulus

Gaining a value in reasonable agreement with the expected value requires careful work and analysis on behalf of the students and they will need to be confident in the use of the apparatus before embarking on this practical. For example, it is useful to give them practice in measuring the diameter of wires using a micrometer (screw gauge).

The different methods of measuring lengths and the different order of lengths involved lend themselves to consideration of error and uncertainty. Students can discuss which measurement leads to the greatest percentage uncertainty as well as combining the uncertainties to allow plotting of error bars on graphs.

Other possible resources

https://spark.iop.org/home-made-springs

https://spark.iop.org/stretching-copper-wire-measuring-extension-quantitative

https://spark.iop.org/episode-227-hookes-law

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Key definitions

Brittle material	A material that does not show much plastic deformation when it breaks, e.g. ceramic.
Ductile material	This type of material can be drawn into wires, e.g. copper.
Elastic behaviour	A material that is composed of long chain molecules, e.g. rubber.
Plastic behaviour	A material that has a larger value of breaking stress.
Polymeric material	A material with this behaviour does not return to its original shape after forces are removed; the material shows permanent deformation.
Stiff material	A material with this behaviour will return to its original shape after forces are removed.
Strong material	A material with a larger value of Young modulus.

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Modelling Young modulus using springs

Connecting springs in series

1. Use a number of identical springs, e.g. five springs.
2. Load one spring with a 100 g mass and determine the extension *x* of the spring.
3. Determine the force constant of the spring using $k = 0.100\ g/x$
4. Now connect two springs in series (see Figure 1) and repeat the process above.
5. Continue with all the springs and record your results in a table.
6. Plot a graph extension *x* against the number *N* of springs.
7. The extension *x* should be directly proportional to *N*. Does the graph drawn confirm this?

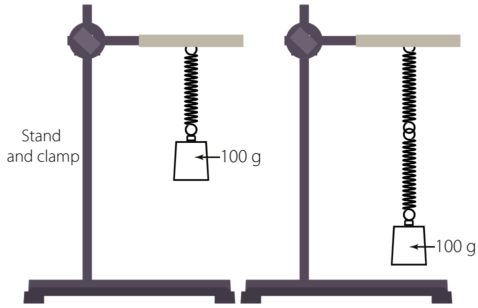

Figure 1

Connecting springs in parallel

1. Use a number of identical springs, e.g. five springs.
2. Load one spring with a 1.00 kg mass and determine the extension *x* of the spring.
3. Determine the force constant of the spring using $k = 1.00\ g/x$
4. Now connect two springs in parallel (see Figure 2) and repeat the process above.
5. Continue with all the springs and record your results in a table.
6. Plot a graph of extension *x* against the number *N* of springs and also a graph of *x* against $1/N$.
7. The extension *x* should be inversely proportional to *N*. Does one of the graphs drawn confirm this?

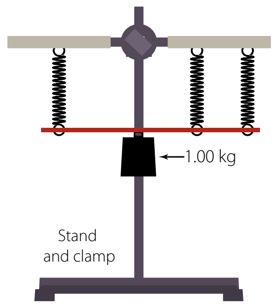

Figure 2

Drawing conclusions

- Young modulus E = tensile stress/tensile strain
- force constant $k = F/x$

Which of these constants relates solely to the **material** and is independent of shape, and which is a function of the **shape** of the object?

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Breaking stress

1. Carefully cut a strip of aluminium foil that is about 1.0 cm wide and 15 cm long.
2. Use a test strip clamp (for example SciChem catalogue number XPS130010) to secure both ends of the strip.
3. Secure one end to a clamp rod and hang a 100 g holder from its bottom end: see Figure 3.
4. Use a micrometer screw gauge to measure the average thickness *d* of the strip. Also record the absolute uncertainty.
5. Use a plastic ruler to measure the average width of the strip. Also record the absolutely uncertainty.
6. Carefully add 100 g slotted masses until the strip snaps.
7. Record the mass *M* when the strip snapped.
8. Calculate the breaking force *F* for the strip using $F = Mg$.
9. Calculate the cross-sectional area *A* of the strip. Include the percentage uncertainty in *A*.
10. Determine the breaking stress for material (aluminium) of the foil. Include the percentage uncertainty.

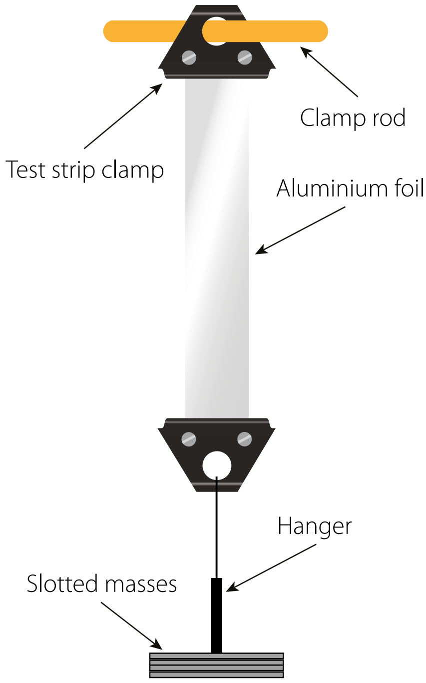

Figure 3

Drawing conclusions:

- The breaking stress for aluminium is about 90 MPa according to one data book.

What is the percentage difference between your value and this value?

How reliable is your experimental value for the breaking stress?

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