Iris Eisenbach

English for Materials Science and Engineering

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# English for Materials Science and Engineering

Exercises, Grammar, Case Studies

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Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

**Iris Eisenbach** has extensive experience in teaching all levels of English to speakers of other languages and for a wide range of educational and professional purposes. The author graduated in English and French from the University of Mainz and from the Teacher Training College (Studienseminar) in Wiesbaden, (both Germany) with the Second State Examination. After teaching foreign languages to students at different levels for some years, she got tenure as a civil servant (Oberstudienrätin). Iris Eisenbach has spent the past 20 years concentrating on teaching English to students in university settings. Presently she is working as a university language instructor at the English and German Departments of the Language Center of the University of Stuttgart, Germany.

1st Edition 2011



Editorial Office: Imke Zander | Thomas Zipsner

Vieweg+Teubner Verlag is a brand of Springer Fachmedien.
Springer Fachmedien is part of Springer Science+Business Media.
www.viewegteubner.de



Cover design: KünkelLopka Medienentwicklung, Heidelberg
Layout: Stefan Kreickenbaum, Wiesbaden
Pictures: Graphik & Text Studio, Dr. Wolfgang Zettlmeier, Barbing; Stefan Kreickenbaum, Wiesbaden
Printed on acid-free paper
Printed in Germany

ISBN 978-3-8348-0957-5

## Introduction

This textbook is intended for students of materials science, of different branches of engineering and of related disciplines who need to re-activate their English language skills. Using authentic materials and figures selected from scientific texts, students will improve their reading, writing and speaking skills in a context relevant to their specialist studies. This work does not attempt to teach the subject of materials science.

In addition to covering linguistic features specific to scientific and technical purposes, this book also presents review and practice activities in common problem areas of general English usage. The material for the textbook has been developed and tested in classes at the English Department of the University of Stuttgart over several semesters, and it addresses most of the problems English-language learners confront.

Students' feedback has been incorporated into the textbook; the author gratefully acknowledges these contributions, which make the book useful for successful teaching and self-study purposes.

Since the book is designed as both textbook and workbook, it is suitable for classroom use and for self-study. It contains extensive monolingual glossaries, tasks, grammar reviews and word studies directly related to the texts and figures. Solutions are offered in the back of the book.

The textbook offers sufficient material for a one-semester language class of about 14 sessions. Subjects, grammar reviews and word studies can also be studied independently.

## Acknowledgements

This book would never have been written without the support of the Materials Research Laboratory (MRL) of the University of California, Santa Barbara, where I was accompanying my husband, Professor Claus D. Eisenbach, in 2007–2008. I am very grateful to the MRL for kindly offering me the use of the visiting scholar's office and for providing equipment and support.

The MRL also made it possible for me to attend classes by two excellent researchers and dedicated teachers, Professor Ram Seshadri and Professor Susanne Stemmer. Professor Seshadri in particular introduced me to the field of materials science and directed me to my most valuable source, *Materials Science and Engineering: An Introduction*, by William D. Callister Jr.

I am also indebted to my husband who was a constant source of knowledge and expertise and who read and commented on the manuscript. Special thanks to my good friend Pamela Lavigne, whose experience in TESOL (Teaching English to Speakers of Other Languages) and in editing were of great help. I am likewise grateful to the editors of "Lektorat Maschinenbau" at Vieweg+Teubner for their technical assistance.

Stuttgart, Autumn 2010 — Iris Eisenbach

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# Chapter 1 Introduction

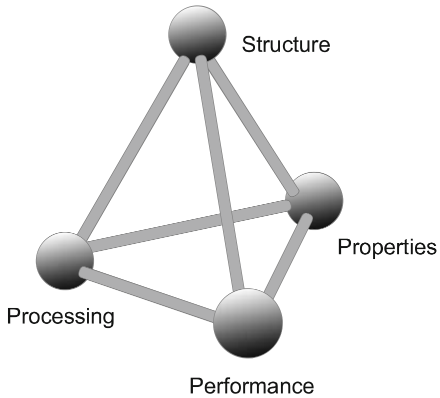


*Figure 1:* Materials science tetrahedron [wikipedia]

## 1.1 Historical Background

***Task 1.*** *Work with a partner. Fill the gaps in the text with words from the box in their correct form.*

| |
|---|
| alloy; characteristic; communication; clay; crystal; heat; housing; manipulate; metal; pottery; property (2); skin; specimen; substance; structure; technological; wood |

Materials used in food, clothing, ……………………, transportation, recreation and …………………… influence virtually every segment of our everyday lives.

Historically, materials have played a major role in the development of societies, whose advancement depended on their access to materials and on their ability to produce and …………………… them. In fact, historians named civilizations by the level of their materials development, e.g. the Stone Age (beginning around 2.5 million BC), the Bronze Age (3500 BC), and the Iron Age (1000 BC). The earliest humans had access to only a very limited number of materials, those that occur naturally, e.g. ……………………, …………………… and ……………………. With time they discovered techniques for producing materials that had properties superior to those of the natural ones; these new materials included …………………… and various ……………………. Furthermore, early humans discovered that the properties of a material could be altered

I. Eisenbach, *English for Materials Science and Engineering,* DOI 10.1007/978-3-8348-9955-2_1,

by ........................................................ treatments, e.g. to soften metals, and by adding other ........................................................ to produce a new material, e.g. by melting copper, then mixing it with tin to form bronze which could be regarded as the first ........................................................

Until recently, selecting a material involved choosing from a number of familiar materials the one most appropriate for the intended application by virtue of its characteristics but without knowing much about its structure. Only in the 19th century did scientists begin to understand the relationships between the structural elements of materials and their ......................................................... In 1864 the Englishman Henry Sorby first showed the microstructure of a metal when he developed a technique for *etching* the surface layer of a polished metal ........................................................ by a chemical reaction. He used a light reflecting microscope to show that the material consisted of small ........................................................ which reflected the light in different ways because they were oriented in different directions. The crystals were well fitted together and joined along *grain boundaries*.

Modern techniques such as x-ray diffraction, transmittance electron microscopy (TEM) and scanning electron microscopy (SEM) make possible to see further into the ........................................................ of materials, which leads to a better understanding of their characteristics and promotes intentional alteration and improvement of their ......................................................... By now more than 50,000 materials with specialized ........................................................ have been developed and are available to the engineer, who has to choose the one best suited to serve the given purpose. Since much of what can be done ........................................................ is limited by the available materials, engineers must constantly develop new materials with improved properties.

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| to etch | to cut into a surface, e.g. glass, using an *acid* |
| acid | a chemical, usually a sour liquid, that contains hydrogen with a pH of less than 7 |
| grain boundary | a line separating differently oriented crystals in a polycrystal |

***Task 2.*** *Different verbs in English can be used to describe the action of changing, such as adjust; alter; change; modify; transform; vary. Refer to a dictionary or thesaurus, then list the differences in usage and meaning.*

.................................................................................................................................................

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***Task 3.*** *Give a short explanation for x-ray diffraction, TEM and SEM.*

.................................................................................................................................................

.................................................................................................................................................

.................................................................................................................................................

.................................................................................................................................................

.................................................................................................................................................

## 1.2 Grammar: Simple Past versus Present Perfect

Scientific and technical texts in English frequently use the present tense, since in most cases they state facts. Sometimes, the present perfect and simple past have to be used, as the text about the historical development of materials science shows.

**Formation of the Simple Past**

Use the so-called second form of the verb

write – *wrote* – written

She *wrote* the second proposal last month.

**Formation of the Present Perfect**

Use have/has + the third form of the verb (the past participle).

write – wrote – *written*

She *has* just *written* the second proposal.

**Use of the Simple Past**

Use the simple past for actions in the past that have **no** connection to the present and when the **time** of the past action **is important** or **shown.**

Signal words are yesterday, last Thursday, two weeks ago, in November 1989

**Use of the Present Perfect**

Use the present perfect for actions in the past **with** a connection to the present and when the **time** of the past actions **is not important.**

Use the present perfect for recently completed actions and actions beginning in the past and continuing in the present.

Signal words are: just, never, ever, yet, already, recently, since, for, so far, up to now

***Task 1.*** *Work in a group. Revise English irregular verbs, by using a table, e.g. from a dictionary or English grammar book. Take turns eliciting the correct forms from members of your group.*

***Task 2.*** *Work with a partner. Fill the gaps in the sentences with the verbs in their correct tense (present perfect or simple past).*

Materials .................................................. (always play) a major role in the development of societies.

Civilizations ............................................. (designate) by the level of their materials development.

The earliest humans ............................................. (have) access to only a very limited number of materials.

The microstructure of a metal ..................................................... (be) first revealed in 1864 by the Englishman Henry Sorby who ....................................................... (develop) a technique for etching the surface layer of a polished metal.

Modern techniques such as x-ray diffraction, transmission electron microscopy (TEM) and scanning electron microscopy (SEM) ............................................................. (make) it possible to better understand their characteristics.

By now, more than 50,000 materials ............................................................. (develop).

Materials scientists ......................................................... (long envy) the *resilience* of certain naturally occurring materials.

Past efforts to reproduce the architecture of, e.g. a shell ................................................... (not be successful).

To copy the microstructure of the shell, the researchers ........................................................... (mix) water with finely ground ceramic powder and polymer *binders*.

**Glossary**

| | |
|---|---|
| resilience, *n*<br>resilient, *adj* | elasticity; property of a material to resume its original shape/position after being bent/stretched/compressed |
| binder | a polymeric material used as *matrix* in which particles are evenly distributed |
| matrix | a substance in which another substance is contained |

*n* = noun *adj* = adjective *v* = verb

## 1.3 Materials Science versus Materials Engineering

The discipline of materials science and engineering includes two main tasks.
Materials scientists examine the structure-properties relationships of materials and develop or *synthesize* new materials.

Materials engineers design the structure of a material to produce a *predetermined* set of properties on the basis of structure-property relationships. They create new products or systems using existing materials and/or develop techniques for processing materials.

Most graduates in materials programs are trained to be both materials scientists and materials engineers.
(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| to synthesize,<br>synthesis, *n* | to produce a substance by chemical or biological reactions |
| predetermined | decided beforehand |

***Task 1.*** *Read the text above. Then decide whether the statements are true or false. Rewrite the false statements if necessary.*

Materials scientists do research on finished materials.

.................................................................................................................................................................

New products are based on new materials only.

.................................................................................................................................................................

Materials science can be subdivided because different approaches to materials are employed.

.................................................................................................................................................................

Materials engineers investigate the correlation between structure and property.

.................................................................................................................................................................

## 1.4 Selection of Materials

Selecting the right material from the many thousands that are available poses a serious problem. The decision can be based on several criteria. The in-service conditions must be characterized, for these will dictate the properties required of the material. A material does not always have the maximum or ideal combination of properties. Thus, it may be necessary to trade off one characteristic for another.

The classic example includes *strength* and *ductility*. Normally, a material having a high strength will have only a limited ductility. A second selection consideration is any deterioration of material properties that may occur during service operation.

For example, significant reductions in mechanical strength may result from exposure to elevated temperatures or *corrosive* environments. If a compromise concerning desired in-service properties cannot be reached, new materials have to be developed.

Probably the most important consideration is that of economics. A material may be found that has the ideal set of properties but is extremely expensive. Some compromise is inevitable. The cost of a finished piece also includes any cost occurring during fabrication to produce the desired shape. For example: *commodity* plastics like polyethylene or polypropylene cost about $ 0.50/*lb*, whereas engineering *resins* or Nylon cost $ 1,000/lb.

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| strength | the power to resist stress or strain; the maximum load, i.e. the applied force, a *ductile* material can withstand without permanent deformation |
| ductility, *n*<br>ductile, *adj* | a material's ability to suffer measurable *plastic deformation* before fracture |
| plastic deformation | a non-reversible type of deformation, i.e. the material will not return to its original shape |
| corrosive, *n*, *adj*<br>to corrode, corrosion | a corroding substance, e.g. an acid |
| commodity | article of trade |
| lb | pound, 453.592 grams |
| resin | a natural substance, e.g. amber, or a synthetic *compound*, which begins in a highly *viscous* state and hardens when treated |
| compound | a pure, macroscopically homogeneous substance consisting of atoms/ions of two/more different elements that cannot be separated by physical means |
| viscous, *adj*<br>viscosity, *n* | having a relatively high resistance to flow |

***Task 1.*** *Explain the grammatical use of the term prohibitively in the sentence below.*

A material may be found that has the ideal set of properties but is prohibitively expensive.

..........................................................................................................................................................................

***Task 2.*** *Write short answers to the questions.*

What are necessary steps when considering a material for a certain application?

..........................................................................................................................................................................

..........................................................................................................................................................................

..........................................................................................................................................................................

..........................................................................................................................................................................

Which trade-offs are unavoidable when choosing a particular material?

..........................................................................................................................................................................

..........................................................................................................................................................................

..........................................................................................................................................................................

..........................................................................................................................................................................

## 1.5 Some Phrases for Academic Presentations

**Introduction** (after greeting the audience and introducing yourself or being introduced)
The subject/topic of my presentation today will be …
Today I would like to present recent result of our research on …
What I want to focus on today is …

**Outlining the structure of the presentation**
I will address the following three aspects of …
My presentation will be organized as can be seen from the following slide.
I will start with a study of … . Next, important discoveries in the field of … will be introduced.
Finally, recent findings of … will be discussed.

**Introducing a new point or section**
Having discussed …, I will now turn to …
Let's now address another aspect.

**Referring to visual aids**
As can be seen from the next slide/diagram/table …
This graph shows the dependency of … versus …
The following table gives typical values of …
In this graph we have plotted … with …

**Concluding/summarizing**

Wrapping up …

To summarize/sum up/conclude …

**Inviting questions**

Please don't hesitate to interrupt my talk when questions occur.

I'd like to thank you for your attention.

I'll be happy/pleased to answer questions now.

**Dealing with questions**

I cannot answer this question right now, but I'll check and get back to you.

Perhaps this question can be answered by again referring to/looking at table …

## 1.6 Case Study: The Turbofan Aero Engine

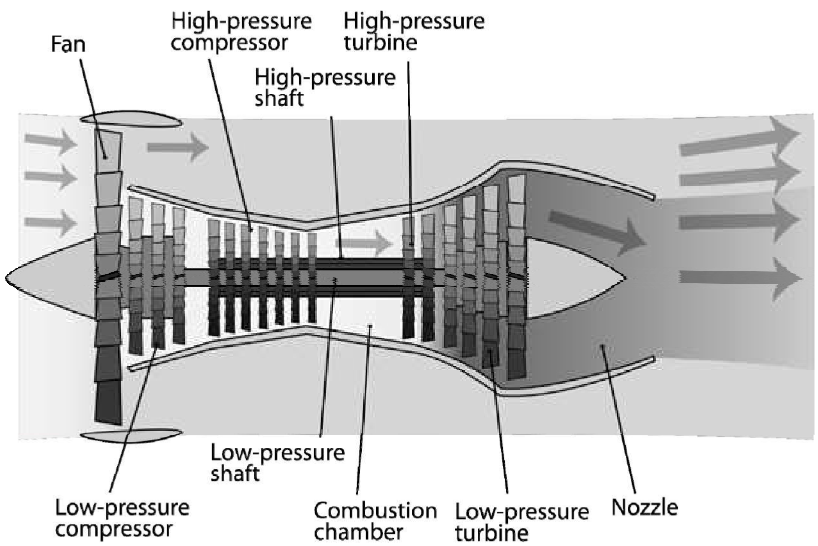


*Figure 2:* Cross-section of a turbofan aero engine [wikipedia]

***Task 1.*** *Work with a partner. Study the following notes. Then refer to* 1.5 Phrases for Academic Presentation *and give a short presentation about the subject.*

In the turbofan aero engine, which is used to power large planes, air is propelled past and into the engine by the turbofan, providing aerodynamic *thrust*. The air is further compressed by compressor blades, then mixed with fuel and burnt in the *combustion* chamber. The expanding gases drive the turbine blades, which provide power to the turbofan and the compressor blades, and finally pass out of the rear of the engine, adding to the thrust.

Two kinds of materials were considered:

**Metal, a titanium *alloy***

material's properties and in-service requirements:

*Young's Modulus*, *yield strength*, *fracture toughness* sufficiently good

high *density* (the heavier the engine, the less payload can be carried)

resistance to *fatigue* (due to rapidly varying loads)

resistance to surface wear (striking water drops, large birds)

resistance to corrosion (salt sprays from ocean entering the engine)

**Composite, carbon-fiber reinforced polymer (CFRP)**

material's properties and in-service requirements:

low density (half of that of titanium)

low weight

low toughness (potential deformation of blade by bird strike)

The problem posed by choosing CFRP for a blade can be overcome by cladding, which means giving the CFRP a metallic leading edge.

(from Ashby/Jones, modified and abridged)

**Glossary**

| | |
|---|---|
| thrust | a forward directed force |
| combustion | the process of burning; here of fuel |
| alloy | a metallic substance that is composed of two or more elements which keep the same crystal structure in the alloy |
| Young's Modulus | elastic modulus (E), a material's property that relates *strain* (ε, epsilon) to applied *stress* (σ, sigma) |
| strain | the response of a material when *tensile stress* is applied |
| tensile stress | a force tending to tear a material apart |
| stress, *n* | the force applied to a material per unit area; (σ, sigma = F/A or lb/*in*$^2$) |
| in | inch, 2.54 cm |
| yield strength | the point at which a material starts to deform permanently |
| fracture toughness | the measure of a material's resistance to fracture when a *crack* occurs |
| crack, *n*, *v* | a break, fissure on a surface |
| density | mass per volume |
| fatigue | the weakening/failure of a material resulting from prolonged stress |

## 1.7 Some Abbreviations for Academic Purposes

***Task 1.*** *Add your notes in the column on the right.*

| | | |
|---|---|---|
| AC | alternating current | |
| approx., ca. | approximate(ly) | |
| AT | air temperature | |
| at. no. | atomic number | |
| at. wt. | atomic weight | |
| avg. | average | |
| b.p. | boiling point | |
| c., cu., cub. | cubic | |
| cath. | cathode | |
| cc | cubic centimetre(s) | |
| cf. (conferre) | confer, compare | |
| C. of C. | coefficient of correlation | |
| co. | column | |
| cont(d). | continue(d), contain(ed) | |
| ctr. | center | |
| DC | direct current | |
| Dept. | department | |
| dup. | duplicate | |
| e.g. (exempli gratia) | for example | |
| esp. | especially | |
| est(d). | estimated | |
| etc. (et cetera) | and so on | |
| ex. | example | |
| f., ft. | foot, feet, frequency | |
| hor. | horizontal | |
| i.e. (id est) | that is | |
| in., ins. | inch(es) | |

| | | |
|---|---|---|
| incl. | including, included, inclusive | |
| kWh | kilowatt-hour(s) | |
| l., ll. | long, length, line, lines | |
| liq. | liquid | |
| max., min. | maximum, minimum | |
| mech. | mechanical | |
| misc. | miscellaneous | |
| mol wt. | molecular weight | |
| m.p. | melting point | |
| n.a. | not applicable | |
| NB, nb (nota bene) | note particularly | |
| No., no. | number | |
| ord. | ordinary, ordinal | |
| oz(s). | ounce(s) | |
| par. | parallel | |
| prev. | previous | |
| pt. | part | |
| qt. | quantity, quart | |
| resp. | respectively | |
| rpm | revolutions per minute | |
| stat. | statistics | |
| std. | standard | |
| syn. | synthetic | |
| tech. | technical(ly) | |
| vel. | velocity | |
| vs. | versus | |
| w/ | with | |
| w/o | without | |
| yd(s). | yard(s) | |

# Chapter 2 Characteristics of Materials

## 2.1 Structure

The structure of a material is usually determined by the arrangement of its internal components. On an atomic level, structure includes the organization of atoms relative to one another. Subatomic structure involves electrons within individual atoms and interactions with their nuclei. Some of the important properties of solid materials depend on geometrical atomic arrangements as well as on the interactions that exist among atoms or molecules.

Various types of primary and secondary interatomic bonds hold together the atoms composing a solid.

The next larger structural area is of nanoscopic scale which comprises molecules formed by the bonding of atoms, and particles or structures formed by atomic or molecular organisation, all within 1 *nm* – 100 nm dimensions. Beyond nano scale are structures called microscopic, meaning that they can directly be observed using some kind of microscope. Finally, structural elements that may be viewed with the naked eye are called macroscopic.

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| nm | nanometer ($10^{-9}$ m) |

***Task 1.*** *Work with a partner. Fill in the table with the different structural levels and their characteristics as described in the text.*

| structural level | characteristics |
|---|---|
| | |
| | |
| | |
| | |
| | |

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***Task 2.*** *Choose the correct terms for the following definitions.*

A sufficiently stable, electrically neutral group of at least two units in a definite arrangement held together by strong chemical bonds. ........................................................

The smallest particle characterizing an element ........................................................

A fundamental subatomic particle, carrying a negative electric charge. ........................................................

It makes up almost all the mass of an atom. ........................................................

A positively charged subatomic particle. ........................................................

An electrically neutral subatomic particle. ........................................................

## 2.2 Some Phrases for Academic Writing

**Introduction**

In this paper/project/article we will focus on …
In our study, we have investigated …
Our primary objective is …

**Making a generalization**

It is well known that …
It is generally accepted that …

**Making a precise statement**

In particular
Particularly/especially/mainly/ more specifically

**Quoting**

According to/referring to …
As has been reported in … by …
Referring to earlier work of …

**Introducing an example**

e.g. …
if … is considered for example

**Interpreting**

The data could be interpreted in the following way …

These data infer that …

This points to the fact that …

**Referring to data**

As is shown in the table/chart/data/diagram/graph/plot/figure

**Adding aspects**

Furthermore our data show …

In addition … has to be considered

**Expressing certainty**

It is clear/obvious/certain/noticeable that …

An unequivocal result is that …

**Expressing uncertainty**

It is not yet clear whether …

However it is still uncertain/open if …

**Emphasizing**

It has to be emphasized/stressed that …

**Summarizing**

Our investigation has shown that …

To summarize/sum up our results …

**Concluding**

We come to the conclusion that …

Our further work will focus on …

Further studies/research on … will still be needed.

Detailed insights into … are still missing.

## 2.3 Case Study: The Gecko

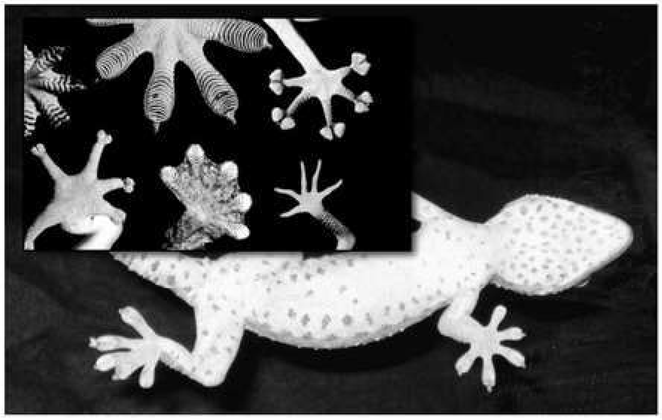

*Figure 3:* The underside of a gecko and its feet [adapted from Seshadri]

***Task 1.*** *Work with a partner. Fill the gaps in the text with words from the box in their correct form. Some terms are used more than once.*

| |
|---|
| adhesion; *adhesive;* design; horizontal; mass; microscopic; molecule; *release; residue;* self-cleaning; sticky; surface; underside; vertical |

The photograph shows the ........................................ of a gecko, a harmless tropical lizard, and its toes. Researchers worldwide are studying the animal's adhesive system. The scientists want to learn from nature how to ........................................ dry adhesives such as geckos apply when moving their feet over smooth surfaces. The animals achieve high adhesion and friction forces required for rapid ........................................ (running up walls) and inverted (running along the underside of ........................................ surfaces) motion, since their ........................................ feet will cling to virtually any surface. Yet they can easily and quickly release the sticky pads under their toes to make the next step. A gecko can support its body ........................................ with a single toe, because it has an extremely large number of ........................................ small ordered fiber bundles on each *toe pad*. When these fibrous structures come in contact with a surface, weak forces of attraction, i.e. van der Waals forces, are established between hair ........................................ and molecules on the surface. The fact that these fibers are so small and so numerous explains why the animal grips ........................................ so tightly. To ........................................ its grip, the gecko simply curls up its toes and peels the fibers away from the surface. Another fascinating feature of gecko toe pads is that they are ............................................. that is, dirt particles don't stick to them. Scientists are just beginning to understand the mechanism of ............................................. for these tiny fibers, which may lead to the development of ............................................. self-cleaning synthetics. Imagine *duct tape* that never looses its stickiness or bandages that never leave a sticky .............................................

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| adhesive *n*, *adj*, to adhere, adhesion, *n* | a substance used for joining surfaces together, sticky |
| release, *v*, *n* | to let go |
| residue | the remainder of sth after removing a part |
| toe pad | a cushion-like flesh on the underside of animals' toes and feet |
| duct tape | an adhesive tape for sealing heating and air-conditioning ducts |

## 2.4 Property

While in use, all materials are exposed to external stimuli that cause some kind of response. A property is a material characteristic that describes the kind and magnitude of response to a specific stimulus. For example, a specimen exposed to forces will experience deformation, or a metal surface that has been polished will reflect light. In general, definitions of property are made independent of material shape and size.

Virtually all important properties of solid materials may be grouped into six different categories:

- mechanical
- electrical
- thermal (including melting and *glass transition temperatures*)
- magnetic
- optical
- deteriorative

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| glass transition temperature $T_g$ | the temperature at which, upon cooling, a non-crystalline ceramic transforms from a supercooled liquid to a solid glass |
| supercooled | cooled to below a phase transition temperature without the occurrence of transformation |

**Mechanical Properties** relate deformation to an applied load or force; examples include *elastic modulus* and strength.

**Glossary**

| | |
|---|---|
| elastic modulus (E) | or Young's Modulus, a material's property that relates strain (ε, epsilon) to applied stress (σ, sigma), cf. p. 9 |

**Electrical Properties** are, e.g. electrical *conductivity*, *resistivity* and *dielectric constant*. The stimulus is voltage or an electric field.

**Glossary**

| | |
|---|---|
| conductivity | ability to transmit heat and/or electricity |
| resistivity | a material's ability to oppose the flow of an electric current |
| dielectric constant | a measure of a material's ability to resist the formation of an electric field within it |

**Thermal Properties** of solids can be described by heat capacity and thermal conductivity.

Poor thermal conductivity is responsible for the fact that space shuttle *tiles* containing amorphous, porous silica ($SiO_2$) can be held at the corners, even when glowing at 1000 °C.

**Glossary**

| | |
|---|---|
| tile | a flat, square piece of material |

***Task 1.*** *Work with a partner. Refer to the texts, then answer the questions.*

What is a material's property?

..............................................................................................................................................

Do mechanical properties deal with deformation?

..............................................................................................................................................

How can the thermal behavior of solids be characterized?

..............................................................................................................................................

**Magnetic Properties** demonstrate a material's response to the application of a magnetic field.

**Optical Properties** are a material's response to electromagnetic or visible light. The index of *refraction* and *reflectivity* are representative optical properties.

**Glossary**

| | |
|---|---|
| refraction | the bending of a light beam upon passing from one medium into another |
| reflectivity | the ability to reflect, i.e. to change the direction of a light beam at the interface between two media |

**Deteriorative Properties** relate to the chemical reactivity of materials. The chemical reactivity, e.g. corrosion, of a material such as an alloy, can be reduced by heat treating the alloy prior to exposure in salt water. Heat treatment changes the inner structure of the alloy. Thus crack propagation leading to mechanical failure can be delayed.

**Glossary**

| | |
|---|---|
| propagation | the process of spreading to a larger area |

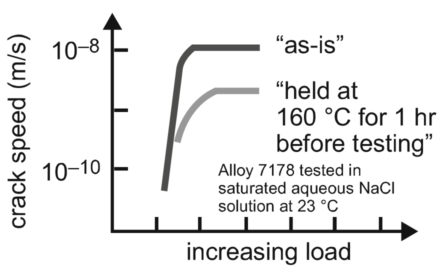


*Figure 4:*
Crack propagation and load [adapted from Seshadri]

***Task 2.*** *Refer to 2.5* Some Phrases for Describing Figures, Diagrams and Reading Formulas *and write a short paragraph for the plot in the figure above, describing what is shown.*

*The graph in the figure above shows*

.......................................................................................................................................................................

.......................................................................................................................................................................

.......................................................................................................................................................................

.......................................................................................................................................................................

.......................................................................................................................................................................

.......................................................................................................................................................................

.......................................................................................................................................................................

## 2.5 Some Phrases for Describing Figures, Diagrams and for Reading Formulas

**Graph/Diagram**

the graph/diagram/figure represents …

it shows a value for …

it shows the relationship between …

the curve shows a steep *slope*, a peak, a trough

the curve rises steeply/flattens out/drops/extrapolates to zero

**Plot**

to plot points on/along an axis

to plot/make a plot … versus … for …

$x$ is plotted as a function of $y$

**Coordinate System**

abscissa ($x$-axis) and ordinate ($y$-axis)

the coordinate system shows the frequency of … in relation to/per …

**Angle**

parallel; perpendicular; horizontal to

right angle (90°)

acute angle (smaller than 90°)

obtuse angle (larger than 90°)

straight angle (180°)

**Mathematics**

to apply a law

to equal, to be equal to

to calculate/compute

to determine/assume/substitute a value

to *derive* an equation

in a fraction, there are numerator and divisor (denominator)

**Glossary**

| | |
|---|---|
| slope | a line that moves away from horizontal |
| to derive | to deduce; to obtain (a function) by differentiation |

***Task 1.*** *Complete the table.*

| | |
|---|---|
| 10,000 | is read ten thousand |
| 0.28 | is read … |
| $^1/_4$ | |
| $^1/_{12}$ | one over twelve |
| $6\ ^3/_5$ | |
| $x^2$ | |
| $x^3$ | |
| $x^{-4}$ | |
| $\sqrt{4}$ | |
| $^3\sqrt{a}$ | |
| $1/x$ | |
| $a_n$ | |
| $^n a$ | |

**Glossary**

| | |
|---|---|
| slope | a line that moves away from horizontal |
| to derive | to deduce; to obtain (a function) by differentiation |

## 2.6 Grammar: Comparison

Comparing Two or more Things in English

Add **-er** and **–est** to adjectives with one syllable

strong – stronger – strongest

to adjectives with two syllables and ending with **-y**

oily – oilier – oiliest

Use **more** and **most** for adjectives with more than two syllables and not ending with -y

resistant – more resistant – most resistant.

for adverbs

Polyethylene is more frequently produced than poly(tetrafluoro ethylene).

***Task 1.*** *Fill the gaps in the table with the correct forms.*

Irregular Forms:

| | | | |
|---|---|---|---|
| good | ........................ | ........................ | |
| bad | ........................ | ........................ | |
| far | ........................ | ........................ | (when referring to distance) |
| far | ........................ | ........................ | (when referring to extent/degree) |
| little | ........................ | ........................ | (when referring to amount) |
| little | ........................ | ........................ | (when referring to size) |
| much/many | ........................ | ........................ | |

Use **as … as** when comparing items of the same characteristics.

Physics is as interesting as chemistry.

Use **not as (so) … as** when comparing items of dissimilar characteristics.

Polymers are not as brittle as ceramics.

Alternatively use -**er / more … than.**

Some alloys are easier to process than others.

## 2.7 Processing and Performance

In addition to structure and properties, materials differ in terms of processing and performance. Processing determines structure and structure affects property. Last, property influences performance.

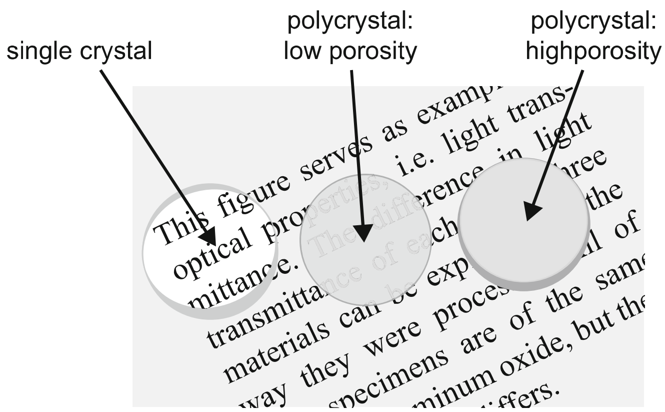


*Figure 5:* Crystallinity and light transmittance

This figure serves as example for optical properties, i.e. light transmittance. The difference in light transmittance of each of the three materials can be explained by the way they were processed. All of these specimens are of the same material, aluminum oxide, but their crystal structure differs.

***Task 1.*** *Work with a partner. Complete the short paragraph for the figure above, explaining the difference in optical properties.*

Figure 5 illustrates the relationship among processing, structure, properties and performance. The photograph shows three thin disk specimens of the same material, ............................................., placed over ............................................. The optical properties (i.e. the light transmittance) of each of the three materials are different. The one on the left ............................................., i.e. virtually all of the light reflected from the printed page passes through it. The disk ............................................. translucent, meaning that some of this ................................................................................. through the disk. The disk on the right is ......................................., i.e. none of the ....................................... passes through. Optical properties are a consequence of ............................................. of these materials which result from the way the materials were processed. The leftmost one is a ............................................. which causes its ............................................. The polycrystal in the center is composed of numerous small crystals that are all connected, the *boundaries* between these small crystals *scatter* a portion of the ......................................................................................................................................................, so this material is optically translucent. The specimen on the right is not only composed of many small interconnected crystals but also of many very small pores. These pores also effectively scatter the reflected light and make this material opaque.

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| boundary | the interface separating two neighboring regions having different crystallographic orientation |
| to scatter | to distribute in all directions |

## 2.8 Classification of Materials

Solid materials can be grouped into three basic classifications:

metals, ceramics and polymers.

This classification is based primarily on chemical makeup and atomic as well as molecular structure. Most materials fall into one distinct grouping, although there are some intermediates. More engineering components are made of metals and alloys than of any other class of solid. But increasingly, polymers are replacing metals, because they offer a combination of properties more attractive to designers.

New ceramics are developed worldwide, which will permit materials engineers to devise more efficient heat engines and lower friction *bearings*. Ceramics have been found that become superconducting (showing electrical conductivity with very limited resistance) at extremely low temperatures (about 100 K, approximately minus 170 °C). If this phenomenon is ever achieved at *ambient temperature*, it may increase the use of ceramics and revolutionize electronics.

The best properties of materials can be combined to make composites which often combine two or more materials from these three basic classes. In high-technology applications, a new classification called advanced or smart materials emerges. These materials are semiconductors, biocompatible materials, and nano-engineered materials.

Natural materials like wood or leather should also be mentioned, since they offer properties that, even with the innovations of today's materials scientists, are hard to beat.

(from Callister and Ashby/Jones, modified and abridged)

**Glossary**

| | |
|---|---|
| bearing | a device to reduce friction between a rotating staff and a part that is not moving |
| ambient temperature | the temperature of the air above the ground in a particular place; usually room temperature, around 20 – 25 °C |

***Task 1.*** *Read the text then decide whether the statements are true or false.*
*Rewrite the false statements if necessary.*

Polymers belong to a distinct material group.

.............................................................................................................................................................

Ceramics will increasingly be used for applications in electronics because of their hardness.

.............................................................................................................................................................

Man-made materials are superior to natural materials.

.............................................................................................................................................................

## 2.9 Grammar: Verbs, Adjectives, and Nouns followed by Prepositions

The texts above contain verbs, adjectives, and nouns that are followed by prepositions. Learning to use the correct preposition following a verb, adjective or noun can be challenging; particularly when the preposition differs from, e.g. German usage.

to depend **on** – *abhängen **von***.

Below are some examples taken from the texts you have worked with so far.

***Task 1.*** *Work with a partner. Add the correct prepositions to the terms. Give examples with collocations, i.e. two or more words often used together.*

**Verbs**

to expose to *materials that are exposed to external stimuli*

to rely

..........................................................................................................................................................

to trade

..........................................................................................................................................................

to relate

..........................................................................................................................................................

**Adjectives/ Participles**

transparent

..........................................................................................................................................................

based

..........................................................................................................................................................

composed

..........................................................................................................................................................

according

..........................................................................................................................................................

**Nouns**

in response

..........................................................................................................................................................

decrease

..........................................................................................................................................................

in reference to

..........................................................................................................................................................

# Chapter 3 Metals

## 3.1 Introduction

Metallic materials have large numbers of non-localized electrons; i.e. these electrons are not bound to particular atoms. Many properties of metals are directly attributable to these electrons, often referred to as electron gas, cloud or sea.

***Task 1.*** *Work with a partner. Study the following notes. Then refer to the* 2.2 Some Phrases for Academic Writing *and write an introductory text about metals, adding details you know.*

**Mechanical Properties**

relatively *dense,* stiff and strong, ductile, resistant to fracture
hard and solid at ambient temperature,
except for: sodium (soft), mercury (liquid at room temperature)

**Conductivity**

very good conductors of electricity and heat
e.g. copper, iron (conduct heat better than stainless steel)

**Optical Properties**

opaque, colored
*lustrous* appearance of metal surface when polished, but
dull appearance after oxidization of surface by contact and reaction with air

**Magnetic Property**

most metals non-magnetic (including many steels)
some metals magnetic, e.g. iron, cobalt, nickel

**Application**

widespread applications *(add examples of your own)*
e.g. in construction, plumbing, electrical and mechanical engineering

**Processing**

molding, casting, plastic deforming, cutting, joining, etc. *(add examples)*

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| dense,<br>density, *n* | referring to mass per volume |
| lustrous,<br>luster, *n* | shining brightly and gently |

I. Eisenbach, *English for Materials Science and Engineering,* DOI 10.1007/978-3-8348-9955-2_3,

***Task 2.*** *Work in a group. Add the chemical symbols of the metals and list what you know about them. Refer to the metal's properties and applications, as shown in the example.*

iron, Fe a lustrous, malleable, ductile, magnetic or magnetizable metallic element occurring in minerals; rusts easily; used to make steel and other alloys, important in construction and manufacturing

copper ..............................................................................................................

..............................................................................................................

nickel ..............................................................................................................

..............................................................................................................

mercury ..............................................................................................................

..............................................................................................................

sodium ..............................................................................................................

..............................................................................................................

zinc ..............................................................................................................

..............................................................................................................

aluminum ..............................................................................................................

..............................................................................................................

gold ..............................................................................................................

..............................................................................................................

lead ..............................................................................................................

..............................................................................................................

tin ..............................................................................................................

..............................................................................................................

## 3.2 Mechanical Properties of Metals

Bend Strength

Fracturing, e.g. a *rod* of brittle material, can be done by fixing it tightly at both ends and applying a force upwards at two central points. Fracture will appear almost *perpendicular to* the length of the rod. This is one way of measuring the bend strength of material.

Shear Strength

Breaking the rod by fixing it at one end and twisting the other end, applying shear load or stress ($\tau$, tau), will result in fracture that occurs at an oblique angle to the length of the rod.

Stress ($\sigma$, sigma) is the ratio of a force F to the area A on which the force acts:

$\sigma = F/A = lb/in^2$ (lb meaning 453.592 grams, in meaning inch).

Shear strength is important for rods of material that rotate like rotating *axles* in machinery which sometimes fail this way.

Tensile Strength

Most metals show macroscopically noticeable stretching. Brittle materials, like ceramics, show very little plastic, i.e. permanent deformation, before they fail.

Materials with high tensile strength, like plastic and rubber, will stretch to several times their original length before they break.

**Glossary**

| | |
|---|---|
| rod | a thin, straight piece/bar, e.g. of metal, often having a particular function |
| perpendicular to | forming an angle of 90° with another line/surface |
| axle | a supporting shaft on which wheels turn |

***Task 1.*** *Explain the testing of tensile strength in a few words with the help of Figure 6 below.*

……………………………………………………………………………………………………………

……………………………………………………………………………………………………………

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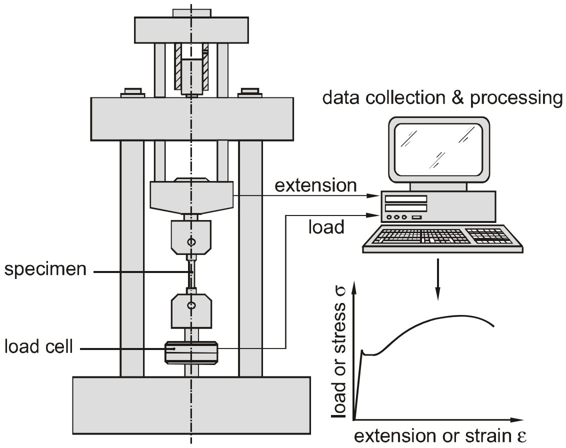


*Figure 6:*
Testing tensile strength [V. Läpple]

Yield Strength (YS)

Yield strength or yield stress is the beginning of plastic deformation. The load required to permanently stretch a rod by 0.2 % of its original length is called yield strength.

A 100 cm rod, for example, that has been loaded so that it has a permanent stretch of 0.2 % has been permanently lengthened to 100.2 cm, when the load is removed.

Compressive Strength

Compressive stress in comparison to tensile strength is negative stress. Failure occurs as yield for ductile metals, whereas brittle materials, e.g. cast iron, will *shatter.* Fracture occurs at an oblique angle to the length of the sample. It is unlikely that a clean break will result; rather, several pieces will occur from compressing the material.

Stiffness

If the same tensile stress is applied to two materials, the stiffer of the two will lengthen less. Stiffness is defined by Young's Modulus (YM) or elastic modulus, the ratio of applied stress to the strain it produces in the material. The smaller the strain, the greater the stiffness.

**Glossary**

| | |
|---|---|
| to shatter | to break suddenly into very small pieces |

***Task 2.*** *Complete the table.*

| | | |
|---|---|---|
| hard versus soft | equals | .......................... yield strength (resistance to plastic deformation) versus .......................... yield strength |
| ductile versus .......................... | equals | appreciable plastic deformation before fracture versus .......................... plastic deformation before fracture |
| stiff ........................ easily bent | equals | high ...................................................... versus low Young's Modulus |

## 3.3 Important Properties for Manufacturing

One of the most important aspects in manufacturing is to choose the right material for a particular application. The properties, cost and availability of the material have to be considered.

When referring to metals in manufacturing, five properties are of importance:

ductility
durability
elasticity
hardness and
*malleability*

***Task 1.*** *Choose one of the above properties as an appropriate title for the paragraphs. Add the proper names to the chemical symbols.*

……………………………………………………………

The metals are easy to form and stretch without breaking or fracturing and keep their new shape. Metals like Cu ……………, Sn ……………, Au …………… and Ag …………… all have this property and are often used to make, e.g. wire and tubing.

The same is true for soft low-carbon steels but high-carbon steels and cast iron soon fracture when stretched, as they are too brittle.

……………………………………………………………

The metals can be stretched to some point, but go back to their original shape as soon as the stress is removed. Among metals, some steel alloys show this property, e.g. a high-carbon steel called spring steel. Other hard steels, e.g. tool steel and cast iron, can be stretched very little or not at all.

……………………………………………………………

The metals can withstand friction. This characteristic makes them suitable for moving parts of machines and cutting edges of tools, e.g. steel alloys with a high C …………… content.

……………………………………………………………

These metals are easy to form without fracturing, and keep their new shape. Forming is done by, e.g. rolling or pressing, often with the application of heat. Au, Ag, Pb ……………, Cu and low-carbon steel alloys belong to this group and are made into containers, wheels and, of course, jewelry.

**Glossary**

| | |
|---|---|
| malleability | the property of sth that can be worked/hammered/shaped without breaking |

***Task 2.*** *Translate the following paragraph. You may need the terms in the box.*

| |
|---|
| alloy; be in short supply; chromium; coat; coating; corrode; corrosion; durable, durability; paint; be resistant to; tungsten |

**Korrosionsbeständigkeit**

Korrosionsbeständige Metalle korrodieren praktisch nicht, wenn sie Luft und Feuchtigkeit ausgesetzt sind. Cr und Pt verfügen über hohe Korrosionsbeständigkeit, sind aber teuer und knapp. Au, Ag und Al sind ebenfalls sehr korrosionsbeständig. As, Fe und Stahl korrodieren schneller und müssen deshalb mit einer Korrosionsschutzschicht versehen werden, z. B. durch einen Farbanstrich. Es gibt Stahllegierungen, die sehr korrosionsbeständig sind, z. B. Wolfram-Stahl, der aus W, Cr, C und Fe besteht.

............................................................................

..................................................................................................................................................................................................

..................................................................................................................................................................................................

..................................................................................................................................................................................................

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..................................................................................................................................................................................................

## 3.4 Metal Alloys

A metal alloy is a metallic substance composed of two or more elements, which keep the same crystal structure in the alloy. Metals are combined with metals and/or with non-metal elements, for example carbon. Metal with metal alloys are made by mixing the molten substances and then cooling them until they solidify.

Common alloys are brass (copper + zinc) and aluminum alloys (aluminum + copper, aluminum + magnesium), and steel. Plain carbon steel contains only iron and carbon, while alloyed steels, e.g. stainless steel, contain chromium as the main alloying element.

Alloy systems are classified either according to the base metal, i.e. the metal serving as base of the alloy, or according to some specific characteristic that a group of alloys share.

Depending on their composition, metal alloys are often grouped into two classes:

*ferrous* and non-ferrous alloys.

Ferrous Alloys

The principle constituent is iron as in, e.g. steel and cast iron. They are produced in larger quantities than any other metal type, being especially important as construction materials.

Iron and steel alloys can be produced using relatively economical techniques to be extracted, *refined*, alloyed and fabricated. Ferrous alloys have a wide range of physical and mechanical properties. However, they have relatively high density, which means they weigh a lot; their electrical conductivity is comparatively low and they are *susceptible* to corrosion in some common environments.

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| ferrous | of or containing iron |
| to refine | to make/become free from impurities |
| to be susceptible to<br>susceptibility, *n* | to be easily affected/influenced by |

Nonferrous Alloys

Since nonferrous alloys have distinct limitations, other alloy systems are used for many applications, e.g. copper, aluminum, magnesium, titanium alloys, super alloys, the noble metals, and other alloys, including those that have nickel, lead, tin, zirconium and zinc as base metals.

(from Callister, modified and abridged)

***Task 1.*** *Practice so-called chain questions. Ask a classmate a question about information provided by the texts above. The student who has answered the question asks another student a question, who answers and so on.*

Question: *What does the term metal alloy refer to?* Answer: *It refers to …*

How ……………………………………………………………………………………………?

……………………………………………………………………………………………

Which ……………………………………………………………………………………………?

……………………………………………………………………………………………

What ……………………………………………………………………………………………?

……………………………………………………………………………………………

Why ……………………………………………………………………………………………?

……………………………………………………………………………………………

## 3.5 Case Study: Euro Coins

*Figure 7:* Euro coins

In deciding which metal alloys to use for the euro coins, their physical properties were an important issue.

***Task 1.*** *Add captions to the following paragraphs.*

**Required Characteristics**

........................................................

Differences in size and color help to distinguish *denominations* of coins which requires alloys to keep their distinctive color without *tarnishing*.

........................................................

Coins should be difficult to *counterfeit*. Most vending machines use electrical conductivity to prevent false coins from being used. Thus, each coin has its own unique electronic signature, which depends on its alloy composition.

........................................................

The alloy must be easily coined to allow design reliefs to be stamped into the coin surfaces.

........................................................

Wear resistance against long-term use is necessary, to retain the reliefs.

………………………………………………

In common environments it is required to ensure minimal material losses over the lifetimes of the coins.

………………………………………………

Coins no longer fit for use should be recyclable.

………………………………………………

The alloys should prevent undesirable microorganisms from growing on the coins' surface.

**Selection of Alloys**

As the base metal for all euro coins, copper was selected. Several different copper alloys and alloy combinations were selected for the different coins.

The 2 Euro Coin

A bimetallic coin, consisting of the silver-colored outer ring, a 75Cu-25Ni alloy, and the inner disk which is composed of a gold-colored, three-layer structure of high-purity nickel that is *clad* on both sides with a nickel brass alloy (75Cu-20Zn-5Ni).

The 1 Euro Coin

Also bimetallic; the alloys used for its outer ring and inner disk are reversed from those of the 2 euro coin.

The 50, 20 and10 Euro Cent Pieces

These coins are made of so-called Nordic Gold alloy (89Cu-5Al-5Zn-1Sn).

The 5, 2, and 1 Euro Cent Pieces

These coins are made of copper-plated steel.

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| denomination | a unit of value, esp. for money |
| to tarnish<br>tarnish, *n* | to discolor a metal surface by oxidation, to become discolored |
| to counterfeit | to make a copy of sth, with criminal intent, to fake |
| to clad | to cover a material with a metal |

## 3.6 Grammar: Adverbs I

Adverbs are frequently used in scientific writing, since they describe activities and characterristics. The way adverbs are formed and used in English differs considerably from other languages.

***Task 1.*** *Complete the survey on adverbs and add examples.*

**Formation of Adverbs**

Add ............ to an adjective.

slow – ........................................................................

Change adjectives ending in **-le** to ............

possible – ....................................................................

Change adjectives ending in **-y** to ............

sticky – .......................................................................

Change adjectives ending in **-ic** to ............

magnetic – ..................................................................

**Irregular Forms**

good – ........................................................................

hard – .........................................................................

(The form **hardly** exists, but it means .......................................................................)

fast – ..........................................................................

friendly – ....................................................................

**Use of Adverbs**

***Task 2.*** *Work in a group. Look through the texts about metals starting with* 3.1. *Make a list of the phrases that contain adverbs in combination with adjectives.*
*Describe the use of adverbs in these phrases.*

..........................................................................................................................................................

..........................................................................................................................................................

..........................................................................................................................................................

..........................................................................................................................................................

..........................................................................................................................................................

## 3.7 Case Study: The Titanic

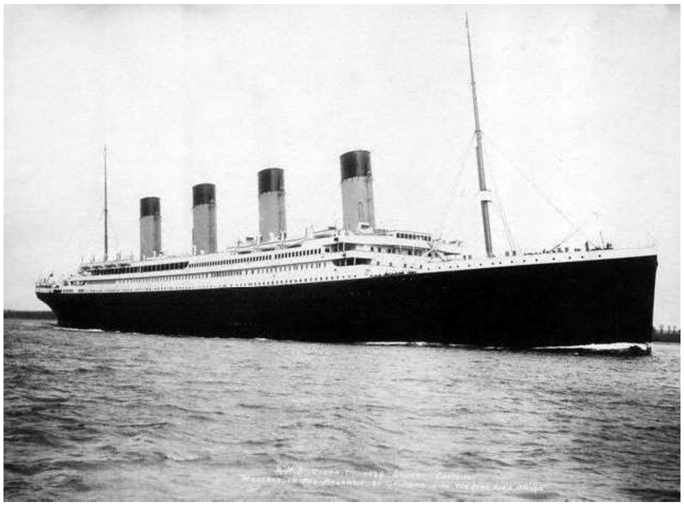

*Figure 8:* The Titanic [wikipedia]

As is well known, the Titanic sank on her first trip across the Atlantic Ocean in 1912 after hitting an iceberg. 1,513 of the 2,224 people on board died, mainly because there were only 1,178 places in the ship's lifeboats. At the time of the collision, the Titanic was traveling at the relatively high speed of 22 knots, which equals 41 km/h, a dangerous speed at this time of the year, as icebergs are common in the North Atlantic in early spring. The *hull* of the Titanic was double-bottomed and divided into 16 compartments. As the ship would not sink even if four of these compartments filled with water, she was thought to be unsinkable.

After divers had found the wreck of the Titanic at a depth of about 13,000 ft (3,950 m) in 1985, a 1996 expedition used *sonar* imaging to discover a series of six narrow cuts in the hull. The damage totaled only 12 square ft, about the size of a human body, but the cuts were located 20 ft below the waterline, where water pressure forced the sea water through them at a rate of almost 7 *t/s*.

Researchers began questioning if poorly manufactured materials played a role in the ship's sinking. A major factor contributing to the disaster was the brittleness of the steel used.

***Task 1.*** *Add the chemical symbols.*

Steel produced at the time the Titanic was built generally had a higher percentage of S (......................) and P (......................) than would be allowed today, resulting in steel that fractured easily. Samples of Titanic fragments were tested to determine the steel's chemical make-up, tensile strength, microstructure and grain size, as well as its responses to low temperatures. As the metallurgists had suspected, the steel was full of large MnS (......................) impurities that created weak areas and caused the metal to be brittle.

Under extreme conditions, such as the unusually cold, 28 F water temperatures of the North Atlantic at the time of the disaster, the steel became fragile and, subjected to the violent impact, immediately fractured.

**Glossary**

| | |
|---|---|
| hull | the body of a ship |
| sonar | a system using transmitted and reflected underwater sound waves to detect/locate/examine submerged objects |
| t/s | tons per second |

***Task 2.*** *Read the text above, then decide whether the statements are true or false. Rewrite the false statements if necessary.*

Most passengers drowned because the ship sank fast.

.......................................................................................................................................................

*Median* speed for a cruise ship was 22 knots.

.......................................................................................................................................................

Divers found one deep cut in her hull.

.......................................................................................................................................................

Impurities in the steel were responsible for the poor performance of the Titanic's steel.

.......................................................................................................................................................

**Glossary**

| | |
|---|---|
| median | relating to or constituting the middle value in a distribution, e.g. the median value of 17, 20 and 36 is 20 |

## 3.8 Grammar: The Passive Voice

The passive voice appears in scientific texts rather frequently. This is appropriate for an impersonal use of the language, where the acting person is of no importance and therefore does not have to be mentioned. The passive is also used to describe a process.

**Formation of the Passive**

The passive form of the verb consists of two parts:

the form of **be** in the appropriate form and tense

plus the past participle of the verb, i.e. the so-called third form, as in write –wrote – **written.**

***Task 1.*** *Fill in the missing verb forms*

**Tenses of the Passive**

Simple Present: simple present of be + past participle (p.p.) of the verb

The article **is published** in *Nature*.

Present Progressive: simple present of be + being + p.p. of the verb

The paper ........................................................................ (print) right now, it can't be changed.

Simple Past: simple past of be + p.p. of the verb

The book ........................................................................ (edit) last month.

Present Perfect: present perfect of be + p.p. of the verb

The article ........................................................................ (publish) recently.

Past Perfect: past perfect of be + p.p. of the verb

The draft ........................................................................ (finish) before the lecture.

Future Tenses: future I or II of be + p.p. of the verb

The hand-outs ........................................................................ (copy) as soon as possible.

The thesis ........................................................................ (hand in) by now.

Conditional: conditional I or II of be + p.p. of the verb

If universities received more money, more research ........................................................................ (do)

The report ........................................................................ (write) by now, if the student had not gone skiing and broken his wrist.

## 3.9 Case Study: The Steel-Making Process

*Figure 9:* Steel-making machinery [wikipedia]

***Task 1.*** *Work with a partner. Refer to* 3.8 Grammar: The Passive Voice. *Put in the verbs in brackets in the correct form.*

There is no single substance ............................................ steel: there are dozens of different types of steel – of different compositions and with different properties. (call) "Ordinary" steel can ............................................ as an alloy of iron containing a small but fixed amount (up to 1.5 %) of carbon. (describe) The many special steels which are available have several other metals ............................................ in as well. (mix) The properties of steel depend not only on its composition but also on any heat treatment ............................................ to it after manufacture. (give) *Pig iron*, with its high proportion of impurities, is too brittle for most purposes, and the bulk of what ............................................ in *blast furnaces* ............................................ into steel. (convert; produce)

The steelmaking process requires that, after most of the carbon and practically all of the other impurities (Si, S, P) ............................................ by oxidizing, the right amount of each of the required elements ............................................ (add; remove)

Of the main steelmaking processes ............................................ today, the one by which most steel is manufactured is the basic oxygen process. (use) This method is fast and over 300 t of steel can .................................... in as little as 40 min. (produce) A converter, which is a huge steel, *pear*-.................................... container, called vessel, of up to 300 t capacity, is mounted so that it can .................................... either way for charging and tapping. (move; shape)

It is charged with .................................... pig iron from the blast furnace, along with up to about half of its mass of *scrap* iron or steel. (melt) A water-.................................... tube, called lance, can .................................... vertically into the vessel, delivering a high powered jet of pure oxygen, thus burning the carbon .................................... in the iron. (cool; dissolve; lower) The impurities .................................... rapidly, (C to $CO_2$ and S to $SO_2$) and escape as gases. (oxidize)

**Glossary**

| | |
|---|---|
| pig iron | crude iron |
| blast furnace | the oven in which ore is melted to gain metal |
| ore | a mineral from which a metal can be extracted |
| pear-shaped | having a round shape becoming gradually narrower at the end |
| to tap | to remove by using a device for controlling the flow of a liquid |
| scrap iron | metal objects that have been used |

# Chapter 4 Ceramics

## 4.1 Introduction

The term ceramic comes from the Greek word *keramikos,* which means burnt substance. The desirable properties of these materials are normally achieved through a high-temperature heat treatment called firing. Up until the past sixty years, the most important materials in this class were called traditional ceramics, for which the raw material is *clay*, e.g. *china*, *bricks*, tiles and in addition, glasses and high-temperature ceramics. Recently, significant progress has been made in understanding the fundamental character of these materials and of the *phenomena* that occur in them that are responsible for their unique properties. Consequently, a new generation of these materials has evolved, and the term ceramic has taken on a much broader meaning. These new materials are applied in, e.g. electronics, computers, communication technology, biomedical implants and aerospace.

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| clay | a kind of earth that is soft when wet and hard when dry |
| china | high-quality porcelain, originally made in China |
| brick | a rectangular block of baked clay used for building |
| phenomenon, phenomena, *pl* | a fact/event that can be identified by the senses |

***Task 1.*** *Work with a partner. Translate the following sentences into German. Cover the German version and translate them into English. Compare the two English versions*

| English | German | English |
|---|---|---|
| The Greek word *keramikos* shows that the desirable properties of these materials are normally achieved through a high-temperature heat treatment called firing. | | |
| Traditional ceramics are those for which the primary raw material is clay. | | |

I. Eisenbach, *English for Materials Science and Engineering,* DOI 10.1007/978-3-8348-9955-2_4,

## 4.2 Structure of Ceramics

Ceramics are compounds between metallic and non-metallic elements. They are most frequently oxides, nitrides and carbides. A composite material of ceramic and metal is cermet. The most common cermets are cemented carbides, which are composed of an extremely hard ceramic, bonded together by a ductile metal such as cobalt or nickel. In addition, there are the traditional ceramics mentioned before, those composed of clay minerals, as well as cement and glass. As ceramics are composed of at least two and often more elements, their crystal structures are generally more complex than those of metals.

(from Callister, modified and abridged)

***Task 1.*** *Read the text above and decide whether the statements are true or false.*
*Rewrite the statements if necessary.*

Ceramics are non-metallic, inorganic materials.

.................................................................................................................................................

Ceramics can be compounds of at least three elements.

.................................................................................................................................................

.................................................................................................................................................

## 4.3 Word Formation: Suffixes in Verbs, Nouns and Adjectives

The texts you have worked with so far contain nouns, adjectives and verbs with suffixes worth remembering. Most of them are of Latin origin and are typically used in scientific texts. Germanic suffixes, e.g. -en and -ship, appear as well.

***Task 1.*** *Work in a group. Add examples with collocations, i.e. two or more words often used together. Scan previous or following texts to find collocations.*

| suffix | example with collocation |
|---|---|
| -(a)tion | *plastic deformation* |
| -able/<br>-ible | |
| -al | |
| -ance<br>-ence | |
| -ant<br>-ent | |
| -ary | |

| | |
|---|---|
| -ate | |
| -en | |
| -ic/-ical | |
| -ify | |
| -ion<br>-ition | |
| -ist | |
| -ity | |
| -ive | |
| -ize<br>-ization | |
| -ment | |
| -ness | |
| -ous | |
| -ship | |

***Task 2.*** *Fill in the table, adding the appropriate preposition if necessary.*

| noun | adjective | verb |
|---|---|---|
| *arrangement* | n.a (not applicable) | to arrange |
| atom | | |
| | | to apply for |
| | | to bond |
| | n.a. | to configure |
| dependence | | |
| example | | |
| geometry | | n.a. |
| | | to interact with |
| | | to notice |
| | soft | |

| noun | adjective | verb |
|---|---|---|
| | solid | |
| structure | | |
| | | to vary |

## 4.4 Properties of Ceramics

***Task 1***. *Work with a partner. Fill the gaps in the text with words from the box in their correct form.*

| characteristic; conductivity; deformation; ductility; fracture; load; magnetic; strength |
|---|

With regard to mechanical behavior, ceramic materials are relatively stiff and strong. Their stiffness and ............................................. are comparable to those of the metals. In addition, ceramics are typically very hard. On the other hand, they are extremely brittle, i.e. lack ............................................., and are highly susceptible to fracture, which limits their applicability in comparison to metals. The principal drawback of ceramics is a *disposition* to catastrophic ............................................. in a brittle manner with very little energy absorption. At room temperature, both crystalline and non-crystalline ceramics tend to fracture before plastic ............................................. can occur in response to an applied tensile .............................................

Ceramics typically insulate against the passage of heat and electricity, i.e. they have low electrical ............................................., and they are more resistant to high temperatures and harsh environments than metals and polymers. With regard to optical ............................................., ceramics may be transparent, translucent or opaque, and some of the oxide ceramics, e.g. $Fe_3O_4$, exhibit ............................................. behavior.

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| disposition | a physical property/tendency |

***Task 2.*** *Define the following terms:*

transparent ..........................................................................................................................................

translucent ..........................................................................................................................................

opaque ..........................................................................................................................................

***Task 3.*** *Work with a partner. Match the German terms in the box with the corresponding English terms, and add statements about the properties of ceramics.*

| Anwendbarkeit; Anfälligkeit; Isolation |
|---|

Anwendbarkeit:

..........................................................................................................................................

Anfälligkeit:

..........................................................................................................................................

Isolation:

..........................................................................................................................................

## 4.5 Case Study: Optical Fibers versus Copper Cables

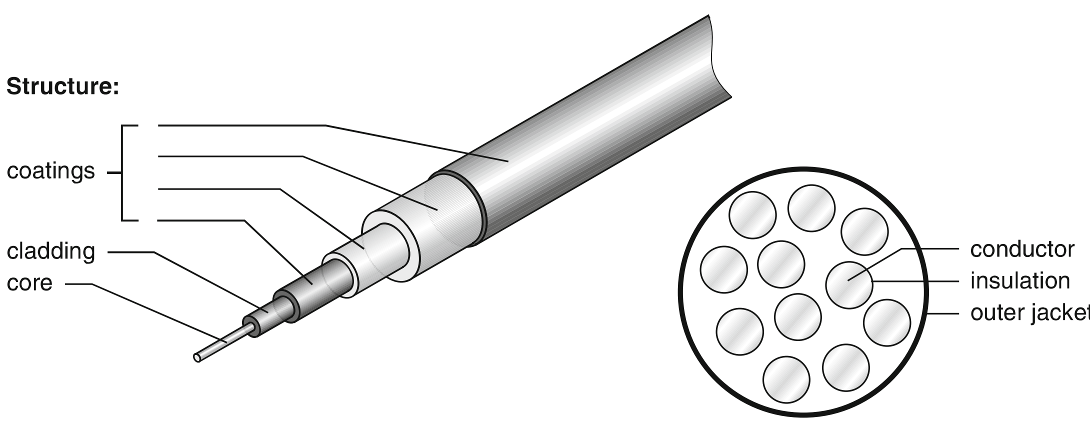


*Figure 10:* Optical fiber

Optical fibers, used in modern optical communication systems are an example for the application of an advanced ceramic material. They are made of extremely high-purity silica, which must be free of even extremely small levels of impurities and other defects that would absorb, scatter or weaken a light beam. Sophisticated processing has been developed to produce fibers that meet the rigorous restrictions required for this application, but such processing is costly.

Optical fibers started to replace some uses of copper cables in the 1970s, e.g. in telecommunications and cable TV. In these applications they are the preferred material, because the fibers carry signals more efficiently than copper cable and with a much higher bandwidth, which means that they can carry more channels of information over longer distances. For optical fibers, the longer transmission distances require fewer expensive repeaters. Also, copper cable uses more electrical power to transport the signals. In addition, optical fiber cables are much lighter and thinner (about 120 micrometers in diameter) than copper cables with the same bandwidth so that they take up less space in underground cabling *ducts*. It is difficult to steal information from optical fibers and they resist electromagnetic interference, e.g. from radio signals or lightning. Optical fibers don't *ignite* so they can be used safely in *flammable* atmospheres, e.g. in petrochemical plants.

Due to their required properties, optical fibers are more expensive per meter than copper. In addition, they can't be *spliced* as easily as copper cable, thus special training is required to handle the expensive splicing and measurement equipment.

(from Callister, modified and amplified)

### Glossary

| | |
|---|---|
| duct | a pipe for electrical cables and wires |
| to ignite,<br>ignition, n | to begin to burn, to cause to burn |
| flammable | easily ignited, capable of burning, inflammable |
| to splice, e.g. cables | to join two pieces at the end |

***Task 1.*** *Work with a partner. Refer to* 2.6 Grammar: Comparison. *Compare glass fibers to copper cables, listing the pros and cons of each material.*

……………………………………………………………………………………………………………

……………………………………………………………………………………………………………

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## 4.6 Grammar: Adverbs II

In 3.6 Grammar: Adverbs I, the use of adverbs that modify the following adjective is introduced. Examples of such modifying adverbs appear in the texts about ceramics as well.

In addition, these texts contain examples of another use of adverbs, namely adverbs modifying a sentence.

***Task 1***. *Work in a group. Search the texts on ceramics to find examples of sentences with adverbs. Make a list of the phrases and name the modified element.*

*Recently, significant progress has been made in understanding the fundamental character of these materials. (recently modifies the sentence).*

## 4.7 Case Study: Pyrocerams

*Figure 11:* Ceramic cook ware

***Task 1.*** *Add captions to the following paragraphs.*

Pyrocerams or glass ceramics are widely used for ovenware, manufactured by, e.g. Corning-Ware or the German manufacturer Schott. The covalently bonded silicon carbide, silicon nitride and silicon aluminum oxynitrides, or sialons (alloys of $Si_3N_4$ and $Al_2O_3$), are the best materials for high-temperature structural use.

..............................................................................

The *creep* resistance of the materials is outstanding up to 1300 °C, and their low thermal expansion and high conductivity make them resist thermal shock well in spite of their typically low toughness, the thermal shock resistance being better than that of most other ceramics. Pyrocerams exhibit excellent resistance to corrosion, which accounts for their use in the chemical industry.

..............................................................................

These materials are manufactured by the high-temperature reaction of silicon nitride with aluminum oxide. They can be formed by hot pressing fine powders and sintering them in the process, or *slip casting* followed by pressureless sintering, which provides greater shape and manufacturing flexibility. If the constituents are varied, the properties of the final ceramic vary too. However, continuous exposure to high temperatures can result in the material's degrading back to these constituent parts.

..............................................................................

Typical uses include burner and immersion heater tubes, injectors for nonferrous metals and protection tubes for nonferrous metal melting and welding fixtures.

(from Ashby/Jones, modified and amplified)

**Glossary**

| | |
|---|---|
| creep, *n* | time-dependent permanent deformation of materials at high temperatures or stress |
| slip casting | the process of pouring liquefied material into a mold; after the liquid is drawn out, the solid is removed from the mold |

***Task 2.*** *Work with a partner. Reconstruct statements about high-temperature ceramics from the jumbled words without referring to the text. The first word is given.*

better ceramics is most of other resistance shock than that

Thermal ..............................................................................................................................................

..............................................................................................................................................

corrosion excellent exhibit resistance to too

Pyrocerams ................................................................................................................................................

................................................................................................................................................

and be by can fine formed hot powders pressing sintering them

They ................................................................................................................................................

................................................................................................................................................

are ceramics constituents final of properties the too varied vary

If ................................................................................................................................................

................................................................................................................................................

are best for high materials structural temperature the use

Sialons ................................................................................................................................................

................................................................................................................................................

ceramics for high include melting metal nonferrous of temperature tubes uses

Typical ................................................................................................................................................

................................................................................................................................................

## 4.8 Case Study: Spheres Transporting Vaccines

In order to find a way of delivering waterproof, time-release payloads of vaccines to the body, researchers at Cambridge Biostability Laboratory (CBL) in the UK studied the way body cells called osteoclasts remove *stray* bone fragments by attacking and dissolving them. Using calcium phosphate, the main mineral constituent of bone, the researchers developed *spheres* that can be slowly dissolved by osteoclasts, thus releasing the enclosed vaccine.

To build the spheres, a mixture of vaccine and calcium phosphate crystals in an *aqueous* solution is sprayed out of a *nozzle* into a stream of gas at around 170°C. The crystals are surrounded by a cloud of water molecules, which evaporate in the gas. As the water molecules evaporate, the crystals partially join together to form solid glassy spheres, five micrometer in diameter, with the vaccine embedded inside. The heat of the gas is absorbed by evaporative cooling before it can destroy the vaccine. The spheres prevent the vaccines from deteriorating or breaking down if not kept dry before release. They can be injected as a follow-up booster dose at the same time as the initial dose, releasing their contents over a period of months.

(from Biever, modified and abridged)

**Glossary**

| | |
|---|---|
| to stray | to move away from the place where sth/sb should be |
| sphere | a solid figure that is completely round |
| aqueous | watery |
| nozzle | a device with an opening for directing the flow of a liquid |

***Task 1.*** *Read the text above then answer the following questions.*

Why do researchers study the way the body removes bone fragments?

.................................................................................................................................................................

.................................................................................................................................................................

How are the embedded vaccines released from the spheres?

.................................................................................................................................................................

.................................................................................................................................................................

Why is the evaporation of the water molecules essential?

.................................................................................................................................................................

.................................................................................................................................................................

## 4.9 Useful Expressions for Shapes and Solids

***Task 1.*** *The table contains English terms for shapes. Add the corresponding adjectives and either draw the shape next to the term or write a short sentence that clarifies its meaning.*

| |
|---|
| circle |
| cone |
| cube |
| cylinder |
| disc, *n.a.* |

| |
|---|
| ellipse |
| hemisphere |
| hexagon |
| pentagon |
| prism |
| rectangle |
| rhombus |
| semicircle, *n.a.* |
| sphere |
| square, *n*, *adj* |
| star-shape |
| trapezium |
| triangle |

# Chapter 5 Polymers

## 5.1 Introduction

***Task 1.*** *Work with a partner. Fill the gaps in the text with words from the box in their correct form.*

| |
|---|
| animal; application; cotton; industry; leather; molecule; plant; produce; property; rubber; silk; synthetic; wool |

Naturally Occurring and Synthesized Polymers

Naturally occurring polymers, those derived from plants and animals, have been used for many centuries, for example wood,

..............................................................................................................................................................................................................................

Other natural polymers such as proteins, enzymes, *starches* and cellulose are important in biological and physiological processes in ............................................... and ..............................................

With modern research tools it is possible to determine the molecular structures of these groups of materials and to develop numerous polymers that are *synthesized* from small organic ............................................... referred to as *monomers*. ............................................... polymers and, to a limited extent, biopolymers form the basis for plastics, rubbers, *thermosets*, fibers and adhesive and coating materials. Most monomers for such polymers are the products of the petrochemical ............................................... For such applications, as well as for the structural function of some biopolymers in nature, adequate mechanical ............................................... such as stiffness and strength are required. The synthetics can be ............................................... inexpensively, and their properties may be controlled so that many are superior to their natural *counterparts*. In some ..............................................., metal and wood parts have been replaced by plastics, which have satisfactory properties and may be produced at lower costs.

(from Callister, modified and abridged)

### Glossary

| | |
|---|---|
| starch | a white, tasteless powder found in plants, e.g. rice, potatoes |
| to synthesize, synthesis, *n* | to prepare a substance by chemical reaction |

I. Eisenbach, *English for Materials Science and Engineering,* DOI 10.1007/978-3-8348-9955-2_5,

| | |
|---|---|
| monomer | a molecule that can combine with others of the same kind to form a polymer |
| thermoset | a polymeric material that, once having cured or hardened by chemical reaction, will not soften or melt when heated |
| counterpart | here sth that has a similar function |

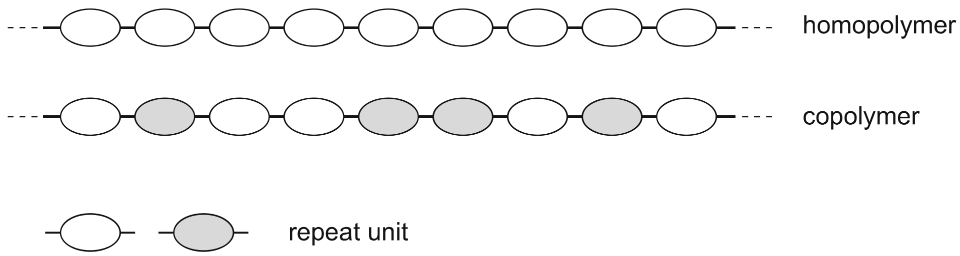


*Figure 12:* Structure of a homopolymer and a copolymer

Polymer can be defined as a substance whose molecules consist of many parts

(Greek *poly* + *meros*). The term refers to molecules with many units joined to each other through covalent bonds, often repeating the units. That is why the units are called mers or repeat units. When the units are all of the same kind and joined together linearly, it is a homopolymer, whereas a copolymer has more than one type of repeat unit. Polymers can contain up to several hundreds or thousands of repeat units. Because of the resulting long chain, high molecular weight and large size, these polymers are called macromolecules. Polymers can be named on the basis of the monomer(s) from which they are derived by adding the prefix poly- to the monomer. Alternatively, a polymer can be named on the basis of its repeat unit structure. Complex biopolymers, e.g. cellulose, or synthetic polymers are often referred to by their trivial name, e.g. Nylon 6,6, the structure-based name of which is poly(hexamethylene adipamide).

***Task 2.*** *Work with a partner. Draw a diagram of the chain structure of polyethylene with its repeat units.*

## 5.2 Word Formation: The Suffix -able/-ible

Adjectives ending in **-able/-ible** are often used in scientific texts, as they can replace longer verbal phrases:

The specimen exhibits elongation **that can be appreciated**.

The specimen exhibits appreci**able** elongation.

The suffix –able is derived from ‘to be able to do sth’ and can mean that something can be done. The form -able also occurs in the form -ible as in non-reversible, meaning ‘cannot be reversed’. As the two forms are pronounced in almost the same way, they are often confused in spelling.

***Task 1.*** *Work in a group. Form adjectives with the suffix -able/-ible that belong to the same word family as the verbs in the box. Add a suitable noun to form a collocation.*

| access; appreciate; attribute; compare; desire; flex; notice; perceive; rely; reproduce; suit |
|---|

| -able | -ible |
|---|---|
| | access: make science *accessible to* all students |
| | |
| | |
| | |
| | |
| | |
| | |

## 5.3 Properties of Polymers

***Task 1.*** *Add the names of the polymers.*

Some of the common and familiar polymers are PE (……………………………………), Nylon, PVC (……………………………………), PC (……………………………………), PS (……………………………………) and silicone rubber. Polymers typically have low densities. Except for so-called high-performance polymers they are not as stiff or as strong as ceramics or metals. However, considering the polymers' low densities in comparison to metals and ceramics, their stiffness and strength on a per mass basis are equal or even superior to metals and ceramics. Many polymers are extremely ductile and pliable, thus they are easily formed into complex shapes. In general, they are relatively inert chemically (do not react with other substances) and are unreactive in a large number of environments. One major drawback to polymers is their comparatively poor heat stability. The tendency to soften and/or *decompose* at modest temperatures in some instances limits their use. Furthermore, they have low electrical conductivities and are nonmagnetic, features which may prove to be of advantage.

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| to decompose | to change chemically, to decay |

***Task 2.*** *Make a list of the properties of polymers as mentioned in the text. Then name a property and ask a student in the class to give an explanation and/or additional information.*

Student 1 states: "Polymers show poor heat stability."

Student 2 adds: "This means they tend to …"

## 5.4 Case Study: Common Objects Made of Polymers


*Figure 13:*
Objects made of polymers

***Task 1.*** *Work with a partner. Describe the required material properties of four common objects: billiard balls, bike helmets, plastic spoons, water bottles.*

| | |
|---|---|
| | |
| | |
| | |
| | |

## 5.5 Case Study: Ubiquitous Plastics

**Plastics today**

Uta Scholten, of the German Plastics Museum Association in Düsseldorf says: "Most people today don't know there was a time before plastics." This was a time when a soccer ball still was made of leather, not foamed PU, and a surfboard was made of wood not PE.

Today, yogurt tubes are made of PS, CDs of PC, shoes of PU, waste baskets of PP, computer keyboards of ABS (a copolymer of acrylonitrile, butadiene and styrene), and soda bottles of PET poly(ethylene terephthalate). These materials, called plastics in English, were given the name Kunststoffe by the German chemist Dr. Ernst Richard Escales in 1910, later also referred to as Plastik in a critical way. But over the last few years they have shaken off their image as cheap or inferior substitutes. "These days, plastics have a high-quality image," says Dirk Ziems, manager of a market research institute in Köln, Germany. "The elegant appearance of the iPod cannot be topped, and the functionality of modern athletic clothing will not be surpassed soon."

**Plastics in architecture, fashion and design**

The Swiss architects Jacques Herzog and Pierre de Meuron gave the Allianz Arena in Munich an inflatable covering made of EFTE (ethylene – tetrafluoroethylene copolymer) plastic that can be illuminated in white, blue and red, the colors of Munich's two professional soccer teams.

The Allianz Arena consists of 66,500 square meters of EFTE film, 0.2 mm thick, cut into rhombus-shaped cushions. Fans inflate the cushions, which have an estimated service life of 25 years. Karsten Moritz from Rosenheim who engineered the arena's plastic façade is convinced that film skins give architects new opportunities, especially when combined with sophisticated technologies, such as liquid crystal layers that can be laminated with film, or the special effects created when light hits the edges of the film.

Fashion is another field with its sight set on plastics. Fashion guru Karl Lagerfeld surprised an interviewer by naming not *velvet* or silk as his favorite material, but plastics.

According to the local newspaper of San Francisco, the Chronicle, "Plastic furniture has become the focal point in some of the most elegantly designed rooms." The Prada Store in Beverly Hills, designed by Rem Kohlhaas, has wall coverings made of spongy, translucent PU mats. Spaces for items on display are simply cut out as needed. "No other material can be so lightweight and luminescent," says the designer.

**Plastics in aircraft engineering**

Jets have to be safe and airlines need planes that can fly economically. Consequently, the percentage of plastics integrated in jet planes is rising steadily. The development of the giant Airbus 380 has taken the use of plastics to a new level. For the first time in civil aviation, fiber composites were used to build wing boxes, which are the heart of any jet. Compared to a conventional aluminum structure, fiber composites help to reduce the total weight by 1.5 tons, which reduces fuel consumption while increasing payload and range. In comparison with the new jumbo jet, the proportion of plastics in an older Boeing is less than 5 % of the total weight. The A380 brings the figure up to 20 %, and in the Boeing 787, plastics make up more than half of the material used.

**Plastics as a Commodity**

For commodity manufacturers, plastic has become the material of choice for getting ahead of the competition. With its brightly colored iMac models, Apple proved that computers don't have to be gray boxes. However, the greater the demands imposed by industry on plastics, the more expensive their manufacturing becomes. For this reason, industry is called on to develop corresponding methods that make the cost of manufacturing equal to or less than that of metallic materials.

(from Bayer *MaterialScience*, modified and abridged)

## Glossary

| | |
|---|---|
| velvet | a type of cloth with a thick, soft surface |

***Task 1.*** *Work with a partner. Match the following terms with the definitions.*

commodity ..........

cushion ..........

foam ..........

luminescent ..........

payload ..........

spongy ..........

ubiquitous ..........

*definitions:*

bubbles of air together in a mass
emitting light
found everywhere
merchandise
resembling an artificial or natural material that is soft, light and full of holes
soft, protective pad
total weight an airplane can carry

***Task 2***. *Work with a partner. Make a list of plastic objects and their characteristics mentioned in the text. Refer to architectural design, interior design and aircraft engineering.*

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## 5.6 Grammar: Reported Speech (Indirect Speech)

When reporting what another person said, the so-called back shift of tenses is often used.

If the reporting verb, e.g. to say, add, state, answer, is in the **past**, the verb in the reported clause in most cases shifts back into a form of the past.

Direct Speech:

Uta Scholten said: “Most young visitors of the museum **do** not know much about plastics.”

Indirect Speech:

Uta Scholten **said** that most young visitors **did** not know much about plastics.

**Formation and Use of the Back Shift**

***Task 1.*** *Back shift the verb in the reported sentence.*

Back shift of simple present to simple past

He said: "I **know** this author well."

He mentioned that he ............................ this author well.

Back shift of simple past and present perfect to past perfect

She said: "The first time I **read** about recycling plastics **was** forty years ago.

She stated that the first time she ............................ about recycling plastics ............................ forty years ago.

She added: "But I **have been interested** in recycling all my life."

She added that she ............................................................. in recycling since then.

Back shift of will to would

He said: "I **will** know more about the experiment next week."

He mentioned he ............................................ more about the experiment the following week.

> **No Back Shift is Used**
> For statements of universal truths or irreversible facts.
> He stated that the earth **turns** around the sun.

***Task 2.*** *Work with a partner. Change some of the quotations in* 5.5 *from direct to reported speech and use different reporting verbs or expression.*

Dirk Ziem

..........................................................................................................................................................................................

..........................................................................................................................................................................................

..........................................................................................................................................................................................

*San Francisco Chronicle*

..........................................................................................................................................................................................

..........................................................................................................................................................................................

..........................................................................................................................................................................................

Rem Kohlhaas

………………………………………………………………………………………………………………………………

………………………………………………………………………………………………………………………………

………………………………………………………………………………………………………………………………

## 5.7 Polymer Processing

Plastics can be shaped in many ways, e.g. some polymeric materials can be cast like metals, i.e. a molten material is poured into a mold and allowed to solidify. This process can be applied for both *thermoplastic* and thermosetting plastics, the latter being then *cured* in the mold to become the thermoset.

### Glossary

| | |
|---|---|
| thermoplastic, *n*, *adj* | a polymer that softens when heated and hardens when cooled |
| to cure | to improve the properties of polymers and rubber by combining with, e.g. sulfur under heat and pressure; cf. to vulcanize |

### Extrusion

Thermoplasts can also be extruded. Plastic chips are filled in a chamber containing a screw. The polymer is then heated by heating elements so that it melts. The screw forces the resulting resin through a *die*, which forms it into a special shape and lets the material cool.

This kind of processing produces, e.g. *tubes*, pipes, *rods*, and sheets or films.

### Glossary

| | |
|---|---|
| die | here: a metal block containing small holes through which the polymer is forced |
| tube | a long hollow pipe through which liquids/gases move |
| rod | a thin, straight piece or bar |

***Task 1.*** *Work with a partner. Read the text above. Then draw a schematic diagram of an extruder.*

***Task 2.*** *Work with a partner. Fill the gaps in the text with words from the box in their correct form.*

| article; eject; manufacture; metal ; pressure; shape; solidify |
|---|

Injection Molding

Injection molding is used to ………………………… both, thermoplastic and thermosetting materials. The first steps are the same as in extrusion. The molten polymer is injected at high ………………………… into the mold and kept under pressure, until it has …………………………. Then the mold is opened and the piece …………………………. The molds are made from …………………………, usually either steel or aluminum, and ………………………… to the desired form of the finished …………………………, e.g. garden chairs.

***Task 3.*** *Use the verbs in the box and the notes to write a text about blow molding.*

| blow in; cool; eject; extrude; fit; melt; place; produce; shape; use |
|---|

Blow Molding:
plastic containers and bottles
hollow tube
in semi-molten state into cooled metal mold
air or steam under pressure
tube walls to contours of mold
hollow bottle or container

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## 5.8 Case Study: Different Containers for Carbonated Beverages

*Figure 14:*
Carbonated beverage containers

***Task 1.*** *Work in a group. Scan the text, then discuss and decide which material you would choose as manufacturer and as consumer for containers for carbonated beverages. Give reasons.*

A common item that represents some interesting material property requirements is a container for carbonated beverages.

The Material of Choice

should provide a barrier to the passage of carbon dioxide ($CO_2$), which is under pressure in the container;

must be nontoxic, unreactive with the beverage (including carbonic acid from dissolved $CO_2$), and preferably be recyclable;

should be relatively strong and capable of surviving a drop from a height of several feet when containing the beverage;

should be inexpensive, and the cost to fabricate the final shape should be relatively low;

should keep its optical clarity if optically transparent;

should be capable of being produced having different colors and/or labels

All three of the basic material types, metal (aluminum), ceramic (glass), polymer (PET) are used. They are all non-toxic and unreactive with the contained beverages. In addition, each material has its pros and cons.

**Aluminum alloy** is relatively strong but easily damaged. It is a very good barrier to the *diffusion* of $CO_2$ and can easily be recycled. The beverages are cooled rapidly and labels may be painted onto its surface. On the other hand, the cans are optically opaque and relatively expensive to produce.

**Glass** is a very good barrier to the diffusion of $CO_2$ and a relatively inexpensive material. It may be recycled, but it cracks and fractures easily and glass bottles are relatively heavy.

**Plastic** is relatively strong and can be made optically transparent. It is inexpensive, lightweight and recyclable. But plastic is not as good a barrier to the diffusion of $CO_2$ as aluminum and glass.

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| diffusion | the movement of atoms/molecules from an area of higher concentration to an area of lower concentration |

Your choice material as manufacturer:

……………………………………………………………………………………………………………………………

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Your choice material as consumer:

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# Chapter 6 Composites

## 6.1 Introduction

***Task 1.*** *Work with a partner. Fill the gaps in the text with words from the box in their correct form.*

| |
|---|
| artificial; aerospace; bone; cellulose; corrosion; dissimilar; phase; transportation; underwater; wood |

A number of composites occur in nature: ................................................ consists of strong and flexible ................................................ fibers surrounded and held together by a stiffer material called lignin. ................................................ is a composite of the strong yet soft protein collagen and the hard, brittle mineral apatite. Yet many modern technologies require materials with unusual combinations of properties that cannot be met by natural composites or the conventional metal alloys, ceramics and polymeric materials. This is especially true for materials that are needed for ................................................, ................................................ and ................................................ applications. Aircraft engineers for example, are increasingly searching for structural materials that have low densities, are strong, stiff and resistant to *abrasion* and *impact* as well as ................................................, a rather impressive combination of characteristics. The problem is that strong materials frequently are relatively dense, i.e. heavy. Increasing the strength or stiffness typically results in a decrease in impact strength.

Generally speaking, a composite is considered to be any ................................................ made multiphase material that shows properties of both *constituent phases* so that a better combination of properties is realized. The constituent phases in a composite are chemically ................................................ and separated by a distinct interface. Many composite materials are composed of just two ................................................, the one phase being the matrix, which is continuous and surrounds the other phase, which is often called the *dispersed* phase.

The properties of composites are a function of the properties of the constituent phases, their relative amounts and the geometry of the dispersed phase, which means the shape, particular size, distribution and orientation of the particles.

(from Callister, modified and abridged)

I. Eisenbach, *English for Materials Science and Engineering,* DOI 10.1007/978-3-8348-9955-2_6,

**Glossary**

| | |
|---|---|
| abrasion, to abrade | the process of being rubbed away by friction, to rub away |
| abrasive, *n*, *adj* | a substance that abrades, abrading |
| impact | a high force or load acting over a short time only |
| constituent phase | one of the *phases* from which a substance is formed |
| phase | a form or state of matter (solid/liquid/gas/plasma) depending on temperature and pressure |
| interface | the area between systems where they come into contact with each other |
| to disperse, dispersion, *n* | to distribute particles evenly through a medium |

***Task 2.*** *Work with a partner. Answer the following questions.*

What is the number of individual materials a composite is composed of?

............................................................................................................................................................

What is the design goal of a composite?

............................................................................................................................................................

............................................................................................................................................................

## 6.2 Case Study: Snow Ski

A modern ski is a relatively complex composite structure, consisting of many parts, being composed of different materials:

the base: compressed carbon (carbon particles embedded in a plastic matrix); hard and abrasion resistant; provides appropriate surface

the top: ABS plastic having a comparatively low *glass transition* temperature; used for controlling and cosmetic purposes

the core: polyurethane plastic; acts as a filler

the core wrap: bidirectional layer of fibreglass; functions as a *torsion* box and bonds outer layers to core

the side: ABS plastic, cf. top

the edge: hardened steel; facilitates turning by cutting into snow

the *damping* layer: polyurethane; improves *shatter* resistance

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| glass transition temperature $T_g$ | the temperature at which, upon cooling, a non-crystalline ceramic or polymer transforms from a *supercooled* liquid to a solid glass |
| supercooled | cooled to below a phase transition temperature without transforming |
| torsion, torsional, *adj* | the stress/deformation caused when one end of an object is twisted in one direction and the other end is twisted in the opposite direction |
| to damp(en) | to make sth less strong, to soften |
| to shatter | to suddenly break into pieces |

***Task 1.*** *Work with a partner. Draw the cross-section of a snow ski, showing the different layers of the composite structure as described.*

***Task 2.*** *The notes on a snow ski contain several expressions that can be used to describe a purpose. Make a list of the expressions. Then use them in sentences.*

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## 6.3 Grammar: Gerund (-ing Form)

The gerund (after Latin *gerundium),* also called **–ing** form, is identical in form to the present participle as in the sentence:

Talk**ing** to Mr. Brown, she left the room.

In this sentence, the present participle *talking* stands for *while she was talking*, and is used to abbreviate the sentence. Some linguists do not differentiate between the gerund and the present participle, but most English grammar books explain the usage of the gerund in a separate chapter.

### Formation of the Gerund

***Task 1.*** *Fill in the missing forms.*

Add **-**ing to the infinitive of a verb.

to avoid – ......................................................

Drop the end-e.

to freeze – ......................................................

Double the final consonant when it is preceded by a stressed vowel.

to stop – ......................................................

**Use of the Gerund**

The gerund can be used like a noun, and it can be modified by determiners like direct and indirect articles (the, a), or pronouns (my, your).

The freezing of water is one of the most common transformations in nature.

The gerund can be used like a verb and have an object.

They finally stopped questioning all information.

Note that some verbs can be used with both the gerund and the infinitive with a change in meaning. These verbs and examples are listed in any English grammar book.

**Gerund after Prepositions**

***Task 2.*** *Work with a partner. Use the gerund and form meaningful sentences with the prepositions from the box and the following phrases.*

| after; before; by; of; on; to; without |
|---|

alter the size of the sample – increase the temperature

*After/before altering the size of the sample, the temperature was increased.*

in spite - study hard – not pass the exam

……………………………………………………………………………………………

look forward – finish the academic year

……………………………………………………………………………………………

the edge of the ski – facilitate turning - cut into the snow

……………………………………………………………………………………………

see the new instrument - enter the lab

……………………………………………………………………………………………

start the instrument – read the manual first

……………………………………………………………………………………………

**Gerund after Adjectives + Preposition**

***Task 3.*** *Add the prepositions from the box, some of which will have to be used several times, and change the verbs into the gerund.*

| |
|---|
| about; against; at; for; in; of; on; to; with; |

She is good/bad ………………………………………… (work) with students.

He is angry ………………………………………… (lose) his notebook,

Professor X. is disappointed ………………………………………… (see) such a bad report.

The instruments are famous ………………………………………… (give) reliable performance.

The company is interested ………………………………………… (hire) him.

**Gerund after Nouns + Preposition**

This is the advantage ………………………………………… (use) underground cable.

Special clothing protects against the danger ………………………………………… (be) exposed to radiation.

**Gerund after Verbs + Preposition**

He was accused ………………………………………… (plagiarize) from the internet.

The research group concentrates ………………………………………… (develop) applications for new composites.

Students have to cope ………………………………………… (solve) many problems.

Medical interns have to get used ………………………………………… (work) long hours.

They decided ………………………………………… (use) non-recyclable materials.

**Gerund after Certain Verbs**

| |
|---|
| Note that certain English verbs require a following gerund. |

Lists of such verbs are listed in any English grammar book. Below are a few examples.

***Task 4.*** *Use the gerund of the verbs in brackets to form meaningful sentences with the verbs from the box and the following phrases.*

| |
|---|
| admit; avoid; consider; include; justify; suggest |

The task ................................................................ (write) an essay.

He had to ................................................................ (pay) that much for the chemical.

Please try to ................................................................ (expose) the sample to light.

We ................................................................ (vary) the temperature and frequency.

She ................................................................ (have, miss) this aspect of the material's failure.

The manual ................................................................ (work) under the exclusion of oxygen.

## 6.4 Case Study: Carbon Fiber Reinforced Polymer (CFRP)

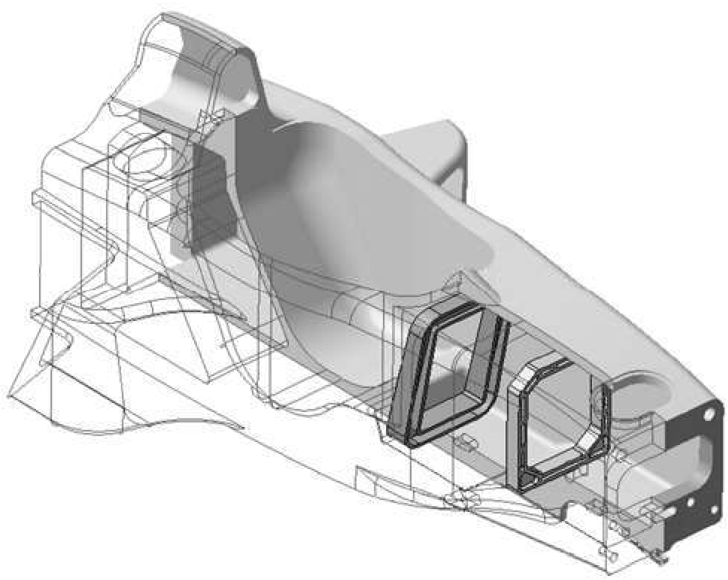

*Figure 15:*
Cross-section of the safety cell of a race car
[M. Trzesniowski]

This composite material is commonly referred to by the name of its reinforcing fibers, namely carbon fibers. To manufacture, e.g. body parts for race cars, carbon fibers are embedded as reinforcement into a matrix, which usually is epoxy. This is done by layering sheets of carbon fibers into a mold in the shape of the final product, the arrangement of the cloth fibers depending on the desired strength and stiffness properties of the product. The mold is then filled with epoxy and heated or air cured.

CFRP is a technologically important material. It is very strong and light-weight, non-corroding, heat-resistant, will not *ignite* and shrinks very little when exposed to high temperatures. Unfortunately, carbon fibers are expensive to manufacture.

**Glossary**

| | |
|---|---|
| to ignite | to start to burn, make sth start to burn |

***Task 1.*** *Work with a partner. Read the text above. Then answer the question in a few sentences. Add anything you know about the subject.*

Why is CFRP used in racecar and, to some extent, mainstream car manufacturing?

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## 6.5 Word Formation: Prefixes

The texts you have worked with so far contain prefixes worth noticing,

e.g. in nouns (**sur**face), adjectives (**in**combustible) and verbs (to **com**press).

Most prefixes are of Latin origin, which is typical of a scientific text, but there are also Germanic prefixes, e.g. to **em**bed.

***Task 1***. *Work in a group. Match the words from the box to the prefixes in the table. Add a collocation as well.*

activate; atomic; author; band; calculate; change; clinic; coloured; compatible; conductor; cooled; crystallization; directional; due; electric; estimated; ethylene; fabricated; ferromagnetism; formation; friendly; function; functional; gram; immune; light; linear; measure; meter; metrical; molecular; notice; purity; similar; size; space; standing; structured; tube; type; typical; watt; zero

| prefix | collocation |
|---|---|
| a- | *atypical behavior* |
| aero- | |
| anti- | |
| auto- | |
| bi- | |
| bio- | |
| co- | |
| counter- | |
| de- | |
| di- | |
| dis- | |
| eco- | |
| ex- | |
| geo- | |
| im- | |
| inter- | |
| kilo- | |
| macro- | |
| mal- | |
| mega- | |
| micro- | |
| milli- | |
| mis- | |
| multi- | |
| nano- | |
| non- | |
| out- | |

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|---|---|
| over- | |
| poly- | |
| pre- | |
| proto- | |
| re- | |
| semi- | |
| sub- | |
| super- | |
| trans- | |
| tri- | |
| ultra- | |
| under- | |
| uni- | |

# Chapter 7 Advanced Materials

## 7.1 Introduction

***Task 1.*** *Work with a partner. Write an outline of the following presentation about advanced materials. Then give a short presentation on the basis of this outline. Take turns.*

"Good afternoon, Ladies and Gentlemen,

The topic of my short presentation today will be an introduction to advanced materials.

First, I am going to discuss two material types that belong to this category. Second, I will mention current applications of advanced materials.

Advanced materials can be of all material types, e.g. metals, ceramics and polymers.

To obtain advanced materials, properties of traditional materials have been improved, that is significantly changed in a controlled manner. Advanced materials include semiconductors, biomaterials as well as smart materials and nano-engineered materials.

Two important classes of advanced materials I want to introduce here are smart materials and nano-engineered materials. Smart materials respond to external stimuli, such as stress, temperature, electric or magnetic fields. By way of example, consider shape memory alloys or shape memory polymers, which are thermo responsive materials, where deformation can be induced and recovered through temperature changes, as can be seen in this figure.

As I have already mentioned, advanced materials also include nano-engineered materials which have unique properties. These properties arise from structural features which are of nanoscale dimensions, i.e. 1 to 100 nanometers. A prominent example are carbon nano-tube filled polymers which can be employed as electrically conducting materials or high performance materials. Please refer to the next diagram showing room temperature electrical conductivity ranges of these polymers.

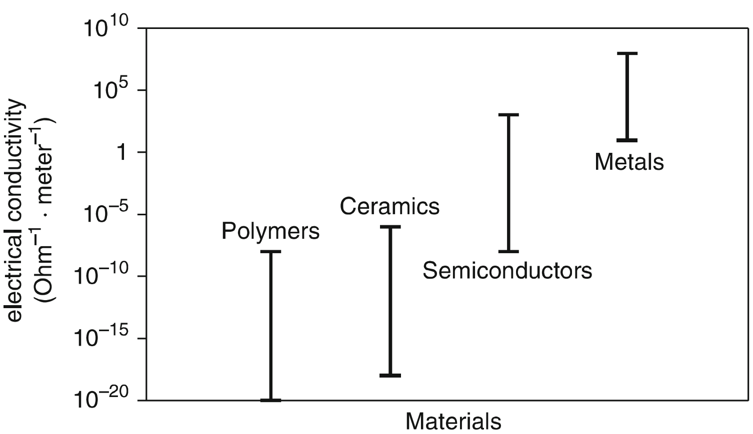


*Figure 16:* Room temperature electrical conductivity ranges for metals, ceramics, polymers and semiconducting materials

I. Eisenbach, *English for Materials Science and Engineering,* DOI 10.1007/978-3-8348-9955-2_7,

Having looked at two classes of smart materials, I will now turn to some applications. Advanced materials are used in high-tech applications for, among others, lasers, *integrated circuits*, magnetic information storage, and liquid crystal displays (LCDs). They function in everyday electronic equipment such as computers, camcorders, or CD/DVD players. But advanced materials also operate in state-of-the-art devices for spacecraft, aircraft, and military *rocketry*.

In conclusion we have seen the structural versatility and wide range of potential applications of advanced materials. This is why they are being investigated in academic and industrial research laboratories world wide, and further developed and optimized for various tasks in industry.

Thank you for your attention, Ladies and Gentlemen. I'll be pleased to answer questions now."

(data from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| integrated circuit | millions of electronic circuit elements incorporated on a very small silicon chip |
| rocketry | the science and technology of rocket design, construction and flight |

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## 7.2 Semiconductors

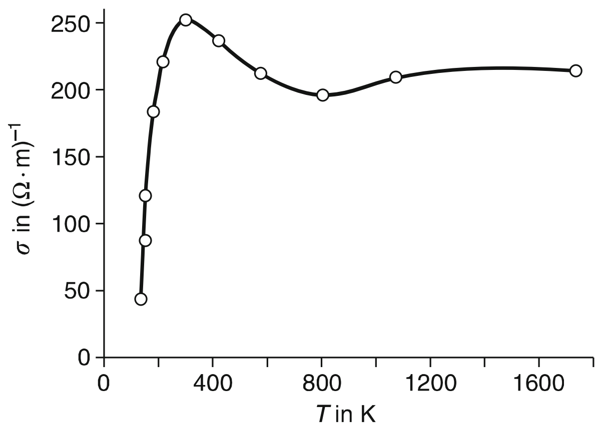


*Figure 17:*
Temperature dependence of electrical conductivity for semiconductors

***Task 1.*** *Fill in the names of the elements.*

Semiconductors may be either elements, namely Si (............................) and Ge (............................), or covalently bonded compounds. Si is used to create most semiconductors commercially.

A semiconductor is a solid material with electrical properties that are intermediate between the electrical conductors such as metals and metal alloys and insulators, namely ceramics and polymers. The electrical characteristics of these materials are extremely sensitive to temperature and *minute* concentrations of *impurity* atoms, called doping. Depending on the type of the impurity, the impurity atom either adds an electron or creates a hole, i.e. a site where one electron is missing.

Intrinsic Semiconductors

The electrical properties are inherent in the pure material, and electron and hole carrier concentration are equal. With rising temperatures, the intrinsic electron and hole concentration increases dramatically.

Extrinsic Semiconductors

An extrinsic semiconductor has been doped, giving it different electrical properties from the intrinsic one. The electron and hole carrier concentration at thermal equilibrium has been changed. For extrinsic semiconductors, with increasing impurity dopent content, the room temperature carrier concentration increases whereas carrier mobility diminishes.

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| minute | extremely small |
| impurity atoms | here atoms of a substance that are present in a different substance |

***Task 2.*** *Work with a partner. Write questions that elicit the answers contained in the sentences. Different questions are possible. Practice questions and answers with a partner, then switch roles.*

| | |
|---|---|
| *Which element is most often used to create semiconductors commercially?* | Si is used to create most semiconductors commercially. |
| | Semiconductors have electrical properties that are intermediate between electrical conductors and insulators. |
| | The electrical characteristics of these materials are extremely sensitive to the presence of impurity atoms. |
| | The intrinsic electron and hole concentration increases dramatically with rising temperatures. |
| | Semiconductors are classified as either intrinsic or extrinsic on the basis of their electrical behavior |

## 7.3 Case Study: Integrated Circuits

***Task 1.*** *Work with a partner. Fill the gaps in the text with words from the box in their correct form.*

| |
|---|
| advancement; approach; consume; electronic; improvement; manufacture; miniaturize; perform |

In electronics, an integrated circuit, also known as IC or microchip, is a ............................................ electronic circuit consisting mainly of semiconductor devices as well as passive components. These circuits are ............................................ on the surface of a thin substrate of semiconductor material. ICs revolutionized the world of electronics and nowadays appear in almost all ............................................ equipment. Integrated circuits were made possible by discoveries which showed that semiconductor devices could ............................................ the functions of *vacuum tubes*. Thanks to technological ............................................ in semiconductor device fabrication in the mid 20$^{th}$ century, large numbers of tiny transistors could be integrated into a small chip.

This was an enormous .............................................. over the *manual assembly* of circuits. The fact that reliable integrated circuits could be mass produced using a building-block .............................................. in circuit design resulted in the fast adoption of standardized ICs in place of designs using transistors. The cost of integrated circuits is low because of mass production and because much less material is used. Being small and close together, the components switch quickly and .............................................. less power than their discrete counterparts. In 2006, chip areas ranged from a few square millimeters to around 350 $mm^2$, with up to 1 million transistors per $mm^2$.

**Glossary**

| | |
|---|---|
| vacuum tube | an electron tube from which all or most of the gas has been removed, letting electrons move without interacting with remaining gas molecules |
| manual assembly | putting together manufactured parts to make a completed product by hand |

## 7.4 Grammar: Subordinate Clauses

Subordinate clauses are phrases that give answers to questions like Why? What … for?

Why are impurity atoms added to these materials?

Impurity atoms are added **in order to influence electrical properties.**

Expressions Introducing Subordinate Clauses

**in order to/so as to** + the infinitive of the verb

The properties of the material were changed in order to/so as to improve performance.

**so that**

The properties of the material were changed so that performance improved.

**for + noun + to + infinitive**

For the metal to melt, higher temperatures must be used.

***Task 1.*** *Rewrite the following sentences, using the expressions in brackets.*

Scientists planned to make possible the development of integrated circuitry. That's why they introduced semiconductors. (in order to)

..............................................................................................................................................................................

..............................................................................................................................................................................

The audience stayed in the lecture hall because they wanted to be able to hear the second lecture. (so that)

……………………………………………………………………………………………………………

……………………………………………………………………………………………………………

Researchers added impurities, because conductivity had to be optimized. (so as to)

……………………………………………………………………………………………………………

……………………………………………………………………………………………………………

Circuit breakers were installed, because one did not want the system to overload. (for … to …)

……………………………………………………………………………………………………………

……………………………………………………………………………………………………………

## 7.5 Smart Materials

***Task 1.*** *Work with a partner. Translate the following text into English.*

Intelligente Werkstoffe sind in der Lage, Veränderungen in ihrer Umgebung zu erkennen und auf derartige äußere Impulse auf festgelegte Weise zu reagieren. Ähnliche Eigenschaften finden sich bei lebenden Organismen.

Intelligente Werkstoffe haben einen Sensor, der ein Eingangssignal erkennt, und einen Aktuator, der eine entsprechende Reaktion und Adaptation auslöst.

Der Aktuator kann als Reaktion auf eine Veränderung von Temperatur, Druck, Licht, oder eines elektrischen bzw. magnetischen Felds eine Veränderung z. B. der Form, Position, oder mechanischer Eigenschaften hervorrufen.

*Smart Materials* ……………………………………………………………………………………

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***Task 2.*** *Work with a partner. Reconstruct the text about materials for actuators from the jumbled sentence parts in the brackets.*

**Materials Used for Actuators**

Shape Memory Alloys

Shape memory alloys … (alloys can consist metal of or polymers)

*Shape memory alloys can consist of metal alloys or polymers.*

These alloys are thermo-responsive materials, where deformation can be … (caused changes deformation temperature through).

………………………………………………………………………………………………

………………………………………………………………………………………………

After having been deformed, they return to … (changed is original shapes temperature the their when).

………………………………………………………………………………………………

………………………………………………………………………………………………

Piezoelectric Ceramics

Piezoelectric ceramics expand and contract in response to an applied electric field or voltage; they also generate … (altered an are dimensions electric field their when)

………………………………………………………………………………………………

………………………………………………………………………………………………

Magnetostrictive Materials

The behavior of magnetostrictive materials is analogous to that of the piezoelectrics, except that ... (fields magnetic respond they to)

………………………………………………………………………………………………

………………………………………………………………………………………………

Electrorheological/Magnetorheological Fluids

Electrorheological/magnetorheological fluids are two types of fluids whose properties, e.g. viscosity, can be changed … (an applying by electric field magnetic or)

………………………………………………………………………………………………

………………………………………………………………………………………………

(from Callister, modified and abridged)

## 7.6 Nanotechnology

The history of science shows that, to understand the chemistry and physics of materials, researchers generally have begun by studying large and complex structures and then later investigated smaller fundamental building blocks of these structures.

However, *scanning probe microscopes*, which permit observation of individual atoms and molecules, make it possible to manipulate and move atoms and molecules to form new structures and thus design new materials that are built from simple atomic-level constituents, an approach called 'materials by design'. This ability to arrange atoms provides opportunities not otherwise possible to develop and study mechanical, electrical, magnetic and other properties. In the term nanotechnology, the prefix nano denotes that the dimensions of these structural entities are on the order of a nanometer ($10^{-9}$ m). As a rule, they are less than 100 nanometers (equivalent to approximately 500 atom diameters).

(from Callister, modified and abridged)

**Glossary**

| | |
|---|---|
| scanning probe microscope | (SPM), a microscope that scans across the specimen surface line by line, from which a topographical map of the specimen surface (on a nanometer scale) is produced |

***Task 1.*** *The text refers to two kinds of scientific approaches, the top-down and the bottom-up approach. Explain.*

*In the so-called top-down approach to the chemistry and physics of materials, researchers study* ..........................................................................................................

..........................................................................................................

..........................................................................................................

*In the so-called bottom-up approach,* ..........................................................................................................

..........................................................................................................

..........................................................................................................

..........................................................................................................

## 7.7 Case Study: Carbon Nanotubes

***Task 1.*** *Work with a partner. Fill the gaps in the text with words from the box in their correct form.*

| |
|---|
| applicable; atom; consist; diameter; ductile; efficient; end; field; know; molecule; thickness |

The structure of a nanotube ............................................ of a single sheet of graphite, one atom in ............................................, which is rolled into a tube. At least one ............................................ of the tube is capped with a $C_{60}$ *fullerene* hemisphere. Each nanotube is a single ........................................ composed of millions of ............................................ The length of the molecule is thousands of times greater than its ............................................. Nanotubes are extremely strong and stiff and relatively ............................................. For single-walled nanotubes, tensile strengths range between 50 and 200 GPa, which is the strongest ............................................ material so far. Nanotubes have unique electrical properties and are ............................................ conductors of heat. Because of their unique properties, nanotubes are extremely useful as reinforcement in composite materials and will be ............................................ in many ways in nanotechnology, electronics, optics and other ............................................ of materials science.

(from Callister, modified and abridged)

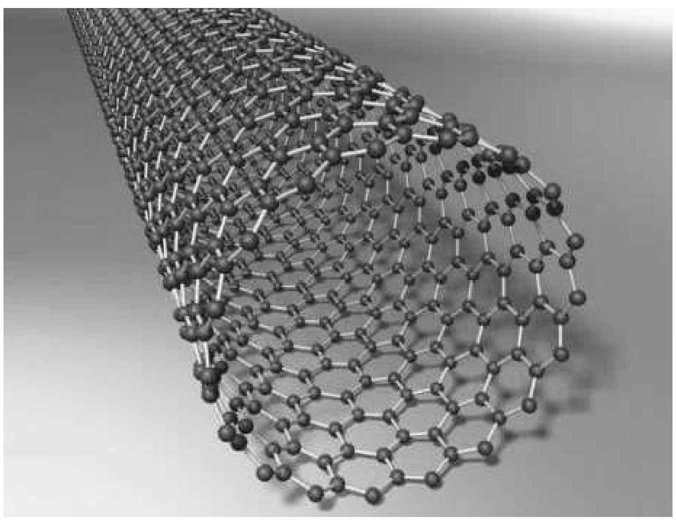

*Figure 18:* Carbon nanotube structure

**Glossary**

| | |
|---|---|
| fullerene | carbon molecule named after R. Buckminster Fuller, sometimes called buckyball, composed entirely of C in the form of a hollow sphere, ellipsoid or tube |

## 7.8 Grammar: Modal Auxiliaries

Scientific texts use constructions with modal auxiliaries, also called 'modals', e.g. when the texts are about a potential future development or when hypothetical statements are made.

**Formation and Use of Modal Auxiliaries**

Modals require the verb in the infinitive.

> Solar energy **could** significantly **reduce** consumption of oil in coming decades.

Modals do not add do/does/did in questions or in negative sentences.

> Fuel cells **may not** provide enough energy to sufficiently reduce fuel consumption.

Modals have no past or future form (except for could and would).

**Modals and their Meanings**

**can** and **could** express

the ability and the permission to do sth, cf. to be able to and to be allowed to;

a request, offer, suggestion, possibility, where **could** is more polite

**may** expresses the possibility and permission to do sth; a polite suggestion

**might** expresses a possibility (less possible than **may**) and a *hesitant* offer

**must** expresses a force, necessity, an *assumption*, an advice, a recommendation;

but **must not** expresses *prohibition* (!)

**need not** expresses that there is no necessity to do sth

**shall** expresses a suggestion

**ought to** and **should** express an advice, an obligation

**will** expresses a wish/request/demand/order (less polite than would); a prediction/assumption, promise, spontaneous decision, *habits*

**would** expresses a wish/request (more polite than will), habits in the past

**Glossary**

| | |
|---|---|
| hesitant | unable to make a decision quickly |
| assumption | here a belief that sth is true |
| prohibition | a law or order that forbids sth |
| habit | a usual behavior |

***Task 1.*** *Fill the gaps with modals. Several modals may apply, depending on the intention you want to express. Remember to use the passive voice when necessary.*

The term smart ............................................................ (apply) to rather sophisticated systems.

Viscosity ............................................................ (change) when applying an electric or magnetic field.

Materials ............................................................ (make) that bend, expand or contract when a voltage is applied.

Recyclable materials .......................... further .................................. (develop).

Materials for more efficient fuel cells .......................... still .................................. (find).

Nanotubes ............................................................ (be) applicable in many ways.

The ecological impact of manufacturing materials ............................................................ (consider).