

# Hints on Layout and Style

for Writers of Dissertations and Theses at the Faculties of Science,  
Engineering and Medicine, Lund University

Helen Sheppard

Hints on Layout and Style for Writers of Dissertations and Theses  
at the Faculties of Science, Engineering and Medicine at Lund University

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Word for Word technical translations

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## Preface

Having edited scientific papers and theses for over 20 years, I have seen the development from relatively simple typewritten manuscripts with photographic line drawings, to modern publications containing digital images and with sophisticated layouts akin to those achieved by professional publishers. As the authors of papers and theses became more aware of layout and more adventurous in their use of desktop publishing programs, I noticed that not only was I making grammatical and linguistic corrections, but also comments and suggestions regarding the style of headings, the layout of paragraphs and tables, and the use of symbols and signs.

The aim of this publication is not to provide a complete guide to literary style; others have done this far more competently. The factual content and methods of scientific writing are also outside the scope of this guide. My intention is to give examples of the kind of things I frequently correct or comment on when editing theses originating from the faculties of Science, Engineering and Medicine at Lund University.

I would like to take this opportunity to thank all friends and colleagues who have given their comments on the manuscript, especially Margaret Newman-Nowicka, and also Johanna Söderström for allowing me to use parts of her thesis as an example of good layout and presentation.

Helen Sheppard  
May 2004

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## Before you Start Writing...

### Thesis or dissertation?

Are you writing a thesis or a dissertation? Well, if you're from the UK you would write a *master's dissertation* and a *doctoral thesis*. If, on the other hand, you lived in the USA, you would write a master's thesis and a doctoral dissertation. Confusing, isn't it? If you're writing your *doctoral* thesis in British English, call it a thesis; if you're using American English, call it a doctoral dissertation. The degree of *Licentiate* is not well known in English-speaking countries, so it's difficult to know whether it should be called a Licentiate dissertation or a Licentiate thesis. My recommendation is to reserve thesis for doctoral degrees and to use dissertation for all others.

### Papers, theses and dissertations

All the above are *publications* or *printed matter*, the aim of which is to disseminate information on research and its results. No study, theoretical or experimental, was ever carried out in a paper or a thesis. Studies themselves are normally carried out in laboratories or in the field, except in the case of theoretical studies. Expressions such as: "In Paper II concentrated hydrochloric acid was used ...", make me want to run for the exit; at best it conjures up a vision of soggy paper, and at worst, a fuming, poisonous mess! You should thus also avoid expressions such as, "The aim of this thesis was to study the effects of...". The aim of every thesis should be to present your research, the findings and conclusions. In Swedish, the term *avhandling* appears to cover the actual research; this is not the case in the English language.

### British or American?

According to the Information Department at Lund University, the recommendation for writing theses in English is to use British English; Sweden is part of Europe, after all. Having said this, many research groups publish their work in American journals and are more used to communicating in American English. Before you start to write your thesis, you should therefore check with your supervisor, faculty office or dean of postgraduate studies regarding the use of British or American English. The golden rule is: don't mix the two!

### British and American spelling

Use British English spelling unless you have a special reason for writing your thesis in American English. You should also be aware that British and American English do not only differ in the spelling of certain words, but also in the use of some prepositions and phrases. For example: *from* March *to* December in British English, but March *through* December in American English.

A list of words common in scientific and medical texts, whose spellings differ in British and American English, is given below. The British English spellings are often related to their French and Greek spelling, while American spellings often reflect the Latin.

<b>British</b>	<b>American</b>
aetiology	etiology
aluminium	aluminum
anaemic	anemic
anaesthetic	anesthetic
analogue	analog
analyse	analyze
behaviour	behavior
caesium	cesium
catalogue	catalog

catalyse	catalyze
centre, centred	center, centered
channelled, channelling	channeled, channeling
co-factor	cofactor
colour	color
co-worker	coworker
defence	defense
dialogue	dialog
dialyse	dialyze
faeces	feces
favour	favor
fibre	fiber
foetus/foetal	fetus/fetal
fulfil	fulfill
grey	gray
haemo-	hemo-
harbour	harbor
labelling, labelled	labeling, labeled
labour (laborious)	labor (laborious)
litre	liter
metre (100 cm)	meter
meter (measuring device)	meter
modelled, modelling	modeled, modeling
mould	mold
neighbour	neighbor
odour	odor
oedema	edema
programme (TV, project etc.)	program
but computer program	
skillful	skillful
sulphur, sulphate, sulphite, sulphide, etc.	sulfur, sulfate, sulfite, sulfide, etc.
through	thru
tumour	tumor
tunnelling	tunneling
vapour	vapor

An exception to this rule is when giving the names of organisations. For example, in a BrE text, the *US Department of **D**efense* is spelt with an *s*, not with a *c*, as that is its official name.

## **-ise and -ize**

It is, or was, a commonly held belief that *-ise* is the BrE spelling and *-ize* the AmE spelling. The Microsoft spellchecker seems to think so, but this is not the case.

In modern English dictionaries the *-ize* form is now the preferred spelling in BrE, with *-ise* as an acceptable variant. Whether you choose to use *-ize* or *-ise* is partly a matter of taste and partly one of age. If you were brought up writing *organise*, as I was, you'll find it difficult to suddenly start writing *organize* instead. Whether you decide to use *-ise* or *-ize*, be consistent. It is not advisable to mix forms, e.g. *organise*, *stabilize*, *polarise* and *utilize*; and you must NEVER spell the same word with *s* and *z* in the same publication.

Some words must always be spelt *-ise*, in both BrE and AmE.

advise	improvise
advertise	incise merchandise
arise	revise
comprise	supervise
compromise	surmise
devise	surprise
enterprise	televise
excise	

### **-yse and -yze**

The spelling *-yse* is preferred to *-yze* in BrE as the suffix for verbs derived from *-lysis*. For example:

analyse	electrolyse
catalyse	hydrolyse
dialyse	paralyse

The preferred AmE spelling is *-yze*.

The above naturally applies to all forms of such words: organise, organised, organising, organisation; analyse, analysed, analysing, etc.



## The General Structure of a Thesis

With the advent of desktop publishing, academic theses have become more like published textbooks, including *preliminary matter*, the *text* and *end matter*.

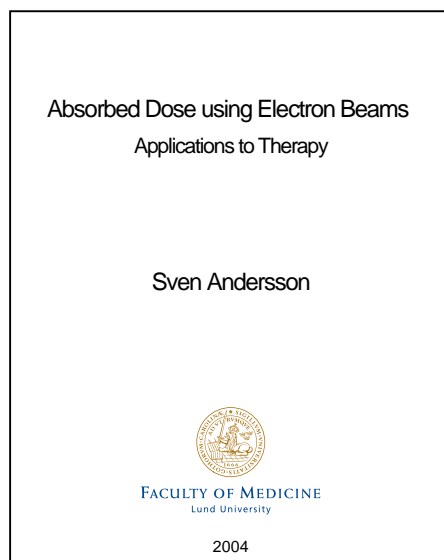
- Preliminary matter consists of a title page, printing and publishing information, perhaps a dedication, and a preface or acknowledgements. Technical and scientific theses also usually include an abstract, a list of the papers included in the thesis, a list of symbols and abbreviations, and the list of contents.
- The text is usually made up of an introduction, a description of the methods employed, the results and conclusions, a discussion and suggestions for future work in the area.
- The end matter will generally include the acknowledgements (if not given in the preliminary matter), references and appendices.

### Preliminary matter

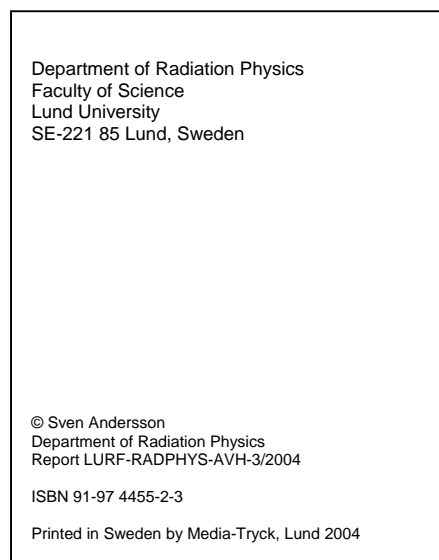
The pages in the preliminary matter may be numbered using Roman\* numerals, i, ii, iii, iv, etc.

#### *Title page*

The *title page* is usually the first right-hand page (*recto*) inside the cover, and contains the title of the work, the author's name and the publisher. In theses, the publisher's name is often replaced by the University logotype. The back of the title page (*verso*) gives *printing and publishing information*, such as the name of the publisher, the date of publication, copyright notices, the ISBN or ISSN (International Standard Book Number, or Series Number) if applicable, the names of the printer and binder if desired, and other information on font type, paper etc.



The title page



Printing and publishing information  
(Text size enlarged for legibility.)

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\* Roman or roman, see page 17.

## **Dedication**

A *dedication* is highly personal and optional, and is presented on the next right-hand page facing the printing and publishing information.

## **Preface**

The *preface* is the author's introductory address to the reader, in which he or she explains the purpose and scope of the work. It starts on a new right-hand page. The preface may also be used to acknowledge the help of colleagues and the support of friends and family. In this case, there should naturally be no separate acknowledgements section.

## **Acknowledgements**

*Acknowledgements* may be given in the preliminary matter or in the end matter. The style is usually highly personal, but avoid being too personal or emotional. What seemed suitable at the time may be embarrassing after a year or two.

## **Abstract**

As well as being printed on a separate sheet (*dokumentblad*) inserted into the thesis, the *Abstract* can be presented before the text.

## **Papers**

The list of papers is often presented with an introduction such as: "This thesis is based on the following papers, which will be referred to in the text by their Roman numerals. The papers are appended at the end of the thesis."

*Recommendation:* Use a list format and use typefaces and styles to make it easy for the reader to discern the authors from the title of the paper and the journal in which it was published. Give the title of the paper (preferably with capital letters, see p. 18), the names of the authors, and the journal on separate lines, and do not justify the text (i.e. no even right margin). Use the accepted abbreviation of the name of the journal or write it out in full. For example:

**IV** *Scintillation Assays using Molecularly Imprinted Microspheres*  
H. Svensson, W. H. Williams, G. U. Smith and T. Andersson  
Anal. Chem. **75**, 678-683 (2003)

*or*

**IV** *Scintillation Assays using Molecularly Imprinted Microspheres*  
*H. Svensson, W. H. Williams, G. U. Smith and T. Andersson*  
Analytical Chemistry, **75**, 678-683 (2003)

## **Abbreviations and symbols**

A list of *abbreviations and symbols* is common in scientific theses. The list may be given in the end matter, although there is always a risk that the reader will not find it until after having read the thesis. The recommendation in scientific and technical work is thus to place it at the beginning. It is headed *Abbreviations and Symbols*, not List of Abbreviations and Symbols.

## **Contents**

The above are usually followed by a list of the contents, which is headed simply *Contents*, and not List of Contents or Table of Contents. The *Contents* lists the title and page reference of everything that follows it (i.e. the text and the end matter) and nothing that precedes it (the preliminary matter). The pages of the Contents are not normally numbered.

A typical table of contents may have the following appearance.

## Contents

<b>1. Introduction and Aims of the Study</b>	1
<b>2. Theoretical Background</b>	3
<b>3. Experimental Methods</b>	7
3.1 Activity determination	8
3.2 Mass determination	10
<i>etc.</i>	
<b>4. Results</b>	15
4.1 Doses to the subject	17
<i>etc.</i>	
<b>5. Discussion</b>	25
<b>6. Conclusions and Future Work</b>	30
<b>Acknowledgements</b> ( <i>If not included in the preliminary matter</i> )	32
<b>References</b>	35
<b>Appendix</b>	59



Make use of the Insert – Index and Tables function in Word to generate a table of contents automatically. Not only will it ensure that all the headings are included but also that the references to page numbers are correct. (In order to make use of this, you will also have to use the preformatted heading styles in MS Word, see below under Chapters, headings and subheadings.)

## The text

The main text is paginated in Arabic\* numerals (1, 2, 3 etc.) and pagination begins on the first page of text after the Contents. The first page number referred to in the Contents should thus always be page 1, and should be a right-hand page. However, this page number is seldom actually printed, see p. 8 under Chapters, headings and subheadings.

The content of the text will vary depending on the faculty, department and subject. Consult your supervisor, former postgraduate students, the faculty office or the dean for postgraduate studies to obtain more information about the required content in your particular discipline.

## The end matter

The end matter of a scientific thesis will normally consist of the *Acknowledgements* (if not given in the preliminary matter), *References* and *Appendices*. (Note that the plural form of appendix is *appendices*. “Appendixes” is the plural form of the now functionless part of the large intestine causing people to be rushed into hospital for its removal.)

These sections are not normally numbered. If you have only one appendix, call it the Appendix. Use Appendix A (or 1) only if you have Appendix B or C (or 2 and 3) etc.

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\* Arabic or arabic, see page 17.

## Typography and Corporate Image

Most of us would recognise the logos of international corporations such as SAAB or ABB. This is because they have developed a corporate image; they have a logo with a specific design in a specific colour. In 1995 the Lund University Board decided that a typographical style should be developed for the University in order to define its corporate image, and to make publications produced by the University easily recognisable. A preliminary study revealed that no less than 4 different university seals were in use, together with innumerable typefaces and literally a wide spectrum of colours!

After a great deal of discussion, the new typographic style was introduced in October 1998, in which the Lund University seal was defined, together with typefaces and colours to be used in official printed matter distributed by the University. Complete instructions for the use of the University's typographic style can be found in the typographic style manual (which is in Swedish). ([www.lu.se/LUinternt/grafiskprofil/manual/index.html](http://www.lu.se/LUinternt/grafiskprofil/manual/index.html))

### The University logotype

The University logotype consists of the graphical element, the seal (*sigillet*), together with the name "Lund University".

The seal may not be used on its own, except as a decorative element provided certain rules are followed (see Section 2.4 of the manual for instructions). LTH has decided to use its own logotype only in Swedish. For publications in English use the Lund University logotype.



Several faculties or areas of the University have their own logotype, for example:



These can be downloaded from the University web site. ([www.lu.se/LUinternt/grafiskprofil/nedladdning/logotyper/index.html](http://www.lu.se/LUinternt/grafiskprofil/nedladdning/logotyper/index.html))

### Colours

In order to strengthen the corporate image of the University, two colours have been chosen: blue and bronze, each defined as PMS (Pantone Matching System) and CMYK colours for four-colour printing. In colour printing, the seal is printed in bronze and the text in blue. Other colours allowed are black and white and so-called negative printing. (See Section 2.7 of the manual.) These colours should also be used for decoration on the covers of theses.

### Typefaces

The two typefaces making up the University's typographical style are Frutiger and Adobe Garamond (AGaramond). Frutiger is a so-called grotesque, or sans serif, typeface, suitable for headings, subheadings, signs and posters. AGaramond is a classic typeface used for running text. (See Section 2.8 in the manual.) These typefaces should be used whenever possible.



Section 4.4 of the manual describes the use of the University's typographic style in theses.

## General Layout

Layout is, to a certain degree, a matter of personal taste, although a scientific thesis does not leave a great deal of room for the imagination. It is also important to take into account the typographic style of the University (see above). However, you can do much to improve the readability and appearance of your thesis by following a few simple rules.

Make use of white space at the beginning of chapters and in margins to improve the readability of your text, and don't be afraid to alter the line spacing. Single, 1½ and double line spacing are not the only alternatives. A page crammed with text from top to bottom is not very inviting to the reader.



In MS Word, the line spacing can be changed under Format – Paragraph.

## Chapters, headings and subheadings

Each new chapter should start on a right-hand page, and the page number is not normally *expressed* (written out) on this page, although it is included in the pagination. Chapter headings should give a good indication of the content of the chapter without being too long.

- Avoid chapter headings longer than one line if possible.
- If it is necessary to continue any heading on the next line do not divide the word at the end of the first line with a hyphen.
- Never justify headings as is common in running text.
- There is no full stop at the end of headings. Chapters, sections and subsections may be numbered or not, according to your taste.

Use Frutiger for the highest levels of headings, e.g. chapter, section and subsection. If you find it necessary to have a fourth level of headings, you might use the same typeface as in the running text in boldface. A fifth level of headings may be used if necessary, indicated, for example, by italics. Avoid more than five levels of headings and do not number more than three levels. Headings in the text are usually adjusted flush left. A family of headings is suggested below.

## 1. INTRODUCTION

Heading 1, or chapter title

Typeface: Frutiger, all caps or capital first letters

Full stop after chapter number, tab to text

Boldface, four steps up in size from the main text

8 points vertical space from heading to text

The first line of text is not indented.

### 1.2 The Glutathione Peroxidase Family

Heading 2

Same font as heading 1

Full stop between section numbers, but NOT after the final number – tab to text

Boldface, one or two steps up in size from the main text. Lower case, but upper-case first letters may be used.

4 points from heading to text

The first line of text is not indented.

### ***1.2.1 Cellular glutathione peroxidase***

Heading 3

Same font as headings 1 and 2

Full stops between section numbers, but NOT after the final number; space to text

Bold, same size as main text. Lower-case letters for all but the first letter of the first word.

2 points from heading to text

The first line of text is not indented.

### **Discovery**

Heading 4

Same font as main text (AGaramond)

No section numbering

Bold, same size as main text. Lower-case letters for all but the first letter of the first word.

The first line of text is not indented.

*Step 1*

Heading 5

Same font as main text

No section numbering

Italics, same size as main text. Lower-case letters for all but the first letter of the first word.

The first line of text is not indented.



Make use of the Style formats in MS Word. This will ensure consistency in heading styles and allow you to change the style of a particular level of heading if you should wish to do so at a later date. It also allows you to make use of the automatic generation of a table of contents (Insert – Index and Tables...).

## **Paragraphs**

Use AGaramond in running text. The text may be set flush left (uneven right margin) or justified (even right and left margins). The first line of text under a heading is not indented.



### **STARTING ON A NEW LINE DOES NOT INDICATE A NEW PARAGRAPH!**

A new paragraph in the text is indicated by the insertion of a blank line (or suitable space), or by indentation of the first line of the new paragraph. The indentation should be equivalent to a square in the final text. The disadvantage of inserting a blank line is that it is difficult to know when a new paragraph starts at the top of a new page.

Although the length of a paragraph is determined by the subject matter, avoid writing very long (a page of text) or very short (3-4 lines) paragraphs. Very long paragraphs should be divided at suitable points and very short ones combined. Check the style normally adopted in your subject or in the journal in which you usually publish your work. Never allow the first line of a new paragraph to stand alone at the bottom of a page, or the last line to stand alone at the top of a page.

## **Headers and footers**

Headers and footers can be used to provide information to the reader, such as the page number, the title of the publication or current chapter or section. Page numbers can be inserted in the footer; centred, or right (and left) justified for right-hand (and left-hand) pages, or in the header. Personally I prefer centred page numbers in the footer, leaving the header for the title of the thesis or chapter.



If you decide to include the chapter and/or section in the header, be prepared for some tricky layouting using Sections in MS Word (Insert – Break... – Section break types).

## Lists

Lists may be presented in several ways. Short, uncomplicated lists can simply be given in the text with each element separated by a comma.

The equipment included an alpha source, a collimator, lead shielding and a detector.

A comma can be used before *and* if it is necessary or if it helps the reader understand the sentence better, e.g.:

Bacteria are being used increasingly as production organisms in the biotechnological industry, as additives in the food and feed industry, and as biocontrol agents in agriculture.

The method proposed here includes model calibration, model validation and analysis, and optimisation.

In the above example it is made clear by the comma after “analysis” that the second part of the model consists of “validation and analysis”, and the final part of “optimisation”.

(See also the section on the *Oxford comma* under *Punctuation* regarding the use of a comma after the item preceding *and* in lists.)

If the list is somewhat longer or more complicated, each item may be preceded by a number or a letter in brackets.

The solution was made up of the following: (i) sodium chloride, (ii) distilled water, (iii) buffer... etc.

The above types of lists are called *run-in* lists.

The other main kind of lists is *displayed* or *vertical* lists. In displayed lists, each item is written on its own line. Items in displayed lists may consist of part of a sentence, a whole sentence, or more than one sentence. Displayed lists are also used for lengthy or compound elements. The punctuation in a displayed list is treated in the same way as if the items within it had no number or letter separating them. Items that are complete sentences start with a capital letter and end with a full stop; sentence fragments do not, and are usually (but not always) lower case. Each item is labelled (with Arabic or Roman numerals, or a letter) and the text indented. Such lists may be introduced by a full stop or a colon.

1. Weigh the sample on the lab scales.
2. Add the inoculum.
3. Place in an incubator at 20°C for 6 months .
4. Weigh the sample again.

Note that all lists must have a “parallel” structure. This means that each item must be of the same grammatical form. In the list above, for example, each item starts with the imperative form of a verb.



Use the automatic formatting button for numbered lists in MS Word to ensure the correct layout and numbering. You can change the style by right-clicking the list and selecting Bullets and Numbering...

Displayed lists may also be unordered, in which each item is preceded by a symbol such as a bullet or dash:

- heat
- moisture
- pressure

Such lists are useful for short items which have no natural sequence or hierarchy.



Again, make use of the formatting buttons in MS Word, but avoid “fancy” symbols such as \*, ✓ or ★ in scientific publications.

## Tables

The purpose of a table is to display data or other information as plainly and concisely as possible. Tables are most suitable for information that is too complex to be presented clearly in the text or a list, and for information intended for comparison, either within a table or between tables. Tables should be inserted as close as possible to the point of reference, preferably after the reference. Use landscape format if this is more appropriate.

The table number and title are given *above* the table. Make sure that the style (typeface, style and size) used in table titles is consistent throughout. In a scientific thesis it is common to number tables according to the chapter, although if there are very few tables they may be numbered consecutively throughout the thesis. Make sure the text adequately describes the content of the table, without unnecessary repetition of the information given in the text. Also, try to avoid numerous and lengthy footnotes. Leave an adequate amount of space before and after tables.

Guidelines for table layout

- In general, horizontal rules are used in tables whereas vertical ones are not.
- Column headings are often in boldface or some other kind of heading style.
- The units pertaining to the contents of each column are usually given in brackets under the column heading.
- The first letter of the first word of text is capitalised.
- Text in table columns is written flush left, and not justified right or centred.
- Integers are aligned by the right-hand digit, and numbers with decimals should be aligned by the decimal point.
- Columns of numbers with a  $\pm$  symbol or  $<$  symbol, etc. are often aligned according to the symbol.



Below is an example of a simple table.

**Table 3.1** Physical characteristics of the subjects participating in this study.

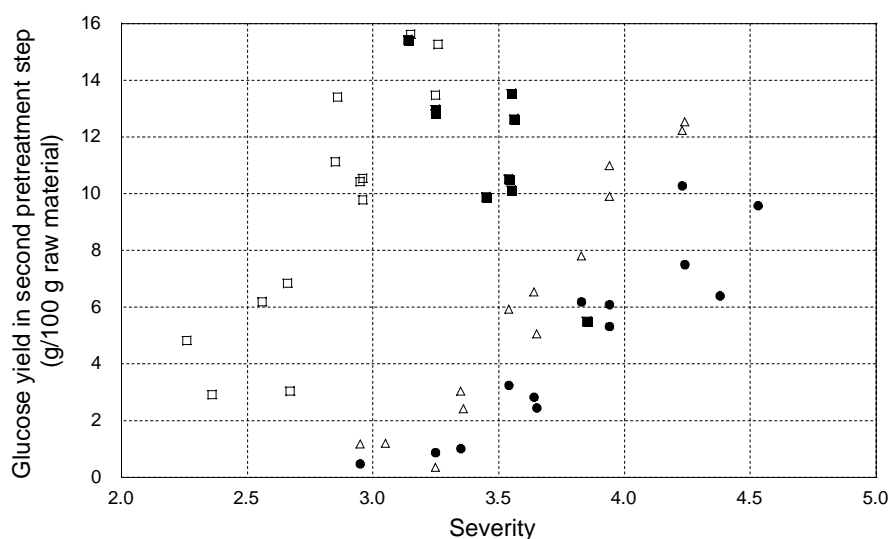
Subject	Age (y)	Height (m)	Weight (kg)
Subject 1	17	1.70	87.5
Subject 2	38	1.98	103.4
Subject 3	65	1.76	79.0
Subject 4	103	1.67	69.0

When referring to specific tables in the text, use a capital letter, e.g. “as can be seen in Table 3.1”.

## Figures

Digital photography and image processing now allow both photographs and figures to be inserted directly into the text. As with tables, they should be inserted as soon as possible after the reference to the figure. Figures are normally numbered according to chapter although, as with tables, if there are few they may be numbered consecutively. Label the x and y axes clearly giving the units in brackets (m) or separated by a comma, m. Use the same number of decimal points in numbers on the axes.

Figure captions are placed *below* the figure. Refer to figures in the running text as Fig. 2.1 or Figure 2.1. The whole word, “Figure” is more reader-friendly, but journals often use “Fig.” to save space. Ensure that the style used for figure captions is consistent throughout the whole thesis. Leave an adequate amount of space before and after figures.



**Figure 5.3** The amount of glucose solubilised during the second pretreatment step as a function of severity ( $\text{Log } R_0$ ) for material impregnated with  $\text{SO}_2$  and of combined severity (CS) for material impregnated with  $\text{H}_2\text{SO}_4$ .  $\Delta$  - impregnation with  $\text{SO}_2$  in both steps;  $\square$  - impregnation with  $\text{H}_2\text{SO}_4$  in both steps, fermentable samples;  $\blacksquare$  - non-fermentable samples;  $\bullet$  - impregnation with  $\text{H}_2\text{SO}_4$  in the first step and  $\text{SO}_2$  in the second pretreatment step.

## Equations

Displayed equations (those written on a separate line, and not included in the running text) are normally indented (if there are many of varying length) or centred (if few and short), not set flush left. Equations may be numbered according to chapter or, if there are few, consecutively. The equation number is placed at the right-hand side of the page. Equations may be referred to in the text as: Eq. (2.1) or Eqn (2.1) (see abbreviations).

$$D_{total} = D_{direct} + D_{scattered} \quad (2.1)$$

Formerly, equations were regarded as being an integral part of the text, and were punctuated accordingly. This is now considered unnecessary.

## Abbreviations, Contractions, Acronyms and Symbols

“Abbreviations should be used for the convenience of the reader, not the writer.” (From the Oxford Guide to Style) I wonder how many of us have ever thought of abbreviations in this way.

- An *abbreviation* is formed by omitting the end of a word, e.g. Eq., Fig. and min., or by taking the first letter of each word making up a term or phrase, e.g. VCR, HPLC or MRI.
- A *contraction* is formed by leaving out the middle of a word, e.g. expt, Eqn and Mr .
- An *acronym* is formed from the initial letters of a number of words, the result being pronounced as a word, e.g. CERN, SALT and radar. (NB: Some style guides also call combinations of letters that do not form pronounceable words acronyms.)
- *Symbols* are generally one or two letters representing an SI unit or a parameter in an equation, e.g. kg, W and  $\chi^2$ .

### Abbreviations and contractions

All forms of abbreviations should be explained or defined at their first occurrence in the text. (Note that the Abstract is not normally considered part of the text.) This is usually done by writing out the expression, followed by its abbreviation in brackets:

...using magnetic resonance imaging (MRI) ...

or conversely:

...using MRI (magnetic resonance imaging) ...

It is not normally necessary to repeat the definition or explanation of an abbreviation in each chapter, unless your thesis is long and there is a risk of the reader forgetting what the abbreviation means. Also, there is no point in defining an abbreviation that is not subsequently used.

One single abbreviation cannot mean different things. For example, HPLC is the common abbreviation for *high-precision liquid chromatography*, i.e. the method. Do not also use HPLC to represent *high-precision liquid chromatograph* (the instrument) or *chromatogram* (the resulting output).

Be aware of whether your abbreviations pertain to singular or plural forms. If you define FFV as meaning *flexible fuel vehicles* (in the plural), you may not at a later stage use FFV to mean *a flexible fuel vehicle*. If in doubt, define the singular form and add a lower-case *s*. For example, define a flexible fuel vehicle as FFV, and flexible fuel vehicles automatically become FFVs.

The possessive form of an abbreviation is written as with any other word, i.e. an apostrophe and an *s*; the VIP's car (if there is one VIP) and the VIPs' car (if there are several VIPs).

It is a good idea to include a list of abbreviations and symbols in a thesis, preferably at the beginning, so that the reader can easily find it and refer to it when necessary. This does not, however, mean that the abbreviations do not need to be defined in the text.

Traditionally, abbreviations have been written with a full stop at the end and contractions without, thus:

Eq. but Eqn (Equation and Equation)

Fig. but Figs etc. (Figure and Figures)

This convention is no longer strictly adhered to, so let consistency be your rule of thumb.

In American English (AmE) punctuation is more likely to be used in abbreviations than in British English (BrE); hence *Dr* Smith in BrE, but *Dr.* Smith in AmE, and the *USA* in BrE but the *U.S.A.* in AmE. In technical texts, however, full stops are less common.



Note that if the full stop of an abbreviation ends the sentence, then there is no extra stop, for example, after etc.

Lower-case abbreviations (e.g., i.e., etc.) cannot be used at the beginning of a sentence; write out the full word or expression, or rephrase the sentence.

The choice of *a* or *an* before an abbreviation depends on how it is pronounced, not the spelling.

a BA degree	an MP
a KLM flight	an MA
a UNICEF card	an MRI measurement

If, for some reason, an abbreviation is pronounced according to the full name, use *a* and *an* accordingly. For example, the abbreviation MS is normally read out as the full word, *manuscript*, thus “a MS”, while MS meaning *multiple sclerosis* is often pronounced *M-S*, thus “an MS patient”.

### ***e.g., i.e., etc., et al. and c.***

Don't confuse “e.g.” (meaning *exempli gratia*, Latin for “for example”; Swedish “t ex”) with “i.e.” (*id est*, meaning “that is”; Swedish “dvs”). Although derived from the Latin, these two abbreviations are *not* usually written in italics but in Roman style. Use a full stop after each letter and no spaces between the letters. Both e.g. and i.e. are preceded by commas, e.g. as in this sentence. Commas are used after e.g. and i.e. in AmE but not in BrE.

The abbreviation e.g. is most suitable when introducing lists, but in other running text “for example” is preferable. A sentence should not start with e.g. or i.e., (see above), but a footnote may, in which case the lower case is retained.

<sup>22</sup> e.g. *Quercus rober*

The Latin *et cetera*, meaning “and other things”, is abbreviated etc. with a full stop and is written in Roman, not italic, style. It is preceded by a comma if it follows more than one listed item: birch, beech, oak etc. Normally, at least two examples are necessary before “etc.”.

The abbreviation et al. meaning “and others” (from the Latin, *et alia*) should have a stop after al. as this is an abbreviation for *alia*, but not after et, and should be written in Roman style.

The Latin *circa*, meaning “about”, is used in English mainly with dates and quantities. It is abbreviated *c.* (in italics) and is set close up to any figures following it: *c.*1890. It is not used as widely as the Swedish *ca.* Use approximately (or approx.) in English where you would use “ca” in Swedish.



Avoid using contractions such as *it's*, *doesn't*, *can't* in scientific texts.

## Acronyms

Acronyms differ from abbreviations in that they form pronounceable words. According to this definition, NATO and UEFA are acronyms, but not MRI or HPLC. Full stops are not used between the letters of acronyms. Some acronyms have become so common that they are written with lower-case letters, e.g. radar, laser, etc.

Acronyms are *not* preceded by the definite article: e.g. *NATO has decided ...*, while abbreviations may be if one would have used “the” together with the full name, e.g. The BBC recently transmitted a programme about Sweden.

## Symbols

Do not start a sentence with a symbol; spell out the word or expression, or rephrase the sentence. For example,

“ $\chi^2$  was found to be 0.99” should be rephrased as: “The value of  $\chi^2$  was found to be 0.99”.

Symbols should not be used in running text in the same way as abbreviations. Avoid writing: “... and C was 71.8 ...” but say instead: “... the value of C was 71.8 ...” or “... the value of the constant, C, was 71.8...”.

Compound symbols such as GeV and MW are written close up, with a space between the number and the symbol: 12.5 GeV, 25 MW. (See, however, % and °C below.)

### % and °C

The symbols for percentage and degrees celsius may be written with or without a space: 20 °C, or 20°C and 50 % or 50%. (Note that the degree symbol ° is always written close up to the C.) The golden rule is to be consistent; choose one style and stick to it. The disadvantage of using spaces is that the number and the unit may fall on different lines. If you choose to use spaces, use a nonbreaking space to avoid this.



In MS Word a nonbreaking space is inserted using Insert – Symbol... – Special Characters... or Ctrl + Shift + Space.

## Mathematical signs

Mathematical signs should be distinguished from normal text. For example, the multiplication symbol X and the letter x, and the minus sign (–) and a hyphen (-). Also, make sure to differentiate between prime ( ' ) and an apostrophe ( ' ). Use a special editor for complicated formulae.

Mathematical signs such as +, –, >, <, ± etc. should be set close up to numbers in lists and tables. For example, –1.0, <0.5 etc.

In equations they should be separated by spaces on each side for readability.

$$x > 0 \quad Y = mX + C$$



Note the difference between an Asterisk →



and an asterisk → \* !

## Capital Letters

Apart from being used at the beginning of a sentence, capital letters are used in running text to denote places, organisations, people and other proper nouns. The longer a proper noun has been in use, the more likely it is to be written with a lower-case letter. For example, the internet has now become part of the English language and no longer has a capital *I*.

There are discrepancies in the use of capital letters; when in doubt, consult a modern English dictionary and be consistent!

## Places

the Baltic Sea  
the Yellow River, but the river Thames  
the Netherlands, but The Hague  
Saturn, Neptune, Uranus

Note that the Earth may be written with a capital letter, but not the sun or the moon.

Countries, their languages and related adjectives also have capital letters in English ...

England, the English language and English roses  
Sweden, Swedish and Swedish traditions  
America, American and American architecture, etc.

... however, usage varies regarding the use of adjectives based on nationality.

Roman numerals	or	roman numerals
Venetian blinds	or	venation blinds
Arabic numbers	or	arabic numbers
Turkish delight	or	turkish delight
Brussels sprouts	or	brussels sprouts

Choose one variant and use it consistently!

## Organisations

the Royal Society  
the American Society of Physicists  
Lund University  
the Lund Institute of Technology  
the Medical Faculty of Lund University  
the Government or the government (see below)

According to the Oxford Guide to Style, *the Government*, when referring to a particular body, is written with a capital *G* in BrE usage and with a lower-case *g* in AmE. The Economist Style Guide claims that *the government* should always be written with a lower-case *g*. Choose one convention and use it consistently. The same applies to *the University* or *the Department* when referring to a particular university or department mentioned previously. Decide whether to use capitals or not.

## People

the Prime Minister (of a specific country), but a prime minister  
the Vice Chancellor (of a specific university), but a vice chancellor  
Professor Andersson  
Dr (BrE) Williams *or* Dr. (AmE) Williams

## Elements, compounds and tradenames

Elements and chemical compounds are not written with capital letters, but trademarked compounds and pharmaceuticals are. (The generic name of a drug is preferable to its proprietary name as this may vary from one country to another.)

germanium	Pyrex
sodium chloride	Plexiglas
copper sulphate	diazepam, not Valium

## Scientific units

When written out in full, scientific units take lower-case letters, e.g. joule, newton, metre, kilogram, volts, watts, etc. The names of the scientists associated with these units retain their capital letters: Newton, Joule, etc.

In expressions such as “Avogadro’s number”, the “Schmidt number” etc. use the possessive form (’s) or the definite article (*the*), but not both together.

## Academic subjects

Academic subjects, such as physics, chemistry and medicine do not have capital letters except in the context of specific courses or degrees: e.g. a Master’s degree in Physics, the Mechanical Engineering Programme at LTH, Basic Course in Ecology.

## Capitalisation in titles and subtitles of works

Capitalise the first word, and all nouns, pronouns, adjectives, verbs and adverbs, but generally *not* articles (*a, the*), conjunctions (*while, etc.*) or short prepositions (*in, on, etc.*), in both titles and subtitles, e.g.

### Studies on the Interaction of Atmospheric Particles with Fog

*Experiments in Aerosol Physics*

Style varies from one publisher to another, and taste varies between authors. Titles are thus sometimes written with lower-case letters.

## Punctuation

It is definitely not my intention here to go through the general rules of punctuation. This section will be restricted to the problems and issues often encountered in theses.

### The apostrophe

Apostrophes are used in English to indicate possession. Use 's after singular nouns, e.g.

the court's decision, the scientist's dream, a week's time.

Use only an apostrophe after plural nouns, e.g.

the courts' decisions, the scientists' dream, in three weeks' time.

In compound expressions the 's is added after the last noun, e.g.

the Institute of Surgeon's guidelines.

In American English it is quite acceptable to write *the treatment's effects*, while in British English the tendency is to transpose the words and insert *of* e.g.: *the effects of the treatment*.

Note the following:



**its** without an apostrophe is the possessive form in the third person singular:  
**it's** with an apostrophe is a contraction of *it is*.



Apostrophes are not used to make plural forms in English. Plural forms are created by simply adding an s (or -es, or by replacing -y by -ies), e.g. the 1990s (not the 1990's).

## Commas and brackets

*Commas* are used to denote a pause in a sentence or to separate main clauses from subordinate clauses. Commas are also used to separate items in a list. A pair of commas can also be used to include extra information in a sentence.

*Brackets* can be used in the much the same way as commas (if you prefer them) to include something interesting. Brackets provide a stronger break than a pair of commas.

### The Oxford comma

In British English a list is usually written as under the heading *Lists* above:

The equipment included an alpha source, a collimator, lead shielding and a detector.

In American English (and Canadian English), a list may be written with a comma after *every* item:

The equipment included an alpha source, a collimator, lead shielding, and a detector.



This convention has been adopted by the Oxford University Press, hence the name, the *Oxford comma* (or *serial comma*). However, if use this kind of comma, someone, somewhere, will think you are confusing the BrE and AmE usage of commas in a list.

A comma may be used after each item in a list if the items are compound items or if confusion may arise; in other words, if you think it helps the reader to better understand what you are trying to convey, as in the example below.

The method proposed here includes model calibration, model validation and analysis, and optimisation.

## Colons and semicolons

A colon fulfils the same function as words such as *namely*, *that is*, *for example*, *for instance*, etc. A colon is used to introduce the part of the sentence that exemplifies, restates, elaborates or explains the preceding part.

The results of the experiment were quite clear: the constant A is always greater than 1.0.

A colon is also often used to introduce a list. Follow a colon introducing a list with a capital letter only if the items in the list comprise a complete sentence, or more than one sentence, or start with a proper name.

Semicolons are used to join together related sentences.

The effects on agriculture may, however, differ considerably between regions; Northern Europe is expected to enjoy mainly positive effects due to extension of the growing season, whereas Southern Europe may suffer from water shortages.

Semicolons can also be used in run-in lists to separate items where the items in the list themselves contain commas.

The main difference between the *semicolon* and the *colon* is that the former leads you in any direction related to the preceding part of the sentence, while the latter takes you along the lines already laid down.

## Exclamation marks

Be *extremely* sparing with the use of exclamation marks in English; *especially* in scientific work.

## Hyphens and dashes

### *Hyphens*

A hyphen is a short symbol (-) used to join words together to form compound words, or to divide them at the end of line.

### *Compound words*

Compound words may consist of two words joined together by a hyphen, or a prefix (or suffix) and a word joined together. Whether or not compound words are written separately, are joined by a hyphen or closed (written together) is largely a question of familiarity. The more common a compound word or expression, or the longer it has been in use, the more likely it is to be written as one word. A good example of this is:

data base → data-base → database.

Examples of hyphenated compound words:

test-tube	by-products	part-time
side-effects	bull's-eye	take-off

Some compound words are hyphenated simply to avoid awkward collisions of vowels or consonants, particularly if this could lead to mispronunciation, as in some of the examples above.

Scientific terms are often written as one word.

wavenumber, spacetime, semicrystalline

Do **not** use hyphens in expressions such as:

SO<sup>2</sup>-study, phosphor-groups, Lac-plasmid, PTS-proteins, the flow-rate, etc.  
as this is the Swedish convention.

The tendency to use a hyphen in words such as *hard disk*, *sugar cane*, *paper mill*, *end product*, etc. is probably influenced by the Swedish. Such expressions are usually two words in English, although the adjectival form will take a hyphen, e.g. *sugar-cane production*. (See below.)

According to my newest dictionaries, *ground water* and *waste water* are still written separately, although *groundspeed* and *wastepaper* are written close up.



There are no hard and fast rules governing the use of hyphens in compound words. If you are unsure, consult a good, modern English dictionary and use the recommended form *consistently*, or check a reliable source of literature in your particular field.

Hyphens are also used to express *numbers* from 21 to 99, and *fractions* when written out:

twenty-six, sixty-eight, ninety-nine  
two-thirds, four-fifths, one-sixth, etc.

According to some style guides, fractions always take a hyphen, while others suggest a hyphen only when fractions are used as a modifier, e.g. two-thirds full.

*Compass points* may be hyphenated or not in BrE: south-east, or southeast, north-west, or northwest, but are not normally hyphenated in AmE.

Hyphens are used with *prefixes* to avoid confusion or mispronunciation, especially when there is a collision of vowels or consonants.

re-entry	quasi-scientific
non-negotiable	semi-insulating

However, in AmE, and the current trend in BrE, is for the hyphen to be dropped.

cofactor	pseudomorph
nonlinear	antifreeze
pretreatment	semisolid
antibody	

Again, there are no rules governing this, so consult a dictionary or the literature in your subject, and write consistently.

Regarding suffixes, compound words are more likely to be written closed.

lifelike, lifeless, waterproof, nationwide, worldwide, tenfold, etc.

### ***Adjectival phrases or modifiers***

When two or more words are used to form an adjective (a compound modifier) preceding a noun they are hyphenated to prevent confusion or misinterpretation, for example:

a stainless-steel vessel	a blood-red colour
a well-defined quantity	a state-of-the-art technique
a long-standing effect	small-scale production

However, when such modifiers follow a noun they will normally not require a hyphen.

a vessel made of stainless steel	the colour was blood red
the quantity is well defined	this technique is state of the art
the effect is likely to be long standing	production on a small scale

*Scientific modifiers* tend *not* to be hyphenated in technical contexts, e.g.

a liquid crystal display, a sodium chloride solution.

Do not hyphenate italicised foreign phrases such as *in situ*, *ad hoc*, *in vitro* and *in vivo*.

Do not automatically hyphenate two or more modifiers; think about the meaning of the expression.

A small-scale factory <i>a factory producing a small amount of something</i>	A small scale factory <i>a small factory producing scales</i>
A little-used car <i>a car that has not been used very much</i>	A little used car <i>a small car that is not new</i>
crude-oil production statistics <i>if you mean that the oil is crude</i>	crude oil production statistics <i>if you mean that the statistics are crude</i>

No hyphen is used when the adjectival compound begins with an *adverb*.

a frequently made error; slightly used equipment; newly discovered compounds

Note the difference between the following:

cheese making (the noun, without a hyphen) **BUT...**  
cheese-making equipment (adjective, with a hyphen)

to run off (verb, without a hyphen) **BUT...**  
run-off (the noun, with a hyphen)

### ***Time and distance***

Hyphens are used together with periods of time or measures of distance when preceding a noun as they then act as modifiers.

a five-hour experiment, *but* six hours' fermentation *or* a twenty-metre pipe, or a 20-m pipe



Note the singular form of the unit of measurement (hour, metre, etc).

Hyphens are also used to divide words at the end of a sentence. The rules governing

word division in English and Swedish are, however, different. You must therefore not divide words *by hand* in an English text if you do not know the English rules. Use the automatic word division function in your word processor *only* if you have the English version installed. See: [www.wordforword.se/download/WordDiv.pdf](http://www.wordforword.se/download/WordDiv.pdf) for more information on word division in English.

## Dashes

There are actually two kinds of dashes; one called an *en rule* or *en dash*, and the other an *em rule* or *em dash*. An *en* rule takes its name from the width of the letter *n* in the text (–), and an *em* rule the width of the letter *m* (—).

The Oxford University Press and most American publishers use an unspaced em rule (—) as a parenthetical dash (instead of a pair of brackets), while other British publishers use an en rule with spaces on either side ( – ). For the sake of simplicity, let us assume that theses from Lund University are written in British English and will *not* be published by the Oxford University Press. When referred to below, a dash is an en dash (–). An example of its use as a parenthetical dash is given below.

A third possibility – and perhaps the best – is to use background correction.



Until recently, the use of dashes to introduce pauses in sentences was very limited in scientific texts. Use them sparingly, never more than one pair per sentence, and preferably no more than one pair per paragraph.

A dash can also be used when expressing *intervals* or *ranges*.

pp. 23–36    35.7–37.6 m<sup>2</sup>,    1990–9,    1999–2003,    30–40% etc.

In the days before desktop publishing, a hyphen was used to express intervals. You may continue to use a hyphen, or insert a dash, but be consistent.

A dash is also used to replace the words *to* or *and* between words of equal importance. For example:

wave–particle duality	dose–response curve
height–depth ratio	cost–benefit analysis
Arab–American League	current–voltage graph
Beer–Lambert law	Permian–Carboniferous boundary
C–H bonds	c–C <sub>6</sub> H <sub>5</sub>



An en dash can be inserted by pressing Ctrl + Num – or Insert – Symbol... – Special characters in MS Word.

Note: If you write a hyphen in running text preceded and followed by a space in MS Word, it will probably change it to an en dash, in the belief that you meant to write a dash and not a hyphen (as hyphens are not normally preceded and followed by spaces). This can either be a nuisance, or a quick way of writing a dash (instead of Ctrl + Num –, or Insert – Symbol...).

## Numbers and their Units

Numbers can be written out in words or expressed as figures. In scientific texts it is more normal to use figures than the written word, although words are required or preferable in some cases. Some style guides recommend that numbers below ten or eleven be written out. This is fine in expressions such as, “five experiments were performed”, but would hardly be appropriate in the expression: “five kg sodium sulphate and seven l water”.

### Numbers

Never start a sentence with figures (digits), write the number out or rephrase the sentence:

*Not:* 49% of the subjects were women ...

*but:* Forty-nine percent of the subjects were women ...

*or:* Almost half (49%) of the subjects were women ...

Note that the use of a hash symbol (#), e.g. Subject #2, is American English.

When writing out numbers from 21 to 99, use a hyphen:

twenty-seven, forty-nine, seventy-six, etc.

Hyphens are used when writing out *fractions*, such as:

two-thirds, three-quarters, nine-tenths, etc. (See p.20 on hyphens in fractions.)

When fractions are given as decimals, include a zero: i.e. write 0.75 and not .75. (This does not apply to quantities, such the level of probability, that never exceed 1.)

Write out ordinal numbers such as *first, firstly, second, secondly*, etc. in running text. When using the figure form, write 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup>, etc. *or* 1st, 2nd, 3rd, 4th, etc. (The use of a colon in such expressions is Swedish.)

The numbers 1, 2, 3 etc. are *integers*, while those with decimals (1.0, 3.14159, etc.) are called *real* numbers. The number 1 is thus not the same as 1.0.



A decimal *point* (.) is used in English to separate the whole part from the decimal part, and not a *comma* (,) as in other European languages.

Thus, 10.449 is about 10½, while 10,449 is about ten thousand, five hundred.

When giving numbers in tables or figures make sure to give the same number of decimal places, i.e. 3.50, 3.55, 3.60, 3.65, etc. The zero is just as important as the five in the second decimal place, as this is a question of scientific precision, not just a style issue.

Do not mix figures and abbreviated forms of units.

9 m	or	nine metres
6 h	or	six hours
1 Ω	or	one ohm

In general texts, numbers greater than four figures (9999) are divided by a comma, e.g. *a population of 20,000, a turnover of 550,000 million dollars.*

In scientific texts, a (nonbreaking) space should be used:

2 000 000      14 349 950      0.000 025 etc.



A nonbreaking space is inserted by pressing Ctrl + Shift + Space, or Insert – Symbol... Special Characters...

In the USA and now in Britain, a *billion* is a thousand million ( $10^9$ ). (Formerly, a British billion was a million million or  $10^{12}$ .) (Did you know that a *milliard* was the old name for a thousand million in the UK? I didn't!)

A *trillion* in both the USA and Britain is now a million million ( $10^{12}$ ).

However, note that in France and Germany these terms are ambiguous. Explain what you mean by a million, billion etc. or use the  $10^x$  convention.

## Time

Write years as 1997, 1887, 2004 etc. rather than '99, '04 etc. (Note that the SI abbreviation for years is *y*, not *yr* or *yrs*.) In historical contexts note: 250 BC, but AD 109.

Dates are written: *5 January 2004* in BrE and *January 5, 2004* in AmE, according to the Oxford Guide to Style, although these conventions are not strictly adhered to.

Be very careful when using all-figure dates as conventions vary and may lead to misunderstanding. All the dates below are January 5, 2004.

Swedish (yy-mm-dd)	British English (d.m.y)	American English (m/d/y)	ISO (yyyy-mm-dd)
04-01-05	5.1.04	1/5/04	2004-01-05

To avoid confusion, write dates clearly, preferably giving the month (abbreviated if necessary).

The days of the week and months of the year are written with capital first letters and are abbreviated as follows:

Sun.	Mon.	Tue.	Wed.	Thur.	Fri.	Sat.					
Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.

When giving spans of dates “elide” to the fewest number of digits, e.g. 1804–7, 1918–26 and 2001–4. However, do not elide dates spanning different centuries: 1998–2003. Use the full date in headings, titles and tables.



**Note:**  
*from 2001 to 2003*; but *between 2001 and 2003*  
 the *1990s*; not the *1990's*

*The time of day* is given in general texts as 9 a.m. or 6 p.m., etc. The abbreviations a.m. and p.m. are derived from the Latin, *ante meridiem* (before noon) and *post meridiem* (after noon) and are written in Roman style. Expressions such as, *in the morning* or *in the afternoon* or *evening*, are superfluous together with a.m. and p.m.

When using the *24-hour* system, write 09.00 or 18.00 with a full stop. Note that midday and midnight are expressed as 12.00 and 24.00, respectively.

## Place

In technical work, degrees of latitude and longitude are written:

40° 42.5' N 74° 1.25' W

As N, S, E and W are specified, the addition of lat. or long. is superfluous. If you prefer to use latitude and longitude, write: Lat. 40.980810, Long. -74.093665

## Currency

Symbols for various currencies are printed close up to the amount.

£100	£5 million	45p
US\$20,000	\$500 million	90¢
€900	€50 million	50¢
SEK500	SEK20 billion	20 öre

Million may be abbreviated M and billion bn, both written close up: £5M and €20bn.

In table headings where thousands of Swedish kronor, euros or dollars are given, write: EUR '000 or EUR thousand, etc.

Sometimes it may be necessary or advisable to “gloss” one currency in terms of another, e.g.

The company was valued at SEK300 million (€32.5 million).

The cost of producing ethanol is thus SEK10 (\$1.4) per litre.

The exchange rate (and date) should be given in brackets or in a footnote.

It is also possible to write out amounts in words: 50 euros, 195 dollars, etc., but this is uncommon in technical texts.

## Translating Swedish & Foreign Names

### Scandinavian versus Nordic

*Scandinavia* is, strictly speaking, the Scandinavian peninsula of *Norway* and *Sweden*, but the term generally includes *Denmark* and *Finland* as well. As a cultural term, *Scandinavian* also embraces *Iceland* and the *Faeroes*. The countries of the Nordic Council include *Denmark*, *Finland*, *Iceland*, *Norway*, *Sweden*, the *Faeroes*, *Greenland* and the *Åland* islands. Nordic is thus a broader term.

You will probably find that most non-Nordic readers will be more familiar with the term Scandinavian and more likely to be able to relate to it than Nordic.

### Countries and cities

When writing in English, use the English names of countries and cities when they exist. A good English atlas or a good dictionary will help you with the names of countries, cities, lakes and seas.

Swedish	English
Helsingfors	Helsinki
Göteborg	Gothenburg
Tjernobył	Chernobyl
Vitryssland	Belarus
Köpenhamn	Copenhagen

### Other geographical names

Use the name in English if there is one, or the original name explaining to the reader what it means. For example:

Skåne	Scania
Vättern	Lake Vättern
Stortorget	Stortorget (the main square)
Kattegat	The Kattegat, the strait between Denmark and Sweden
Bottenhavet	the Baltic Sea
Mälardalen	the Mälaren Valley
Nissan	the River Nissan
Kävlingeån	<i>Kävlingeån</i> , the river flowing from Lake Vomb ( <i>Vombsjö</i> )

### Buildings etc.

Translations of these names can generally be found in dictionaries or on the internet. Note that *slott* can be translated as palace, castle or manor, depending on the size and importance of the building.

Domkyrkan i Lund	Lund Cathedral
Globen	the Stockholm Globe
Stadshuset	the City Hall
Öresundsbron	the Øresund Bridge or the Øresund Link
Drottningholm slott	Drottningholm Palace
Trollenäs slott	Trollenäs Manor



## Organisations

Check to see if the organisation has an official English name. This can be done in dictionaries such as Gullbergs Svensk-Engelsk fackordbok (published by Norstedts), or Utrikes namnbok ([http://justitie.regeringen.se/klarsprak/pdf/utrikes\\_namnbok2003.pdf](http://justitie.regeringen.se/klarsprak/pdf/utrikes_namnbok2003.pdf)), by checking their website, or by telephoning directly. Do not try to translate the name yourself. Some organisations do not have direct translations of their names. In such cases, use the Swedish name together with an explanation.

FOA, Försvarets forskningsanstalt	The National Defence Research Establishment
Vetenskapsrådet	The Swedish Research Council
Försäkringskassan	The National Social Insurance Office
KK-stiftelsen	The Knowledge Foundation
Kunskapsbron	“Kunskapsbron”, an organisation for technology transfer

## Companies

Company names should be quoted as they are and an explanation given when necessary.

Telia	“Telia”, the Swedish telecom operator
IKEA	IKEA
Posten AB	“Posten”, the Swedish postal service
Ericsson	“Ericsson”, the well-known telecommunications company
Apoteksbolaget	“Apoteksbolaget”, the National Corporation of Swedish Pharmacies

## People

People’s names are generally not translated, but historical or biblical names are often different in English and Swedish. Some examples are given below.

Carl von Linné	Carl Linnaeus
Sankte Per	Saint Peter
Kung Bore	Jack Frost
Påven Johannes Paulus	Pope John Paul
Djinghis Kahn	Genghis Kahn
Platon	Plato
Aristoteles	Aristotle

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[http://europa.eu.int/comm/translation/writing/style\\_guides/english/frame\\_index\\_en.htm](http://europa.eu.int/comm/translation/writing/style_guides/english/frame_index_en.htm)

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## **Appendix**

Selected pages from Johanna Söderström's thesis

# Optimisation of Two-step Steam Pretreatment of Softwood for Bioethanol Production

Johanna Söderström

Department of Chemical Engineering  
Lund University, Sweden  
2004

Akademisk avhandling för avläggande av teknologie doktorsexamen vid Tekniska fakulteten vid Lunds universitet. Avhandlingen kommer att försvaras på engelska vid en offentlig disputation på Kemicentrum, Getingevägen 60, Lund, hörsal B, fredagen den 5 mars 2004 kl 10.30.

Fakultetsopponent är Professor Edward Kendall Pye, Vice President R&D, Lignol Innovations Corp., Vancouver, BC, Canada.



**LUND**  
UNIVERSITY

OPTIMISATION OF TWO-STEP STEAM  
PRETREATMENT OF SOFTWOOD  
FOR BIOETHANOL PRODUCTION

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<b>Title and subtitle</b> Optimisation of Two-step Steam Pretreatment of Softwood for Bioethanol Production		
<b>Abstract</b> <p>Fuel ethanol can be produced from lignocellulosics by an enzymatic process consisting of steam pretreatment, enzymatic hydrolysis, fermentation and ethanol refining. This thesis deals with the steam pretreatment step in the enzymatic process used for ethanol production from softwood, which is an abundant lignocellulosic raw material in the Northern hemisphere.</p> <p>Steam pretreatment is an effective method of hydrolysing hemicellulosic sugars, as well as enhancing the accessibility of enzymes to the cellulose. Too mild conditions will result in a material with low enzymatic digestibility. On the other hand, too harsh pretreatment conditions will degrade some sugars to by-products causing a decrease in the yield, as well as inhibition in the following process steps.</p> <p>In this thesis a two-step steam pretreatment process is described where hemicellulosic sugars are recovered after the first pretreatment step, performed under mild conditions, and the enzymatic digestibility of cellulose is increased in the second pretreatment step, performed under harsher conditions. Prior to steam pretreatment either SO<sub>2</sub> or H<sub>2</sub>SO<sub>4</sub> was added to catalyse the hydrolysis. Impregnation with SO<sub>2</sub> in both pretreatment steps resulted in the highest overall ethanol yield, regardless of whether simultaneous saccharification and fermentation or separate enzymatic hydrolysis and fermentation was employed.</p> <p>Experimental data obtained when steam pretreatment and the enzymatic steps were performed in a process development unit resulted in valuable information on overall sugar and ethanol yields.</p> <p>Two-step steam pretreatment results in higher overall ethanol and sugar yields than one-step steam pretreatment. An economic evaluation shows that although the ethanol yield is higher, this advantage is somewhat offset by the higher capital and energy costs. It is possible to perform the second step without a pressure reduction and re-impregnation of SO<sub>2</sub>, without a reduction in ethanol yield. The production cost for such a process is lower than for a one-step steam pretreatment process. However, the process concept has yet to be proved on pilot scale.</p>		
<b>Key words</b> Ethanol production, steam pretreatment, SO <sub>2</sub> , H <sub>2</sub> SO <sub>4</sub> , SSF, enzymatic hydrolysis, fermentation, softwood, spruce, economy		
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**Signature** \_\_\_\_\_ **Date:** January 23, 2004

# List of publications

This thesis is based on the following papers, which will be referred to by their roman numerals in the text.

- I Söderström, J., Pilcher, L., Galbe, M. & Zacchi, G.  
Two-Step Steam Pretreatment of Softwood with SO<sub>2</sub> Impregnation for Ethanol Production. *App. Biochem. Biotechnol.* 2002, 98-100, 5-21.
- II Söderström, J., Pilcher, L., Galbe, M. & Zacchi, G.  
Two-step Steam Pretreatment of Softwood by Dilute H<sub>2</sub>SO<sub>4</sub> Impregnation for Ethanol Production. *Biomass Bioenergy* 2003, 24, 475-486.
- III Söderström, J., Pilcher, L., Galbe, M. & Zacchi, G.  
Combined Use of H<sub>2</sub>SO<sub>4</sub> and SO<sub>2</sub> Impregnation for Steam Pretreatment of Spruce in Ethanol Production. *App. Biochem. Biotechnol.* 2003, 105-108, 127-140.
- IV Söderström, J., Galbe, M. & Zacchi, G.  
Comparison of SHF and SSF of Two-step Steam-Pretreated Softwood for Ethanol Production. *J. Wood Chem. Technol.* (Submitted)
- V Söderström, J., Galbe, M. & Zacchi, G.  
The Effect of Washing in One- and Two-Step Steam Pretreatment of Softwood for Production of Ethanol. *Biotechnol. Progr.* (Accepted)

Other related publications by the author:

Wingren, A., Söderström, J., Galbe, M. & Zacchi, G.  
Process Considerations and Economic Evaluation of Two-Step Steam  
Pretreatment for the Production of Ethanol from Softwood. *Biotechnol. Progr.*  
(Submitted)

Söderström, J., Galbe, M. & Zacchi, G.  
Two-step Steam Pretreatment of Softwood for Ethanol Production.  
Proceedings of ISAF XIV, Phuket, Thailand, 2002



## My contribution to the papers

- Paper I I did practically all the work.
- Paper II I planned the study and evaluated the results. I also performed some of the experimental work and wrote the paper. Dr Robert Eklund at the Mid Sweden University, Örnköldsvik, Sweden, performed the first pretreatment step. Some of the second-step pretreatment experiments as well as some of the SSF and enzymatic hydrolysis experiments were performed by MSc Linda Pilcher under my supervision.
- Paper III I planned the experiments and did most of the experimental work, except the first pretreatment step, which was performed by Dr Robert Eklund. I performed the evaluation of the results and wrote the paper.
- Paper IV I did essentially all the work.
- Paper V I developed the experimental plan and evaluated the results. MSc Gustav Sassner performed most of the experiments under my supervision. I wrote the paper.



# Acknowledgements

During the five years of work that has resulted in this thesis, many people have contributed in one way or another. I am very grateful to all of you; but there are some who deserve special thanks.

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Thank you, mum and dad for your endless love and support throughout the years and for introducing me to science when I was very young. Thank you Andreas and David for always being such great brothers.

Finally, the Swedish Energy Agency is gratefully acknowledged for their financial support of this work.

## Populärvetenskaplig introduktion till avhandlingen

Den här avhandlingen handlar om hur bränsleetanol kan tillverkas från barrved för att användas som ersättning för bensin. Genom att använda etanol tillverkad av biomassa som bränsle, bidrar man inte till koldioxidutsläppen. Biomassan, eller veden, har under sin livstid ur luften tagit upp motsvarande mängd koldioxid, som släpps ut vid den slutliga förbränningen. Utnyttjande av biobränslen medför därför ett slutet kretslopp, dvs. det sker ingen nettoproduktion av koldioxid. Den globala koldioxidhalten ökar stadigt på grund av förbränningen av fossila bränslen och bidrar till växthuseffekten.

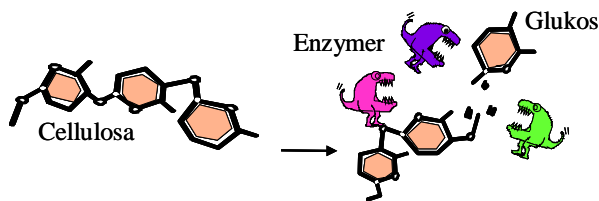
Det är mycket svårare att framställa etanol ur ved än att utgå från socker eller stärkelse, dvs. sockerbetor eller säd. Trä är ett så kallat lignocellulosamaterial. Det betyder att det huvudsakligen består av tre komponenter, nämligen cellulosa, hemicellulosa och lignin. I trä finns sockret i form av cellulosa och hemicellulosa. Cellulosa består av långa, raka kedjor av sammanlänkade sockermolekyler, glukos. Runt dessa cellulosakedjor ligger hemicellulosa, vilken är uppbyggd av grenade kedjor av sockermolekyler, delvis bestående av andra sockermolekyler än glukos, och lignin. Cellulosa och hemicellulosa kan omvandlas till etanol, medan ligninet antingen kan användas som bränsle för processen eller säljas som ett fast torkat bränsle med högt energiinnehåll.

För att etanol ska kunna konkurrera med petroleumbaserade bränslen som diesel och olja, måste framställningsprocessen optimeras. Träflis förbehandlas och delas upp i en vätskefas, som innehåller sockerarter från hemicellulosan, och ett fast material, som består av cellulosa och lignin. En liten del av det fasta materialet används för att tillverka enzymer som bryter ner cellulosa. Den resterande delen av det fasta materialet bryts ner till enkla sockerarter med hjälp av de producerade enzymerna. De bildade sockren jäses till etanol som sedan destilleras för att nå en hög koncentration.

I ett naturligt material sitter cellulosan väl inbäddad mellan hemicellulosa och lignin. Om enzymer tillsätts händer ingenting. Enzymerna kommer helt enkelt inte åt att bryta ner cellulosan eftersom hemicellulosa och lignin är i vägen. Förbehandling av råmaterialet är därför nödvändigt för att göra det möjligt för enzymerna att penetrera in i fibrerna och bryta ner cellulosan till enkla sockerarter, glukos. Förbehandlingen görs med hjälp av ånga. Det är det här steget, förbehandlingen, som huvuddelen av avhandlingen handlar om. Veden hackas först sönder till flis. Detta flismaterial behandlas sedan med ånga med hög temperatur i en tryckbehållare under några minuter, och ångan tränger in i veden. Då trycket sänks till normalt lufttryck expanderar ångan och veden sprängs sönder. Hemicellulosan bryts ner av värmen, och dess sockerarter återfinns i den bildade vätskan. Vätskan bildas då den värmande ångan

kondenserar. Den fasta återstoden består av lignin och cellulosa, vilken nu är mer tillgänglig för enzymerna.

Enzymer är proteiner som i det här fallet påskyndar nedbrytningen av cellulosa till glukos. Enzymer som bryter ner cellulosa kallas cellulaser. Enzymerna produceras av en rötsvamp som härrör från Söderhavet. Denna ställde till med stora problem för de amerikanska soldaterna under andra världskriget där den förstörde kläder och annan materiel som bestod av cellulosa. I hydrolyssteg bryts cellulosan i den förbehandlade träflisen ner till socker (glukos) med hjälp av enzymer. Naturlig cellulosa är resistent mot hydrolysis (nedbrytning) på grund av sin natur. Det behövs därför flera olika enzymer för att klara av nedbrytningen. En del cellulaser bryter ner cellulosamolekylen i kortare kedjor, andra "klipper av" enheter av länkade glukosmolekyler från kedjorna, ytterligare andra klyver sådana enheter av två glukosmolekyler, och det bildas socker (glukos). Enzymerna är kräsna när det gäller den omgivning de lever i. Inte nog med att de vill ha "rätt" sorts mat, de trivs också bäst vid en viss temperatur och ett visst pH.



*Enzymer bryter ner cellulosa till glukos.*

Vanlig bagerijäst omvandlar glukos från cellulosan till etanol och koldioxid med hjälp av enzymer. Det är en väl beprövad metod som testats under tusentals år, vid jäsnings av öl och vin, och vid brödbakning. Koncentreringen av etanolen är inget problem, eftersom man inte behöver tänka på att rena den. Föroreningar, till exempel finkeloljor, som inte får finnas i konsumtionsspirit förbättrar snarare motoralkoholens egenskaper.

Etanolprocessen måste optimeras både tekniskt och ekonomiskt. Avhandlingen beskriver processoptimeringar och ekonomiska beräkningar för det första steget i processen, förbehandlingen.

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# Chapter 1

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## Introduction

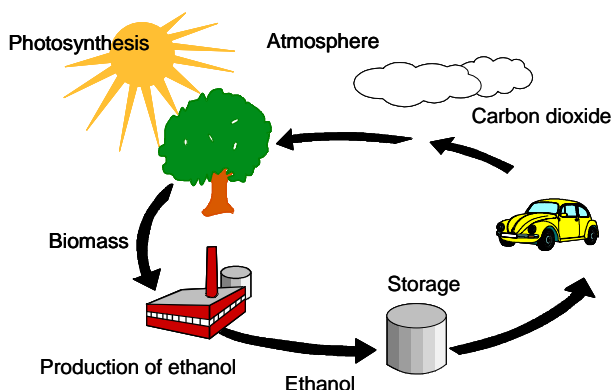
The oil crises of the nineteen seventies resulted in the awakening of interest in alternatives to petrol and diesel to reduce our dependence on oil-producing countries. One of the fuels considered was ethanol. However, when oil prices decreased again, ethanol became too expensive an alternative. In the eighties the so-called greenhouse effect became known and the desire to reduce the emission of greenhouse gases, such as carbon dioxide was increased. Thus, ethanol once again became the subject of discussion.

Interest in producing biofuels, such as ethanol, has grown further since 1997, when the Kyoto protocol was proposed to limit the global net emission of carbon dioxide. The EU adopted a white paper for a Community strategy and action plan, “Energy for the Future” stating that 12% of the total energy consumption should come from renewable sources in 2010. One way of reducing environmental effects and our dependence on fossil fuels is to use renewable bioethanol produced from domestic resources.

In Sweden, the transportation sector is responsible for about one-third of all carbon dioxide emission, around 20 Mton per year. In the year 2000 the total energy consumption in Sweden was 398 TWh, of which 92 TWh originated from transportation. Petrol and diesel constituted 83% of the energy consumed within the transportation sector (1).



Ethanol can be produced from renewable resources such as agricultural waste and forest residues. New crops and forest plantations assimilate the carbon dioxide that is released during the production and combustion of ethanol. Thus there is no net emission of carbon dioxide to the atmosphere, see Figure 1.1. Another advantage of using fuel ethanol is the decrease in the emission of CO and non-combusted hydrocarbons that form smog (2).



*Figure 1.1* The carbon cycle.

Today, the major use of ethanol is as an oxygenated fuel additive. One attractive advantage of introducing ethanol as a fuel is the possibility of using it neat or in a mixture with petrol in conventional internal combustion engines, the spark-ignition engine. Today, all cars with a catalyst can be run on a mixture of 90% petrol and 10% ethanol, and newer cars can use up to 20% ethanol without adjustment of the engine. Engines that can run on pure ethanol and flexible fuel vehicles (FFV) that can use any mixture of petrol and ethanol are available. Several positive effects are achieved when using a blend of ethanol and petrol. As ethanol has a higher octane number (93-113) than petrol, the need for toxic octane-enhancing additives is reduced. Ethanol provides oxygen for combustion, which leads to reduced emissions of carbon monoxide and non-combusted hydrocarbons. Ethanol may also be used in compression-ignition engines to replace diesel. However, it is necessary to add an emulsifier when mixing ethanol with diesel, and in a cold climate it may be difficult to start the engine.

Although ethanol has a volumetric energy content of only 65% of that of petrol, one litre of a blend of 15% ethanol in petrol can replace one litre of petrol. If ethanol completely replaces petrol it is still possible to drive 75-80% of the distance possible with the same volume of petrol, due to the higher engine efficiency (15% higher) obtained with ethanol (2,3). When comparing

the costs of ethanol and petrol it is essential that these differences in energy content be borne in mind.

In spite of the advantages associated with ethanol, Brazil, the USA and Canada are the only countries that produce large quantities of fuel ethanol. The raw materials used are sugar and maize. However, within the European Union it is recommended that petrol for internal combustion engines be mixed with 5% ethanol before 2010 (3). In Sweden, an ethanol plant for production based on grain, with a capacity of 50 000 m<sup>3</sup>, was started up in 2001. In addition, a pilot plant for the production of ethanol from softwood is today (2004) under construction in Sweden. The capacity will be 2000 kg raw material per day, corresponding to 400-500 litres ethanol per day. Initially an acid hydrolysis process will be used, but a process employing enzymatic hydrolysis (EH) or simultaneous saccharification and fermentation (SSF) will be tested after one year. The results obtained from the studies described in this thesis have been of great value in the design of the process.

One of the main reasons for ethanol not being produced on a large scale is that the production cost is still too high. Despite the fact that the efficiency of ethanol production is steadily increasing, tax relief is still required to make fuel ethanol commercially competitive with petrol and diesel (3). To attain an economically viable process the production cost must be reduced to about the same level as for fossil fuels. The cost of the raw material constitutes one of the major contributions to the total production cost, which makes it necessary to use the cheapest raw materials possible (4,5). For example, the raw material accounts for 40% to 70% of the production cost when using sugar cane or maize as a feedstock (6). Lignocellulosic biomass is an abundant and cheap raw material. It accounts for 50% of the total biomass on earth, with an estimated annual production of 10-50·10<sup>12</sup> kg (6).

In the Northern hemisphere the dominating source of lignocellulosic material is softwood. Fifty-five percent of Sweden's area is covered with forest, of which 85% is softwood (7). Being such an abundant and low-cost feedstock, softwood is of great interest for the production of bioethanol in several countries, including Sweden, Canada and the western USA (7-9).

The total ecologically sustainable energy potential of woody biomass for fuel production in Sweden is about 130 TWh per year. Today the production is about 40 TWh per year, leaving about 90 TWh for potential use (10). This roughly corresponds to the energy consumption of the transportation sector (1). However, due to the shutdown of some of Sweden's nuclear power plants, some biomass will be required to generate heat and power, and thus only a small proportion will be available for ethanol production; enough to replace about 20% of the petrol and diesel used today.

The technology used to produce ethanol from crops containing starch, such as wheat, barley and potatoes, is well established and has been used for centuries for the production of alcoholic beverages. However, for fuel ethanol production a cheaper raw material is needed. Lignocellulosic waste such as agricultural residues, municipal waste, energy crops and logging waste from forestry are suitable raw materials. Unfortunately, the production of ethanol from lignocellulosic materials is much more complex and not yet fully optimised.

When ethanol is produced from lignocellulosic biomass, the sugars in the hemicellulose and cellulose are converted to ethanol using either acid or enzymatic processes. Acid and enzymes break down the cellulose and hemicellulose to sugars, which can be fermented by bacteria or yeast. The weak ethanol solution is then concentrated by distillation. The solid residue, lignin, has a high energy content and can be used as a solid fuel.

Man has known for more than 100 years how to hydrolyse cellulose. This can be done with either concentrated or dilute acid. Processes employing concentrated acids, such as sulphuric and hydrochloric acid, result in high yields but are associated with problems concerning corrosion and acid recovery. In addition, large amounts of gypsum are formed during neutralisation of the acid hydrolysate when  $\text{H}_2\text{SO}_4$  is used.

Dilute acid hydrolysis is usually performed at a high temperature. The process is non-specific. Sugars may be degraded to furfural, 5-hydroxymethylfurfural (HMF) and other compounds, reducing the sugar yield and also causing problems in the fermentation step (11-14).

The enzymatic process provides more specific conversion of cellulose and thus has the potential to give higher yields of ethanol. It is the enzymatic process that is discussed in this thesis.

## **1.1 The aim and outline of the thesis**

The main purpose of this work was to investigate the pretreatment step in the wood-to-ethanol process based on softwood. For the process to be feasible, it is essential to use optimal pretreatment conditions in order to maximise the yield of ethanol in the subsequent process steps and to minimise the formation of by-products. The enzymatic process has the potential of producing ethanol from softwood in an environmentally friendly and cost-effective way. The

pretreatment step is one of the most costly in the process and it is thus important to improve and to optimise it as much as possible.

The first three chapters of this thesis provide background information and put this work into perspective. The lignocellulosic biomass is described, and differences between various kinds of raw materials are discussed. A short introduction to the production of ethanol from biomass with different techniques, as well as problems associated with degradation and inhibition, is also given.

In Chapter 4 various pretreatment methods that can be used in the wood-to-ethanol process are described. The mechanisms of steam pretreatment are presented together with some previously obtained results.

The next three chapters summarise the results presented in *Papers I-V*. In Chapter 5 optimisation of a two-step steam pretreatment method for spruce is discussed, and a comparison of different pretreatment strategies is presented. Chapter 6 describes the differences between small and large scale in the pretreatment step, and the differences between the different process configurations SSF (simultaneous saccharification and fermentation) and SHF (separate hydrolysis and fermentation). Some aspects of the economy of two-step steam pretreatment are discussed in Chapter 7.

Finally, Chapter 8 gives some concluding remarks and suggestions for future work.



# Chapter 2

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## Lignocellulosic Materials

Wood has long been used as a raw material. Thousands of years ago giant forests covered large areas of the earth's surface. Man used wood for fuel and for tools. However, wood is also a very modern raw material. It is used for building and furniture, but is also a basic substance in pulp and paper, fibre products, films, additives and many other products. In the presented work, wood has been used as a raw material for the production of fuel ethanol. Oddly enough, primeval forests form the basis of many of the fossil fuels we use today, such as oil and coal.

### 2.1 Composition of lignocellulosic biomass

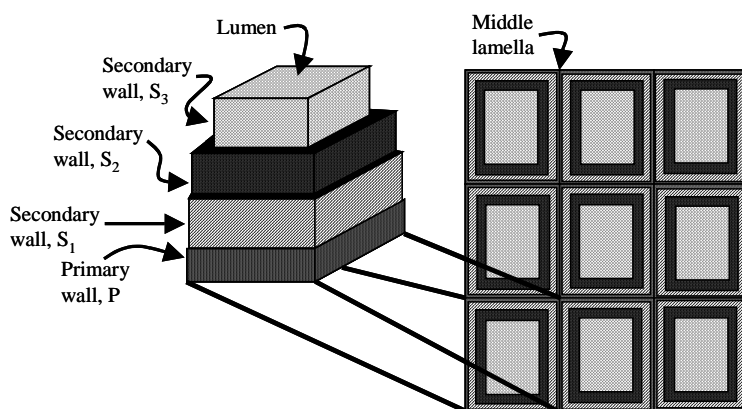
Lignocellulosic biomass from different plant species may appear quite different, however, the chemical composition is fairly similar. All lignocellulosic material consists mainly of three components: cellulose, hemicellulose and lignin. These three polymers comprise about 90% of the dry material. The rest consists of small amounts of ash, soluble phenolics and fatty acids called extractives, and other minor components. Some variation in the composition can be seen between different species and within the same species depending on environmental and genetic variability, and within the same plant

between trunks, bark and branches. Table 2.1 gives typical compositions of some different lignocellulosic materials.

**Table 2.1** *Composition of various lignocellulosic materials as percentage of dry material. (–, below detection limit; n.d., not determined)*

	Glucan	Mannan	Xylan	Galactan	Arabinan	Lignin	Ref.
<b>Hardwoods</b>							
White oak	43.6	2.9	18.0	0.4	2.4	23.2	(15)
Yellow poplar	49.9	4.7	17.4	1.2	1.8	18.1	(15)
Birchwood	38.2	1.2	18.5	–	n.d.	22.8	(16)
Aspen	43.2	0.2	15.1	–	–	16.7	(16)
Willow	36.8	1.9	12.7	n.d.	1.2	20.7	(17)
<b>Softwoods</b>							
Pinus radiata	42.8	11.3	5.9	2.5	1.6	27.2	(16)
Pine wood	37.7	7.0	4.6	–	–	27.5	(16)
Spruce wood	41.9	14.3	6.1	–	1.2	27.1	(16)
Spruce bark	27.3	3.2	3.2	–	4.1	37.1	(16)
<b>Other</b>							
Bagasse	42.7	–	21.0	–	0.6	18.6	(16)
Wheat straw	36.5	0	18.4	–	2.2	17.6	(16)
Corn stover	36.0	–	19.8	1.3	2.8	17.8	(18)
Douglas fir	42.0	23.5	–	–	–	27.8	(19)

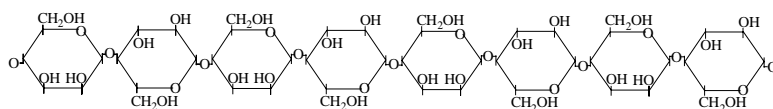
Wood cells are composed of fibres held together by the middle lamella, Figure 2.1. The cellulose fibrils in the thin primary wall (P) are embedded in a matrix of lignin and hemicellulose and arranged in a network, allowing the cell to expand while growing. The secondary wall consists of three layers, S1, S2 and S3, where S3 is sometimes called the tertiary wall. The second layer, S2, is the thickest layer in the wood cell and comprises about 80% of the wood. This layer is responsible for the strength of the fibres. The lumen is the inner part of the wood cell. Between the individual cells there is a thin layer, the middle lamella, which “glues” the cells together. This layer is in principle free of cellulose, consisting mainly of lignin (20).



**Figure 2.1** Structure of wood cells (adapted from Fan et al. (20)).

## 2.1.1 Cellulose

Cellulose is a linear polymer of D-glucose molecules. These units are bound together by  $\beta$ -(1,4)-glycosidic linkages. Two adjacent glucose units are linked by the elimination of one molecule of water between their hydroxylic groups at carbon atoms 1 and 4. The repeating unit in the cellulose chain is strictly speaking the cellobiose unit, consisting of two glucose units, as shown in Figure 2.2. The degree of polymerisation (DP), that is, the number of glucose units in the cellulose chain, is typically in the range of 7500-15 000 for plant cellulose. Cellulose in spruce has a DP around 8000 (21).



**Figure 2.2** The structure of cellulose.

The glucose molecules in the cellulose are free to rotate; this may cause the OH groups to form H bridges both within its own molecule (intramolecular) forming fibrils, and with neighbouring chains (intermolecular), forming microfibrils. This leads to a very rigid macromolecular structure, which is responsible for the surprising strength of plants.

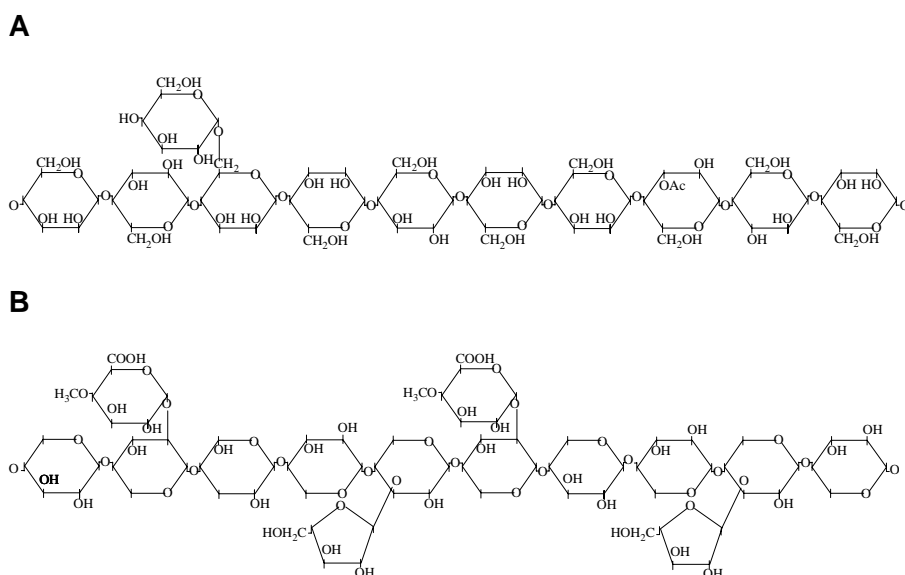
Most of the cellulose chains are highly ordered and crystalline, but some regions have a lower crystallinity between the fibrils, *i.e.* amorphous regions.



These regions are less recalcitrant to enzymatic hydrolysis (20). The degree of crystallinity varies with plant species. However, the pore size is considered to be of great importance for enzymatic digestibility (22,23).

### 2.1.2 Hemicellulose

Hemicelluloses, or polyoses, found in wood are mainly short, highly branched heteropolymers of hexoses such as glucose, mannose and galactose, and pentoses such as xylose and arabinose (24). Hemicellulose also presents various substitutes, *e.g.* acetyl groups or uronic groups that are attached to the main chain or to the branches, see Figure 2.3. The linkages between these compounds are various types of glycosidic bonds (21). The degree of polymerisation ranges from 20 to 300, which is much lower than for cellulose. The chemical structure of hemicellulose makes it highly hydrophilic, allowing for good access by water. It also explains why the degradation of hemicelluloses is very much facilitated compared with that of cellulose. Hemicelluloses are usually bound covalently to lignin and through hydrogen linkage to cellulose, thus acting as a glue between the cellulose and the lignin.



**Figure 2.3** The structure of hemicellulose from softwood, A: O-acetyl-galactomannan, B: arabino-4-O-methylglucuronoxylan.

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