A GRADUATE STUDENT'S GUIDE TO LATEX AND AMS-LATEX

DR. RAFAL ABLAMOWICZ

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Cookeville, TN 38505

A Graduate Student's Guide to
LaTeX and $\mathcal{AMS}$-LaTeX

Rafal Ablamowicz

Department of Mathematics, Box 5054

Tennessee Technological University

Cookeville, Tennessee 38501, U.S.A.

E-mail: rablamowicz@tntech.edu

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Abstract

In this article we will show the basic usage of LaTeX in writing mathematical papers. We will concentrate on describing various parts of a standard source document of type 'article', from its preamble through sections with mathematical contents to references. Usage of several standard commands from LaTeX, $\mathcal{AMS}$-LaTeX, and, `amsmath`, `amsthm`, and `amssymb` packages will be discussed. We will also briefly discuss the usage of `ttuthesis.sty` style file for composing master theses and doctoral dissertations that conform to the requirements of the TTU Graduate School.[1]

Keywords: Source file, composing or typesetting, displaying formulas, automatic referencing, LaTeX, LaTeX 2_ε, $\mathcal{AMS}$-LaTeX, TeX.

Contents

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[1] At the time of writing of this article. Please check the current style and formatting requirements in the TTU Graduate School.

1   The structure of a LaTeX document

In this article by LaTeX we mean $\text{LaTeX}\,2_\varepsilon$ which is the current version of LaTeX used by PCTEX32 ver. 4 and higher installed in Bruner 305. Many of the commands and structures described in this article, like for example `\documentclass{...}`, do not apply to the older version of LaTeX called LaTeX 2.09. The main reference for this article is [5].

The *source file* of a LaTeX document has an extension `.tex` and it is divided into several parts including a preamble and a body (see Figure 1). Fortunately, we can use ready-made templates from PCTEX32 software. Just go to Help → PCTEX Helper → Templates → Article and select the right article template. A better way is just to copy some existing file and modify it. For example, if one downloads all necessary files needed to compose a master thesis from [1], among the files one will find `Thesis.tex` source file which provides a structure (skeleton) for a thesis or a dissertation. It already contains all necessary parts of the LaTeX thesis document, so it is enough to copy it and modify the contents of the remaining files.[2] It will suffice to say that the preamble contains definitions and instructions that affect the entire document while the body is the document itself. When the document is complicated, like a master thesis, or to simplify its creation, it helps to create chapters, appendices, and even references as separate `.tex` files rather than create one big file with the entire document. This approach was taken when creating template files for the master thesis that are posted and described at [1]. Then, command `include` is used to include these separate files in the final document. Notice that in that case the skeleton file of a thesis, `Thesis.tex` has a very simple structure as shown on [1].

Once the `.tex` file is finished, it is then typeset (or composed) by pressing the button `Typeset` in PCTEX32. Notice that in the drop-down box to left of the `Typeset` button one must have a word `LaTeX` appear, and not `Plain TeX` or `AMSTeX`, or an error will result. When the document such as `sample.tex` is composed, at least two files are created: `sample.aux` and `sample.log`. One can ignore the `sample.aux` and, for the most part, also the `sample.log` unless errors are reported and typesetting is terminated. Usually, when error is spotted in the source file, PCTEX32 will stop scrolling down the `.log` file to show a line number where the error occurred, a precise place where the error occurred, and a question mark indicating a need for the user input. User can cancel typesetting altogether, or ask to open the editor in which case PCTEX32 will display the source file with the cursor positioned at the error. It is possible, of course, upon canceling the typesetting to open the `.log` file in the editor to read it more carefully. Usually the error can be located and fixed without having to open the `.log` file.

If no errors are found, PXTeX32 may need to run the typesetter again and again in order to get the mapping between the labels and the actual numbers or references right. Eventually, when finished, a `.dvi` file is created that has the same name as the source file, hence `sample.dvi` in this case. Then, a DVI viewer opens to display the file. This file can then be printed or converted to a Postscript file with extensions `.ps` from File → Save As menu. For more information see [3].

---

[2] The thesis skeleton file uses in fact a 'report' format rather than an 'article' format due to its complexity.

```
\documentclass{article}
%%% Here starts the preamble of the document
%%% Formatting commands, if needed
\setlength{\oddsidemargin}{-0.25in}
\setlength{\textwidth}{7.00in}
\setlength{\topmargin}{-0.25in}
\setlength{\textheight}{9.0in}
...
\mathsurround 1.5pt
%%% Commands to load extra packages, if needed
\usepackage{amsmath}
\usepackage{amssymb}
...
%%% Custom definitions and macros
\def\beq{\begin{equation}}
\def\eeq{\end{equation}}
...
\newcommand{\Id}{{\bf 1}}
\newcommand{\ed}{\end{document}}
...
%%% New environments
\newtheorem{lemma}{Lemma}
...
%%% Here starts the top matter of the document body
\begin{document}
\title{...}
\author{...}
\date{...}
\maketitle
\tableofcontents
%%% Here starts the abstract
\begin{abstract}
...
\end{abstract}
%%% Here starts the main matter of the document body
\chapter{...}

\section{...}

\subsection{...}

\appendix{...}
...
%%% Here starts the back matter of the document body
\begin{thebibliography}{9}
...
\end{thebibliography}
\end{document}
```

Figure 1: The structure of an 'article' document

In this article we will concentrate primarily on specific LATEX commands and examples of their usage that are useful when writing a mathematical paper or a thesis. However, it is expected that these examples will also be useful when preparing a quiz or a test. Then, it is enough of course to have one `.tex` file which is nothing else but a modified article template.

2   Proclamations

Proclamations in LaTeX are theorems, propositions, lemmas, definitions, corollaries, etc., which otherwise constitute major components of any mathematical writing. They come in different styles and can be numbered in many different ways. We will discuss the basic ones that are already predefined in LaTeX and a few more fancy ones that become available upon loading package `amsthm`. Notice that to load this package we have placed in the preamble command `\usepackage{amsthm}`. This way, we are loading three of the most useful packages that extend LaTeX:

```
\usepackage{amsmath}
\usepackage{amssymb}
\usepackage{amsthm}
```

2.1   Basic LaTeX proclamations

In order to use a proclamation, it needs to be defined first in the preamble with the command `\newtheorem`. For example, to define theorem, proposition, lemma, corollary, example, definition, and remark environments, we place the following commands in preamble:

```
\newtheorem{theorem}{Theorem}
\newtheorem{proposition}{Proposition}
\newtheorem{lemma}{Lemma}
\newtheorem{corollary}{Corollary}
\newtheorem{example}{Example}
\newtheorem{definition}{Definition}
\newtheorem{remark}{Remark}
```

To invoke any of these proclamations, it needs to be used as a an environment. For example, to state a theorem one begins the theorem environment with `\begin{theorem}` and ends the theorem with `\end{theorem}` as follows:

```
\begin{theorem}
In category {\bf Set}, the monomorphisms are just the injective functions (the functions $f$
such that $f(x)=f(y)$ implies $x=y.)$
\label{T:set1}
\end{theorem}
```

which gives

Theorem 1. *In category* **Set***, the monomorphisms are just the injective functions (the functions f such that $f(x) = f(y)$ implies $x = y$.)*

The first argument in `\newtheorem{theorem}{Theorem}` is the name for the environment that will invoke the theorem; the second argument `Theorem` is the name that will be printed. LaTeX will automatically number the proclamation and print the text in a suitable font.

Any proclamation may have an optional argument; for instance

```
\begin{theorem}[Pierce's Theorem]
In category {\bf Set}, the monomorphisms are just the injective functions (the functions $f$
such that $f(x)=f(y)$ implies $x=y.)$
\label{T:set2}
\end{theorem}
```

which gives

Theorem 2 (Pierce's Theorem). *In category* **Set***, the monomorphisms are just the injective functions (the functions f such that $f(x) = f(y)$ implies $x = y$.)*

Notice that since we have used labels `\label{T:set1}` and `\label{T:set2}` with a theorem counter `T`, we can now refer to theorems. For instance, in Theorem 2 we have shown how an optional parameter can be used. If we now insert another proclamation, its numbering will start afresh. For example,

```
\begin{definition}
An arrow $f : A \rightarrow B$ is an {\bf epimorphism} if, for any pair of arrows
$g : B \rightarrow C$ and $h : B \rightarrow C,$ the equality $g \circ f = h \circ f$
implies that $g=h.$
\label{D:epi}
\end{definition}
```

Definition 1. *An arrow $f : A \to B$ is an **epimorphism** if, for any pair of arrows $g : B \to C$ and $h : B \to C$, the equality $g \circ f = h \circ f$ implies that $g = h$.*

Notice that we have introduced yet another counter `D` for definitions. This way, Definition 1 is our definition number 1.

It is possible to number all proclamations consecutively, in which case our first definition would have number 3 since we have stated two theorems so far. It is also possible to number proclamations within a section. For more information see [5].

When the package `amsthm` is loaded, additional options become available. One of them is the style of a proclamation. There are three styles:

(i) `plain`, the most emphatic, and the default,

(ii) `definition`, less emphatic,

(ii) `remark`, the least emphatic.

The style of all proclamations is set in the preamble with the command `\theoremstyle{...}`. In this article we have used

```
\theoremstyle{plain}
```

which is also the default style used by LaTeX.

Another option available with `amsthm` is to use the $*$-ed version of `\newtheorem` which defines a proclamation that is not numbered but named. For example, in the preamble we have defined two such proclamations: `Main Theorem` and `Limit Theorem`.

```
\newtheorem*{main}{Main Theorem}
\newtheorem*{limit}{Limit Theorem}
```

For instance, we can now use the latter proclamation as follows:

```
\begin{limit}
Let $\bf D$ be a diagram in a category $\cC,$ with sets $V$ of vertices and $E$ of edges. If every
$V$-indexed and every $E$-indexed family of objects in $\cC$ has a product and every pair of maps
in $\cC$ has an equalizer, then $\bf D$ has a limit.
\end{limit}
```

Limit Theorem. *Let* **D** *be a diagram in a category $\mathcal{C}$, with sets V of vertices and E of edges. If every V-indexed and every E-indexed family of objects in $\mathcal{C}$ has a product and every pair of maps in $\mathcal{C}$ has an equalizer, then* **D** *has a limit.*

Although we have shown only a few examples, they apply also to all other proclamations.

2.2 Proof environment

The proof environment is of course for proofs. It begins with `\begin{proof}` and ends with `\end{proof}` delimiters, and it is defined in the `amsthm` package. For example:

```
\begin{proof}
This is a proof that is ended by the standard q.e.d. symbol.
\end{proof}
```

produces

Proof. This is a proof that is ended by the standard q.e.d. symbol. □

When the proof ends with an equation but not the text, it is customary to omit the q.e.d. symbol □. Then, we do the following:

```
\begin{proof}
This is a proof that is ended with an equation and not the standard q.e.d. symbol.
$$
A=B.
$$
\renewcommand{\qedsymbol}{}
\end{proof}
```

produces

Proof. This is a proof that is ended with an equation and not the standard q.e.d. symbol.

$$A = B.$$

It is possible to substitute for the word *Proof* another phrase, for example "Uniqueness", as in

Uniqueness. This is the proof. ■

where we have used an optional argument `[Uniqueness]` as follows

```
\begin{proof}[Uniqueness]
This is the proof.
\end{proof}
```

Finally, the optional argument may contain a reference to a theorem. Such reference is especially desirable if the proof does not immediately follow the proven theorem or proposition. For instance, above we stated Theorem 2. If we wanted to prove it now, we should say

```
\begin{proof}[Proof of Theorem~\ref{T:set2}]
State the proof.
\end{proof}
```

which will print

Proof of Theorem 2. State the proof. ■

For more information we again refer to [5].

3   Basic LaTeX

3.1   Formatting first

First let me say that one should not modify any formatting commands in the `Thesis.tex` file as these commands are specifically set to conform to the Graduate School requirements. Thus, the following remarks are only to be used when one works with other LaTeX documents such as, for example, quizzes or tests. Usually, when submitting an article to a professional journal, journal editors provide their own style file. One big advantage of using LaTeX is that it is very easy to change the layout of the entire article just by using a different style file. For example, the following `\documentclass{...}` command has been modified to accept an article style file from Elsevier Publishing

```
\documentclass{elsart}
...
```

while the following command accepts a style file from Kluwer Publishers:

```
\documentstyle[namedreferences]{kapproc}
...
```

Since essentially everything else may remain the same in the document, it is no surprise why LaTeX} is so popular among mathematicians and scientists.

In case one wants to modify the default page setup from `Default Template`, one should use the `Page Format Template` from PCTEX32. Notice the following commands at the top of this source file. We used these margin setting commands to format this article.

- First we set the left margin - The default is 1 inch, so the following command sets a 0.75-inch left margin.

  ```
  \setlength{\oddsidemargin}{-0.25in}
  ```

- Then we set the width of the text - What is left will be the right margin. In this case, right margin is 8.5in - 0.75 - 7.00in = 0.75in.

  ```
  \setlength{\textwidth}{7.00in}
  ```

- To set the top margin, since the default is 1 inch, we use the following command to set it to 0.75-inch:

  ```
  \setlength{\topmargin}{-0.25in}
  ```

- To set the height of the text we issue the following command. What is left will be the bottom margin. In this case, bottom margin is 11.00in - 0.75in - 9.00in = 1.00in

  ```
  \setlength{\textheight}{9.50in}
  ```

3.2   Itemizing and numbering

The above bulleted items were created using the so-called *itemized environment* as follows:

```
\begin{itemize}
\item This is the first item, for example, $f(x) = \sin(2x-3).$
\item While a domain for $f$ is $\[-\pi,\pi).$
\end{itemize}
```

When typeset, this produces

- This is the first item, for example, $f(x) = \sin(2x - 3)$.

- While a domain for f is $[-\pi, \pi)$.

If one prefers to number listed items, one would need to use the so called *enumerated environment* as follows:

```
\begin{enumerate}
\item This is the first item, for example, $f(x) = \sin(2x-3).$
\item While a domain for $f$ is $\[-\pi,\pi).$
\end{enumerate}
```

When typeset, this produces

1. This is the first item, for example, $f(x) = \sin(2x - 3)$.

2. While a domain for f is $[-\pi, \pi)$.

Here one can see the first advantage of using LaTeX: its ability to automatically re-number listed items when a new item is inserted. For example, let us insert a new item in between the two items above:

```
\begin{enumerate}
\item This is the first item, for example, $f(x) = \sin(2x-3).$
\item Here is a new item, say, $\cos(4x+\pi)$ function.
\item While a domain for $f$ is $\[-\pi,\pi).$
\end{enumerate}
```

After typesetting we get

1. This is the first item, for example, $f(x) = \sin(2x - 3)$.

2. Here is a new item, say, $\cos(4x + \pi)$ function.

3. While a domain for f is $[-\pi, \pi)$

with a new numbering. Instead of the numbers one can use letters, but the labels are not changed then automatically. We use again the first environment.

```
\begin{itemize}
\item[(a)] This is the first item, for example,
$$
f(x) = \sin(2x-3).
$$
\item[(b)] While a domain for $f$ is $[-\pi,\pi).$
\item[(c)] The third item now will be displayed and numbered:
\begin{equation}
f(x) = \sin(2x-3).
\label{eq:sine}
\end{equation}
\item[(b)] While a domain for $f$ is $[-\pi,\pi).$
\end{itemize}
```

We get:

(a) This is the first item, for example,
$$f(x) = \sin(2x - 3).$$

(b) While a domain for f is $[-\pi, \pi)$.

(c) The third item now will be displayed and numbered:

$$f(x) = \sin(2x - 3). \tag{1}$$

We will see further that LATEX automatically renumbers equations, sections, subsections, figures, references - you name it! For example, suppose that we want to cite a reference where more information on basic LATEX commands can be found. This would be a book by Hahn listed as reference [2]. Notice that in the source file we refer to that bibliography position via its label `hahn1993` using the command `\cite{hahn1993}` which produces [2]. This way, if we insert a new bibliography item before Hahn's book, our reference to Hahn's book in the text wouldn't need to be changed since the label `hahn1993` does not change. What will change is the number which could then be `[2]` instead.

3.3   Displaying mathematics - general

If one wants to display a mathematical formula inline one may find that the text that surrounds it seems a bit too crowded. For example, suppose that $\forall \epsilon > 0 \, \exists \delta > 0$ so that $|f(x) - L| < \epsilon$ whenever $|x - x_0| < \delta$. In order to control the amount of empty space around the inline mathematics, one inserts in the preamble, that is, in the top part of the source document between `\documentclass{article}` and `\begin{document}` the following command

```
\mathsurround 1.5pt
```

where 1.5pt is the amount of extra space around the math. Usually 1.5pt is sufficient. However, then commas, periods, colons, semicolons, question marks, etc. need to be placed inside of the math environment or there will be a gap between the mathematical expression and the symbol. Compare, for example, $f(x) = \sin(x)$, $g(x) = \cos(x)$ with $f(x) = \sin(x)$, $g(x) = \cos(x)$. A good rule is, however, to display long and complicated mathematical expressions rather than show them inline. Thus, it is better to state the definition of a limit as follows:

Definition 2. *We say that* $\lim_{x \to x_0} f(x) = L$ *if* $\forall \epsilon > 0 \, \exists \delta > 0$ *so that* $|f(x) - L| < \epsilon$ *whenever* $|x - x_0| < \delta$.

Notice the spacing, automatic numbering, and font change. The above Definition 2 has been entered as

```
\begin{definition}
We say that $\lim_{x \to x_0} f(x) = L$ if $\forall \, \epsilon >0 \; \exists \, \delta >0$ so
that $|f(x) - L| < \epsilon$ whenever $|x - x_0| < \delta.$
\label{def:limit}
\end{definition}
```

Notice that in display mode `$$\lim_{x \to x_0} f(x) = L$$` produces the following

$$\lim_{x \to x_0} f(x) = L.$$

instead of $\lim_{x \to x_0} f(x) = L$.

Notice also that we have displayed $f(x) = \sin(2x-3)$ in item (a) above instead of making it appear inline like this $f(x) = \sin(2x - 3)$. In order to display $f(x) = \sin(2x - 3)$ we used double dollar signs in `$$f(x) = \sin(2x-3)$$` as opposed to single dollar signs as in `$f(x) = \sin(2x-3)$` to display it inline.

3.4 Spacing of mathematical symbols

LaTeX provides a large variety of mathematical symbols. For example,

- Greek characters like $\alpha, \beta, \gamma, \ldots, \theta, \omega, \ldots$ that are entered as `$\alpha,\beta,\gamma,\ldots,$`. If you forget their codes, in PCTeX32 go to Help → PCTeX Helper → Math and select `Lower Case Greek Letters` or `Upper Case Greek Letters`.

- Miscellaneous symbols like Re, Im, ∂, ∞, $\emptyset$, ∇, $\forall$, $\exists$,.... They can be found by going in PCTeX32 to Help → PCTeX Helper → Math and selecting `Miscellaneous Ord Symbols`.

- Binary operations like $\pm$, $\times$, $\circ$, $\sqcap$, $\sqcup$, $\vee$, $\wedge$, $\oplus$, $\otimes$, ... You can find them by going in PCTeX32 to Help → PCTeX Helper → Math and selecting `Binary Operations`.

- Relations like $\leq$, $\ll$, $\subset$, $\subseteq$, $\in$, $\geq$, $\supset$, $\supseteq$, $\equiv$, $\simeq$, $\approx$, $\perp$, ... In PCTeX32 go to Help → PCTeX Helper → Math and select `Relations`.

- Negated relations like $\nprec$, $\nsubseteq$, $\neq$, $\not\equiv$, $\nsucc$, $\nsupseteq$, ... In PCTeX32 go to Help → PCTeX Helper → Math and select `Negated Relations`.

- Horizontal arrows like $\leftarrow$, $\rightarrow$, $\Leftarrow$, $\Rightarrow$, $\Leftrightarrow$, $\mapsto$, $\leftrightarrow$, $\hookrightarrow$, ... In PCTeX32 go to Help → PCTeX Helper → Math and select `Horizontal Arrows`.

- Vertical arrows like $\uparrow$, $\downarrow$, $\nearrow$, $\searrow$, ... In PCTeX32 go to Help → PCTeX Helper → Math and select `Vertical Arrows`.

- Large operators like $\sum$, $\prod$, $\int$, $\oint$, $\bigcap$, $\bigcup$, $\bigvee$, $\bigwedge$, $\bigotimes$, $\bigoplus$, ... In PCTeX32 go to Help → PCTeX Helper → Math and select `Large Operators`.

Pointing to any symbol in the above menus will reveal its LaTeX code while clicking on it will insert into the source document. However, when writing mathematical formulas often one needs to control spacing between symbols. Consider theses two expressions:

$$A = \{x \in X \mid x\beta \geq (xy)g(x,y) > (x+1)^{2l} - \alpha\} \tag{2}$$

$$A = \{\, x \in X \mid x\beta \geq (xy)\, g(x,y) > (x+1)^{2l} - \alpha \,\} \tag{3}$$

Notice different small extra spacings in (3) which have been created by inserting $\backslash$, after $\backslash\{$ and before $\backslash\}$, and between $(xy)\backslash,g(x,y)$. In increasing order of space sizes, LaTeX has these pre-defined commands for horizontal spacing: $\backslash$,, $\backslash$:, $\backslash$;, $\backslash$quad, $\backslash$qquad. Generally, command $\backslash$hspace{5ex}, that takes a length parameter like 5ex increases horizontal spacing in formulas. Sometimes one needs to insert these extra spaces for the formula to look better. Here is another such example.

$$
\text{(a)} \int_0^\pi \sin x dx = 2, \text{(b)} |-f(x)| \tag{4}
$$

$$
\text{(c)} \int_0^\pi \sin x\, dx = 2, \qquad \text{(d) } |-f(x)| \tag{5}
$$

where spacing in (5) seems better. It has been accomplished with this code:

```
\mbox{(c)} \int_{0}^{\pi} \sin x \, dx =2, \qquad \mbox{(d)} \, \left|-f(x)\right| \label{eq:eq2}
```

By the way, command $\backslash$mbox{...} is used to print text in Roman characters inside the math mode. Compare, for example,

$$
\text{(c)} \int_0^\pi \sin x dx = 2, \quad and \quad \text{(d)} |-f(x)| \tag{6}
$$

$$
\text{(c)} \int_0^\pi \sin x\, dx = 2, \quad \text{and} \quad \text{(d) } |-f(x)| \tag{7}
$$

where (7) has been typed as

```
\mbox{(c)} \, \int_{0}^{\pi} \sin x \, dx =2, \quad \mbox{and} \quad
\mbox{(d)} \, \left|-f(x)\right| \label{eq:eq4}
```

Finally, one nice and easy to use feature is to box important formulas or results using command $\backslash$boxed{...}. Then, the argument will be boxed. It works as follows:

$$
\boxed{\int_{-\infty}^{\infty} e^{-x^2}\, dx = \sqrt{\pi}}
$$

typed as

```
$$
\boxed{\int_{-\infty}^{\infty} e^{-x^{2}} \, dx = \sqrt{\pi}}
$$
```

For more examples we refer to [4, 5].

3.5   Referencing and citing

In the display (1) we wanted LaTeX to automatically number the displayed item. That was accomplished by using *equation* environment as follows:

```
\begin{equation}
f(x) = \sin(2x-3).
\label{eq:sine}
\end{equation}
```

Notice that we have *labeled* this display using $\backslash$label{eq:sine} where sine is a label arbitrarily chosen. Once it has been assigned, we can now refer to this displayed function via the $\backslash$ref command as ($\backslash$ref{eq:sine}). Then we can say something like that: *"Let's now differentiate function (1)"*. Again, inserting a new equation or a new displayed item in front of (1) won't require us to change how we refer to it since its label has not changed! Instead, if we insert just one displayed and numbered item, its number will change to (2).

One more comment: In the label `\label{eq:sine}` we have an optional name `eq` for a counter that counts equations. It is convenient to have it although it is not required: `\label{sine}` would do too. In the code of the Definition 2 we have used `\label{def:limit}`.

One can really label practically anything. For example, we can refer to this section as section 3.1 because a label has been inserted right after the `\section{...}` command as

```
\section{Formatting first}
\label{formatting}
```

In order to refer to this section it is enough now to invoke the label via `\ref{formatting}` which gives number 3.1. As you may have guessed, if we insert a new section in front of this section, when we refer to this section again via `\ref{formatting}`, number 2 will appear instead of 1.

By the way, if one mistypes a label in `\cite` or `\ref`, which is equivalent to typing label that does not exist, LaTeX will return question marks in the document. For example, if instead of typing `\cite{gratzer1999,gratzer2000}` that yields [4, 5] one types `\cite{gratzer1998,gratzer200}`, upon typesetting LaTeX will return [**?, ?**] with question marks. The same applies to `\ref` command: We will get "equation (**??**)" since we have typed by mistake (`\ref{eq:myeq}`) while label `myeq` has not been assigned as a value to the counter `eq`.

4 Formatting displayed formulas

In this section we will show examples how to display mathematical formulas, and how to create tables, and more complicated expressions. This is not meant to be a complete review of all possible commands and packages, but only a review of the most frequently used structures that may be useful to students writing a thesis. For a complete reference, see [4] and [5].

4.1 Example of `array` environment

In this example we show how a bunch of lines is entered as an *array* where array just means the way objects are arranged or positioned in the display. For example,

```
\begin{equation}
\begin{array}{l}
\e_1\e_2=\e_1\w\e_2+A_{12}+g_{12}=\e_1\w\e_2+B_{12} \\[0.5ex]
(\e_1\e_2)\tilde{\phantom{x}}=-\e_1\w\e_2-A_{12}+g_{12}=-\e_1\w\e_2+B_{21} \\
\qquad =-\e_1\w\e_2+(B^\top)_{12}
\end{array}
\label{eq:8}
\end{equation}
```

$$
\begin{array}{l}
\mathbf{e}_1\mathbf{e}_2 = \mathbf{e}_1 \wedge \mathbf{e}_2 + A_{12} + g_{12} = \mathbf{e}_1 \wedge \mathbf{e}_2 + B_{12} \\
(\mathbf{e}_1\mathbf{e}_2)\tilde{\ } = -\mathbf{e}_1 \wedge \mathbf{e}_2 - A_{12} + g_{12} = -\mathbf{e}_1 \wedge \mathbf{e}_2 + B_{21} \\
\qquad = -\mathbf{e}_1 \wedge \mathbf{e}_2 + (B^\top)_{12}
\end{array}
\tag{8}
$$

The single parameter `l` in `\begin{array}{l}` says that the single item on each line is left-justified in the space provided for it (see more below). If we wanted to center it or to right justify it, we would use `c` or `r` instead. Symbols `\\` mark the end of each line (or row) but `[0.5ex]` in `\\[0.5ex]` allows for extra vertical space between the first and the second line. Since no such extra spacing was entered at the end of the second line, the third line seems to be too close to the second line. We can fix it with

```
\begin{equation}
\begin{array}{l}
\e_1\e_2=\e_1\w\e_2+A_{12}+g_{12}=\e_1\w\e_2+B_{12} \\[0.5ex]
(\e_1\e_2)\tilde{\phantom{x}}=-\e_1\w\e_2-A_{12}+g_{12}=-\e_1\w\e_2+B_{21} \\[0.5ex]
\qquad =-\e_1\w\e_2+(B^\top)_{12}
\end{array}
```

```
\label{eq:88}
\end{equation}
```

$$
\begin{aligned}
\mathbf{e}_1\mathbf{e}_2 &= \mathbf{e}_1 \wedge \mathbf{e}_2 + A_{12} + g_{12} = \mathbf{e}_1 \wedge \mathbf{e}_2 + B_{12} \\
(\mathbf{e}_1\mathbf{e}_2)^{\tilde{}} &= -\mathbf{e}_1 \wedge \mathbf{e}_2 - A_{12} + g_{12} = -\mathbf{e}_1 \wedge \mathbf{e}_2 + B_{21} \\
&= -\mathbf{e}_1 \wedge \mathbf{e}_2 + (B^\top)_{12}
\end{aligned}
\tag{9}
$$

Notice that display (9) looks better than (8). Notice also that in both displays there was one single number assigned to the entire array.

4.2 Example of `align` environment

We can display equations (9) differently using command `align` which allows us to align equal signs. Note however, that this very useful command is not present in standard LaTeX but is available upon loading the `amsmath` package with the command `\usepackage{amsmath}` (see the preamble). We again refer to [4] and [5] for more information.

```
\begin{align}
\e_1\e_2                        &=\e_1\w\e_2+A_{12}+g_{12}=\e_1\w\e_2+B_{12}    \\[0.5ex]
(\e_1\e_2)\tilde{\phantom{x}} &=-\e_1\w\e_2-A_{12}+g_{12}=-\e_1\w\e_2+B_{21} \\[0.5ex]
                                &=-\e_1\w\e_2+(B^\top)_{12}
\end{align}
```

$$
\mathbf{e}_1\mathbf{e}_2 = \mathbf{e}_1 \wedge \mathbf{e}_2 + A_{12} + g_{12} = \mathbf{e}_1 \wedge \mathbf{e}_2 + B_{12} \tag{10}
$$

$$
(\mathbf{e}_1\mathbf{e}_2)^{\tilde{}} = -\mathbf{e}_1 \wedge \mathbf{e}_2 - A_{12} + g_{12} = -\mathbf{e}_1 \wedge \mathbf{e}_2 + B_{21} \tag{11}
$$

$$
= -\mathbf{e}_1 \wedge \mathbf{e}_2 + (B^\top)_{12} \tag{12}
$$

Notice that `&` has been placed in front of each `=` sign that needs to be lined up. Notice also that each equation has received a separate number! It may or may not be a desired feature. It may be desirable to refer to the whole display and use only one number (13) as in

```
\begin{align}\label{eq:allthree}
\e_1\e_2                        &=\e_1\w\e_2+A_{12}+g_{12}=\e_1\w\e_2+B_{12}    \notag \\[0.5ex]
(\e_1\e_2)\tilde{\phantom{x}} &=-\e_1\w\e_2-A_{12}+g_{12}=-\e_1\w\e_2+B_{21}        \\[0.5ex]
                                &=-\e_1\w\e_2+(B^\top)_{12}                \notag
\end{align}
```

$$
\begin{aligned}
\mathbf{e}_1\mathbf{e}_2 &= \mathbf{e}_1 \wedge \mathbf{e}_2 + A_{12} + g_{12} = \mathbf{e}_1 \wedge \mathbf{e}_2 + B_{12} \\
(\mathbf{e}_1\mathbf{e}_2)^{\tilde{}} &= -\mathbf{e}_1 \wedge \mathbf{e}_2 - A_{12} + g_{12} = -\mathbf{e}_1 \wedge \mathbf{e}_2 + B_{21} \\
&= -\mathbf{e}_1 \wedge \mathbf{e}_2 + (B^\top)_{12}
\end{aligned}
\tag{13}
$$

where we have used command `\notag` to indicate that we don't want numbers displayed in lines 1 and 3. This is getting complicated! The best reference for these more advanced environments like `\begin{align}...\end{align}`, `\begin{align*}...\end{align*}`, `\begin{gather}...\end{gather}`, and `\begin{gather*}...\end{gather*}` we refer to [5]. Note however, that these very useful commands are not present in standard LaTeX but become available upon loading the `amsmath` package with the command `\usepackage{amsmath}` (see the preamble).

4.3 Example of matrices created with `array`

The following code displays a matrix with a vertical solid line:

```
\begin{equation}
\left(
\begin{array}{cc|c}
1 & 2 & 3 \\
0 & 0 & 1 \\
0 & 0 & 2
\end{array}
\right)
\label{eq:firstsolution}
\end{equation}
```

that gives

$$
\left(
\begin{array}{cc|c}
1 & 2 & 3 \\
0 & 0 & 1 \\
0 & 0 & 2
\end{array}
\right)
\tag{14}
$$

You can also use square brackets as follows:

```
\begin{equation}
\left[
\begin{array}{cc|c}
1 & 2 & 3 \\
0 & 0 & 1 \\
0 & 0 & 2
\end{array}
\right]
\label{eq:secondsolution}
\end{equation}
```

that gives

$$
\left[
\begin{array}{cc|c}
1 & 2 & 3 \\
0 & 0 & 1 \\
0 & 0 & 2
\end{array}
\right]
\tag{15}
$$

Notice that in both cases we have used parameters {cc|c} after \begin{array} where c indicates centering. If numbers were negative, centering may not give the best looking matrix:

```
\begin{equation}
\left[
\begin{array}{cc|c}
1 & 2 & 3 \\
9 & 0 & -1 \\
0 & -5 & 2
\end{array}
\right]
\label{eq:secondsolution2}
\end{equation}
```

that gives

$$
\left[
\begin{array}{cc|c}
1 & 2 & 3 \\
9 & 0 & -1 \\
0 & -5 & 2
\end{array}
\right]
\tag{16}
$$

So try

```
\begin{equation}
\left[
\begin{array}{rr|r}
1 & 2 & 3 \\
9 & 0 & -1 \\
0 & -5 & 2
\end{array}
\right]
\label{eq:secondsolution3}
\end{equation}
```

that gives

$$
\left[
\begin{array}{rr|r}
1 & 2 & 3 \\
9 & 0 & -1 \\
0 & -5 & 2
\end{array}
\right]
\tag{17}
$$

where matrix (17) looks better than matrix (16). By the way, there needs to be a one-to-one mapping between the displayed items and their labels, hence no two labels may be the same, of course.

You may have guessed also that the vertical bar | in {rr|r} is responsible for the vertical line separating the third column form the second. We could have more vertical lines if they made sense. For example,

```
\begin{equation}
\left[
\begin{array}{r|r|r}
1 & 2 & 3 \\
9 & 0 & -1 \\
0 & -5 & 2
\end{array}
\right]
\end{equation}
```

that gives

$$
\left[
\begin{array}{r|r|r}
1 & 2 & 3 \\
9 & 0 & -1 \\
0 & -5 & 2
\end{array}
\right]
\tag{18}
$$

Since no label was entered for this last display, we can't refer to it even though it is numbered.

4.4   Example of a matrix created with `pmatrix`

Let's work some more with matrices. To get this matrix

$$
B =
\begin{pmatrix}
0 & 0 & 0 & 0 & q & -1-q & 1 & 1 \\
0 & 0 & 0 & 0 & -1-q & q & -1-q & 1 \\
0 & 0 & 0 & 0 & 1 & -1-q & q & -1-q \\
0 & 0 & 0 & 0 & 1 & 1 & -1-q & q \\
1 & 1 & -1 & -1 & 0 & 0 & 0 & 0 \\
q & 1 & 1 & -1 & 0 & 0 & 0 & 0 \\
-1 & q & 1 & 1 & 0 & 0 & 0 & 0 \\
-1 & -1 & q & 1 & 0 & 0 & 0 & 0
\end{pmatrix}.
\tag{19}
$$

we use the following code. Notice that this code is much simpler than the one required to create matrices with the `array` environment and that the delimeters are automatically placed around the matrix entries.

```
\begin{equation}
B =
   \begin{pmatrix}
      0 & 0 & 0 & 0 & q &  -1-q & 1 & 1    \\
      0 & 0 & 0 & 0 &  -1-q & q & -1-q & 1 \\
      0 & 0 & 0 & 0 & 1 &  -1-q & q & -1-q \\
      0 & 0 & 0 & 0 & 1 & 1 & -1-q & q    \\
      1 & 1 & -1 & -1 & 0 & 0 & 0 & 0     \\
      q & 1 & 1 & -1 & 0 & 0 & 0 & 0      \\
     -1 & q & 1 & 1 & 0 & 0 & 0 & 0       \\
     -1 & -1 & q & 1 & 0 & 0 & 0 & 0
   \end{pmatrix}.
\label{eq:ourB}
\end{equation}
```

where we have used a `\begin{pmatrix}`...`\end{pmatrix}` environment. There some 10 different ways matrices can be entered but we won't be discussing them here and refer the reader to [4] or [5].

4.5   Example of a table created with `array`

The following code produces a table:

```
$$
\begin{array}{|r|c|} \Hline
& \\[-2ex]
\cl(B)                  & \e_2  \\
& \\[-2ex] \hline
& \\[-1ex]
\e_1                    & \e_1\w\e_2+a                  \\
\e_2                    & 1                             \\
\e_1\w\e_2\w\e_3        &-c\e_1\w\e_2-\e_1\w\e_3+a\e_2\w\e_3
\\[1.2ex] \Hline
\end{array}
$$
```

$C\ell(B)$	$\mathbf{e}_2$
$\mathbf{e}_1$	$\mathbf{e}_1 \wedge \mathbf{e}_2 + a$
$\mathbf{e}_2$	1
$\mathbf{e}_1 \wedge \mathbf{e}_2 \wedge \mathbf{e}_3$	$-c\mathbf{e}_1 \wedge \mathbf{e}_2 - \mathbf{e}_1 \wedge \mathbf{e}_3 + a\mathbf{e}_2 \wedge \mathbf{e}_3$

While we have already met the array environment above, in this table several custom-made commands (macros) have been used. These commands are defined in the preamble using `\newcommand` definition. Let's review some of them here:

- Command `\e` produces bolded letter **e** and is shorter to type than `{\bf e}`. Likewise command(s)

   (i) `\cA, \cB, \cC,...` give calligraphic $\mathcal{A}, \mathcal{B}, \mathcal{C}, \cdots$;

   (ii) `\vA, \va, \vc, ...` give vectors $\vec{A}, \vec{a}, \vec{c}, \cdots$;

   (iii) `\w` is a short for `\wedge`, the wedge product $\wedge$ in the Clifford algebra $C\ell(Q)$;

   (iv) `\cl` produced the italicized symbol for the Clifford algebra as in $C\ell$;

   (v) `\Hline` produces a thicker horizontal line than the standard command `\hline` used in the middle;

   (vi) `[-2ex]` used after the end of line symbol `\\` produces a negative extra vertical spacing.

Although not used in the above table, symbols very often used in mathematical papers are $\mathbb{R}$ for the real field, $\mathbb{C}$ for the complex field, $\mathbb{H}$ for the quaternionic division ring, $\mathbb{Z}$ for the ring of integers. These the so called "math black board letters" are part of another package `amssymb` which one can load in the preamble using the command `\usepackage{amssymb}`. Note that to get for example $\mathbb{R}$ one can use the long name `${\mathbb R}$` or the abbreviated macro `\BR` defined in the preamble (and likewise for other letters). Then, `$\BR^3$` gives the real 3-dimensional Euclidean space $\mathbb{R}^3$.

4.6 Example of a more complicated table with `tabular`

The following is an example of a more complicated table that has been created using `tabular` environment specifically suited for creating tables.

Saturday, May 25											
From:	To:	Room:	Event:	Room:	Event:	Room:	Event:	Room:	Event:	Room:	Event:
8:15	8:30	BR119	**Announcements**								
8:30	9:30	BR119	PT-S1	*No parallel sessions*							
9:30	9:40	*Break*									
9:40	10:40	BR119	PT-S2	*No parallel sessions*							
10:40	10:50	*Break*									
		Analysis		*Geometry*		*Structures*		*Physics*		*Applications*	
10:50	11:30	BR123	RT-S1A	BR124	RT-S2A	BR126	RT-S3A	BR127	RT-S4A	BR112	RT-S5A
11:30	12:10	BR123	RT-S1B	BR124	RT-S2B	BR126	RT-S3B	BR127	RT-S4B	BR112	RT-S5B
12:10	1:15	**Lunch**									
1:15	1:45	**Coffee Social**									
1:45	2:45	BR119	**General meeting and closing**								

The code for this table looks as follows:

```
\begin{center}
\begin{small}
\begin{tabular}{|r|r|c c|c c|c c|c c|c c|}  %12 columns
\multicolumn{12}{c}{\bf{Saturday, May 25}} \\\hline
From: & To: & Room: & Event: & Room: & Event: & Room: & Event: & Room: & Event: & Room: & Event:\\\hline
8:15  & 8:30  & BR119 & \multicolumn{9}{c|}{\bf{Announcements}} \\\hline
8:30  & 9:30  & BR119 & PT-S1 & \multicolumn{8}{c|}{\emph{No parallel sessions}} \\\hline
9:30  & 9:40  & \multicolumn{10}{c|}{\emph{Break}} \\\hline
9:40  & 10:40 & BR119 & PT-S2 & \multicolumn{8}{c|}{\emph{No parallel sessions}} \\\hline
10:40 & 10:50 & \multicolumn{10}{c|}{\emph{Break}} \\\hline
      &       & \multicolumn{2}{|c|}{\emph{Analysis}} &
                \multicolumn{2}{|c|}{\emph{Geometry}} &
                \multicolumn{2}{|c|}{\emph{Structures}} &
                \multicolumn{2}{|c|}{\emph{Physics}} &
                \multicolumn{2}{|c|}{\emph{Applications}} \\\hline
10:50 & 11:30 & BR123 & RT-S1A & BR124 & RT-S2A & BR126 & RT-S3A & BR127 & RT-S4A
                & BR112 & RT-S5A \\\hline
11:30 & 12:10 & BR123 & RT-S1B & BR124 & RT-S2B & BR126 & RT-S3B & BR127 & RT-S4B
                & BR112 & RT-S5B \\\hline
12:10 & 1:15  & \multicolumn{10}{c|}{\bf{Lunch}} \\\hline
1:15  & 1:45  & \multicolumn{10}{c|}{\bf{Coffee Social}} \\\hline
1:45  & 2:45  & BR119 & \multicolumn{9}{c|}{\bf{General meeting and closing}} \\\hline
\end{tabular}
\end{small}
\end{center}
```

Notice that in order to reduce the size of the entire table we have temporarily used `small` environment that reduces the size of all fonts. That environment of course starts with `\begin{small}` and ends with `\end{small}`.

4.7 Example of another usage of labeled `align`

In this example we use again the `\begin{align}`...`\end{align}` environment but we label each equation.

```
\begin{align}
X+ X\tilde{~}  & = \Id, \label{eq:X1}\\
X^2 & = X,                \label{eq:X2}\\
X X\tilde{~} & = 0        \label{eq:X3}.
\end{align}
```

$$X + X^\sim = \mathbf{1}, \tag{20}$$

$$X^2 = X, \tag{21}$$

$$X X^\sim = 0. \tag{22}$$

4.8 Example of splitting long expressions with `multline` and `split`

Here we show how to split a long expression among several lines using a new environment from the `amsmath` package that needs to be loaded extra into LaTeX. It is \begin{multline}...\end{multline}. For more information about this very useful command not present in standard LaTeX we again refer to [4] and [5]. To load it, use command \usepackage{amsmath}.

```
\begin{multline}
(1+q)z^2+(-q^2 K_4+K_4+q K_2-1+K_2)z+K_4 K_2 + K_2^2\\
-K_4-K_2+q K_4-q^2 K_4^2-q K_4^2-q^2 K_2 K_4+q K_2^2 = 0,
\end{multline}
```

that gives

$$(1 + q)z^2 + (-q^2 K_4 + K_4 + qK_2 - 1 + K_2)z + K_4 K_2 + K_2^2$$
$$- K_4 - K_2 + qK_4 - q^2 K_4^2 - qK_4^2 - q^2 K_2 K_4 + qK_2^2 = 0, \tag{23}$$

There is also a command `split` that allows one to split very long formulas. One convenient feature of using `split` versus `array` or `align` is that it generates one number for the formula. For example,

$$
\begin{split}
f(x) =& (x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8)^{6n-7} + (x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8)^{9n+7} \\
&+ (x_1 x_2)^{8n-9} + (x_3 x_4)^{4n+10} + (x_1 x_2 + x_3 x_4 + x_5 x_6 + x_7 x_8)^{6n} \\
&- (x_1 x_3)^{6n-9} + (x_2 x_4)^{4n-10} + (x_1 x_4 + x_2 x_3 + x_6 x_8 + x_5 x_8)^{6n-12}
\end{split}
\tag{24}
$$

has been typed as

```
\begin{equation}
\label{eq:longone}
   \begin{split}
      f(x)= &(x_{1}x_{2}x_{3}x_{4}x_{5}x_{6}x_{7}x_{8})^{6n-7}
             + (x_{1}x_{2}x_{3}x_{4}x_{5}x_{6}x_{7}x_{8})^{9n+7} \\
           &+ (x_{1}x_{2})^{8n-9}+(x_{3}x_{4})^{4n+10}
             + (x_{1}x_{2}+ x_{3}x_{4}+x_{5}x_{6}+x_{7}x_{8})^{6n} \\
           &- (x_{1}x_{3})^{6n-9}+(x_{2}x_{4})^{4n-10}
             +(x_{1}x_{4}+ x_{2}x_{3}+x_{6}x_{8}+x_{5}x_{8})^{6n-12}
   \end{split}
\end{equation}
```

Notice the difference when the same formula 24 is entered in the `multline` environment:

$$f(x) = (x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8)^{6n-7} + (x_1 x_2 x_3 x_4 x_5 x_6 x_7 x_8)^{9n+7}$$
$$+ (x_1 x_2)^{8n-9} + (x_3 x_4)^{4n+10} + (x_1 x_2 + x_3 x_4 + x_5 x_6 + x_7 x_8)^{6n}$$
$$- (x_1 x_3)^{6n-9} + (x_2 x_4)^{4n-10} + (x_1 x_4 + x_2 x_3 + x_6 x_8 + x_5 x_8)^{6n-12}. \tag{25}$$

The above has been typed as

```
\begin{multline}
 f(x) = (x_{1}x_{2}x_{3}x_{4}x_{5}x_{6}x_{7}x_{8})^{6n-7} +
            (x_{1}x_{2}x_{3}x_{4}x_{5}x_{6}x_{7}x_{8})^{9n+7} \\
       + (x_{1}x_{2})^{8n-9}+(x_{3}x_{4})^{4n+10}+(x_{1}x_{2} +
            x_{3}x_{4}+x_{5}x_{6}+x_{7}x_{8})^{6n} \\
       - (x_{1}x_{3})^{6n-9}+(x_{2}x_{4})^{4n-10} +
            (x_{1}x_{4}+ x_{2}x_{3}+x_{6}x_{8}+x_{5}x_{8})^{6n-12}
\label{eq:longone2}
\end{multline}
```

See [5] for more information.

4.9 Example of `gather` and `gather*`

Command the `gather*` environment is a better version of the `$$...$$` displaying while allowing much control over spacing while `$$...$$` does not allow for any control. The `gather*` environment differs from `gather` environment in that the displayed item or items is not (are not) numbered. For example,

```
\begin{gather*}
\alphaq(b_1) = \displaystyle{\frac{(q-1)\Id}{q} + \frac{b_1}{q}}, \quad
\alphaq(b_2) = \displaystyle{\frac{(q-1)\Id}{q} + \frac{b_2}{q}}, \\[0.5ex]
\alphaq(b_1 b_2) = \displaystyle{\frac{(1-2q+q^2)\Id}{q^2}+\frac{(q-1)b_1}{q^2}+
                           \frac{(q-1)b_2}{q^2}+\frac{b_{21}}{q^2}}.
\end{gather*}
```

Notice that the horizontal spacing in the first row is controlled with command `\quad` while the vertical spacing is increased thanks to `[0.5ex]`. In this environment displayed items are centered.

$$\alpha_q(b_1) = \frac{(q-1)\mathbf{1}}{q} + \frac{b_1}{q}, \quad \alpha_q(b_2) = \frac{(q-1)\mathbf{1}}{q} + \frac{b_2}{q},$$

$$\alpha_q(b_1 b_2) = \frac{(1-2q+q^2)\mathbf{1}}{q^2} + \frac{(q-1)b_1}{q^2} + \frac{(q-1)b_2}{q^2} + \frac{b_{21}}{q^2}.$$

The remaining examples come from files that came with PCT$_{\mathrm{E}}$X32.

5 Additional examples

5.1 Braces and over braces

```
$$
\{{\underbrace{\overbrace{\mathstrut a,\ldots,a}
      ^{k\;a\mathchar'`\rm s},
   \overbrace{\mathstrut b,\ldots,b}
      ^{l\;b\mathchar'`\rm s}}_{k+l\rm\;elements}\}.
$$
```

$$\{\underbrace{\overbrace{a,\ldots,a}^{k\ a\text{'s}}, \overbrace{b,\ldots,b}^{l\ b\text{'s}}}_{k+l\ \text{elements}}\}.$$

5.2 Products and sums

```
$$
\prod_{j\ge0}\biggl(\sum_{k\ge0}a_{jk}z^k\biggr)
  =\sum_{n\ge0}z^n\,\Biggl(\sum_
     \frac{\scriptstyle k_0,k_1,\ldots\ge0}{\scriptstyle k_0+k_1+\cdots=n}
   a_{0k_0}a_{1k_1}\ldots\,\Biggr).
$$
```

$$\prod_{j\geq 0}\left(\sum_{k\geq 0}a_{jk}z^k\right)=\sum_{n\geq 0}z^n\left(\sum_{\substack{k_0,k_1,\ldots\geq 0\\k_0+k_1+\cdots=n}}a_{0k_0}a_{1k_1}\ldots\right).$$

5.3 Binomial expressions

```
$$
\frac{(n_1+n_2+\cdots+n_m)!}{n_1!\,,n_2!\ldots n_m!}
  ={n_1+n_2\choose n_2}{n_1+n_2+n_3\choose n_3}
    \ldots{n_1+n_2+\cdots+n_m\choose n_m}.
$$
```

$$\frac{(n_1+n_2+\cdots+n_m)!}{n_1!\,n_2!\ldots n_m!}=\binom{n_1+n_2}{n_2}\binom{n_1+n_2+n_3}{n_3}\cdots\binom{n_1+n_2+\cdots+n_m}{n_m}.$$

5.4 Using custom commands in `align`

In the following we show we use custom-made commands that were defined in the preamble. We will use the `\newcommand{\reversion}[1]{#1 \, \tilde{}}` command that is, in fact, a function of one parameter that ie referred to as `#1`. This command puts a tilde symbol ˜ to the right of a symbol entered as the argument. The funny command is just a crude way of leaving a blank space whose width is equal to the width of its argument. For example, to enter an empty space of the width equal to the width of the equal sign $=$ we use `\phantom{=}` in the formula below.

```
\begin{align}
C(13) - \reversion{R(13)} &=  2(q^2-q)\Id + (-1-q^2+2q)b_1 + (-1-q^2+2q)b_2 \notag \\
                      &\phantom{=}  +(1-q)b_{12} + (1-q)b_{21},
\label{eq:C13R13}
\end{align}
```

$$
\begin{aligned}
C(13) - R(13)\tilde{} &= 2(q^2-q)\mathbf{1}+(-1-q^2+2q)b_1+(-1-q^2+2q)b_2\\
& +(1-q)b_{12}+(1-q)b_{21},
\end{aligned}
\tag{26}
$$

5.5 A more complicated example of `align`

In the following more complicated example of `align`, we use several new commands not previously encountered:

- Command `\displaystyle` enlarges the size of displayed fractions;

- Command `\hspace*{5ex}` enters a horizontal space equal to `5ex` units;

- Command `\frac{t_1 b_2}{q}}` creates a small fraction $\frac{t_1 b_2}{q}$;

- Commands `\notag` and `\phantom` were described earlier.

```
\begin{align}
XX_1 &= (-K_6 q+K_2 q+K_4)\Id+K_2 b_1+\displaystyle{\frac{t_1 b_2}{q}}
        + K_4 b_{12} \notag\\
    &\phantom{=} \hspace*{5ex}+K_5 b_{21}+K_6 b_{121}, \label{eq:XX1} \\[1ex]
XX_2 &= K_1 \Id+\displaystyle{\frac{t_2 b_1}{q^2 (1+q)}+\frac{t_3 b_2}{q^3 (1+q)}-
                        \frac{b_{12}}{q(1+q)}}\notag \\
    &\phantom{=} \hspace*{5ex}+K_5 b_{21}+K_6 b_{121},\label{eq:XX2}\\[1ex]
XX_3 &= K_1\Id+\displaystyle{\frac{t_4 b_1}{q (q^3+2 q^2+2 q+1)}+
                        \frac{t_5 b_2}{q^2 (q^3+2 q^2+2 q+1)}}\notag \\
    &\phantom{=} \hspace*{5ex}-\displaystyle{\frac{(q-1) b_{12}}{q^3+2 q^2+2 q+1}}
```

```
                 +K_5 b_{21}+K_6 b_{121},
\label{eq:XX3}
\end{align}
```

$$XX_1 = (-K_6 q + K_2 q + K_4)\mathbf{1} + K_2 b_1 + \frac{t_1 b_2}{q} + K_4 b_{12}$$
$$+ K_5 b_{21} + K_6 b_{121}, \tag{27}$$

$$XX_2 = K_1\mathbf{1} + \frac{t_2 b_1}{q^2(1+q)} + \frac{t_3 b_2}{q^3(1+q)} - \frac{b_{12}}{q(1+q)}$$
$$+ K_5 b_{21} + K_6 b_{121}, \tag{28}$$

$$XX_3 = K_1\mathbf{1} + \frac{t_4 b_1}{q(q^3 + 2q^2 + 2q + 1)} + \frac{t_5 b_2}{q^2(q^3 + 2q^2 + 2q + 1)}$$
$$- \frac{(q-1)b_{12}}{q^3 + 2q^2 + 2q + 1} + K_5 b_{21} + K_6 b_{121}, \tag{29}$$

5.6   Commands with optional arguments

We have already given one example of a command `\newcommand{\reversion}[1]{#1 \, \tilde{}}` that takes one argument or parameters. Then, it can be applied to many different entries, for example, $u\tilde{}$ or $A\tilde{}$ just by entering `$\reversion{u}$` or `$\reversion{A}$`.

   Another pretty convenient trick from [5] that saves lots of typing is shown next. Placing in the preamble

```
\newcommand{\NewSum}[1][n]{a_{1}+a_{2}+\cdots+a_{#1}}
```

allows one to vary the final index. Then `\NewSum[m]$` prints $a_1 + a_2 + \cdots + a_m$ while `\NewSum[2k]$` prints $a_1 + a_2 + \cdots + a_{2k}$. Since the parameter `[.]` is optional, its default value of `[n]` from the definition is used when no parameter is entered. Thus, `\NewSum$` prints $a_1 + a_2 + \cdots + a_n$. As one may have guessed, the `\newcommand` may take more parameters up to nine, but *only the first* my be optional.

   For example, `\newcommand{\TwoSum}[2][n]{#2_{1}+#2_{2}+\cdots+#2_{#1}}` takes two parameters! Then `$\TwoSum{a}$` prints $a_1 + a_2 + \cdots + a_n$ while `$\TwoSum[m]{b}$` prints $b_1 + b_2 + \cdots + b_m$.

6   Back matter

6.1   References

Finally, we are getting to the references. In an article, as a rule, references are very simple. The simplest way to insert them is to start the environment `thebibliography`. For example, here is a listing of two reference items from our bibliography:

```
\begin{thebibliography}{9}
\bibitem{hahn1993}
   Jane Hahn (1993): ``{\LaTeX} for Everyone: A Reference Guide and Tutorial
   for Typesetting Documents Using a Computer'', Prentice Hall, Upper Saddle River.
%
\bibitem{gratzer1999}
   George Gr\"{a}tzer (1999): ``First Steps in {\LaTeX}'', Birkh\"{a}user,
   Boston. (136 pages, \$15.37, {\sc ISBN}: 0817641327.)
\end{thebibliography}
```

where we have separated the bibliographical entries with a percent sign just for convenience. Notice that in style references will be numbered. Labels `hahn1993` in `\bibitem{hahn1993}` and `gratzer1999` in `\bibitem{gratzer1999}` follow an easy to remember convention: last name followed by the year of publication. Then, in the text one

can refer (or cite) a reference using the command `\cite{...}`. For example, we can refer to the above two items listed in our references at the end of this article as [2] and [4]. It is also possible to refer to two or more items with one `\cite{hahn1993,gratzer1999}` command to get [2, 4]. One can also cite specific pages. For instance, `\cite[pages~2--12]{gratzer1999}` will give [4, pages 2–12]. The only rule to remember about these labels is that they cannot start with a space and cannot contain a comma or a space.

Although there may be more than one `thebibliography` environment in article, one normally doesn't use that feature unless one wants to list references at the end of each chapter, for example. Furthermore, then in each bibliography the entries will be numbered from 1. However, let me show here standard formatting rules of the $\mathcal{AMS}$. Only the titles are emphasized, and only the volume numbers of the journals are set in boldface.

```
\begin{thebibliography}{9}
\bibitem{Hamermesh}
   Hamermesh, M., \emph{Group Theory and Its Application to Physical Problems}, Addison-Wesley,
   London, 1962.
%
\bibitem{ablam1998}
   Ablamowicz, R., \emph{Spinor representations of Clifford algebras: A symbolic approach}
   Computer Physics Communications, 1998, {\bf 115}, pp. 510--535.
\end{thebibliography}
```

which gives

References

[1] Hamermesh, M., *Group Theory and Its Application to Physical Problems*, Addison-Wesley, London, 1962.

[2] Ablamowicz, R., *Spinor representations of Clifford algebras: A symbolic approach*, Computer Physics Communications, 1998, **115**, pp. 510–535.

Command `\begin{thebibliography}{9}` has an argument. In our example this argument is 9. This tells LaTeX that the widest reference number it will need to generate is one character wide. Use 99 for more than 9 items but less then 100, and then use 999 for one hundred or more items.

6.2   Index

It is possible in larger documents to insert index entries that will be automatically collected in an index file by LaTeX. We will not go into discussing this feature as it is not normally used when writing articles or theses, although it is very desirable when typesetting books. Anyone interested is referred to [5].

7   Summary

For additional sources of information about `ttuthesis.sty` style file we refer to [1] and files posted there. In particular, in this article we have not addressed issues related to the insertion of graphics into a LaTeX document. Reader is advised to download at least one of `Thesis.dvi` or `Thesis.ps` or `Thesis.pdf` for a detailed information how to embed various graphics files of types `.ps`, `.eps`, `.bmp`, `.wmf` into a LaTeX document. There, one can also find how to embed into a LaTeX document pieces of LaTeX code or pictures exported by Maple [6].

A   Final words

An appendix part of the article follows the command `\appendix`. It has been inserted right above as

```
\appendix
\section{Final words}
\label{App:fw}
```

From that point on, commands `\section{...}` ordinarily used to produce section titles will now produce appendix titles that are now labeled rather than numbered. For example, this first appendix is just Appendix A since we have labeled it `\label{App:fw}` and referred to it via `\ref{App:fw}`. Here, `App` is just a new name for the appendix counter. The next appendix entered below will be Appendix B.

Finally, a small advice. In the preamble one can find a new command `\newcommand{\ed}{\end{document}}`. It is convenient to use `\ed` anywhere in the body of the text to indicate a temporary end of the document. This is because typesetting will stop whenever this command is encountered. It is convenient not to typeset the whole document when one works on a small part of it say on page 4 of a 20 pages paper. Once this part is revised, one can delete that command from the text or at least remark it with a percent sign so that it will be ignored. Another convenient method of preparing long documents such as thesis or dissertation is to split the body of the document into separate `.tex` files that are read into the typesetter only when they are "included" with the command `\include` discussed in the sample master thesis `Thesis.tex` that can be downloaded from [1].

B The end

This last appendix may contain some additional information.

References

[1] Rafal Ablamowicz, web page `http://www.math.tntech.edu/TTUthesis/thesis.html`.

[2] Jane Hahn (1993): "LaTeX for Everyone: A Reference Guide and Tutorial for Typesetting Documents Using a Computer", Prentice Hall, Upper Saddle River.

[3] Personal TeX, Inc.: PCTeX32 User Manual, version 4.2, 12 Madrona Street, Mill Valley, CA 94941, U.S.A.

[4] George Grätzer (1999): "First Steps in LaTeX", Birkhäuser, Boston. (136 pages, $15.37, ISBN: 0817641327.)

[5] George Grätzer: "Math Into LaTeX: An Introduction to LaTeX and $\mathcal{AMS}$-LaTeX", 3rd ed. Birkhäuser, Boston. (520 pages, $34.97, ISBN: 0817641319.)

[6] Maple 8 - A general purpose computer algebra system, Waterloo Maple Incorporated, Waterloo, Canada, URL: `http://www.maplesoft.com`