Mathematical Formulas

There are three commonly used environments in the math mode:

1. the `math` environment: Used for formulas in running text
2. the `displaymath` environment: Used to display longer formulas
3. the `equation` environment: Used for displaying equations for numbering and cross reference

math environment

The `math` environment is used to typeset short formulas in the running text. Such formulas are called in-line or in-text formulas. You can use this environment in any of the following forms:

- `\begin{math} . . . \end{math}`
- `\( . . . \)`
- `$ . . . $`

Thus, you could have a line of LaTeX source code like this:

```
A circle in the $x$--$y$--plane has equation \( x^2 + y^2 = 1 \) ....
```

Since there is usually no problem with matching the begin and end of the math environments, you'll most often see $ . . . $. It is best to avoid using this environment for long formulas.

displaymath environment

The `displaymath` environment is used to typeset longer formulas. It is better to have long formulas or equations displayed, that is, indented and with whitespace above and below. You can use this environment in any of the following forms:

- `\begin{displaymath} . . . \end{displaymath}`
- `\[ . . . \]`
- `$$ . . . $$`; however, this last is not recommend in LaTeX2e.

The standard usage here is `\[ . . . \]`, and it is a good idea to put the opening `\[` and closing `\]` on separate lines.

equation environment

The equation environment can be used by typing
`\begin{equation} . . . \end{equation}`.

The amsmath package

If you want to typeset equations beyond the very simplest ones, you will want to use the `amsmath` package, one of the many packages that you can use with LaTeX. This package provides features for aligning several equations, for handling multiline equations, compound symbols and certain kinds of diagrams.

The package is loaded into LaTeX by the command `\usepackage{amsmath}`, which goes in the preamble of the LaTeX source file (that is, between the `documentclass` line and the `begin{document}` line).

Spacing.

In math mode, the spaces in your source file are *completely* ignored by LaTeX with just two exceptions.

1. a space is one of the characters that indicates the end of a command.
2. you can insert a text box (see below) in which everything is in text mode.

For example,
`$a  b$`
is typeset as *ab*.

Therefore, to achieve the appearance that you want, you may have to add or remove space. For example, in an integral, between the integrand and the differential it is usually better to add a "thinspace" `\,`.

Perhaps you will find this feature of LaTeX to be disagreeable, but eventually you should be able to appreciate the balance struck in LaTeX between convenience and the power to control the whitespace completely whenever it seems desirable. Here is a list of the most widely used commands for horizontal spacing.

- `\,          (thinspace)`
- `\;          (thickspace)`
- `\quad   (quadspace)`
- `\qquad  (double quadspace)`
- `\!          (negative thinspace)`

These commands work both in math environments and in text environments.

There are other ways of getting space. If you want 12 points of horizontal whitespace between two characters, you can get it by using the command `\hspace{12pt}` between them. The argument to the `\hspace` command can be specified in inches, for example, .5in if you want a half inch of horizontal whitespace. This command also works in both math and text environments. You may want to keep in mind that there are 72 points to the inch.

If you want whitespace at the beginning of a line, you need the variant form of the `\hspace` command, namely `\hspace*` because LaTeX generally swallows all space at the beginning of a line.

SUPERSCRIPTS SUBSCRIPTS

Operators using subscripts and superscripts

Some mathematical operators may require subscripts and superscripts. The most frequent cases are those of the integral `\int` (check the introduction) and the summation (`\sum`) operators, whose bounds are typeset precisely with subscripts and superscripts.

```
\[ \sum_{i=1}^{\infty} \frac{1}{n^s}
= \prod_p \frac{1}{1 - p^{-s}} \]
```

Open this example in Overleaf.

This LaTeX code produces:

$$\sum_{i=1}^{\infty} \frac{1}{n^s} = \prod_p \frac{1}{1 - p^{-s}}$$

`a_{n_i}`	a_{n_i}
`\int_{i=1}^n`	$\int_{i=1}^n$
`\sum_{i=1}^{\infty}`	$\sum_{i=1}^{\infty}$
`\prod_{i=1}^n`	$\prod_{i=1}^n$
`\cup_{i=1}^n`	$\cup_{i=1}^n$
`\cap_{i=1}^n`	$\cap_{i=1}^n$
`\oint_{i=1}^n`	$\oint_{i=1}^n$
`\coprod_{i=1}^n`	$\coprod_{i=1}^n$

There are also `bigcup` and `bigcap` commands similar to `cup` and `cap` but those are used for larger expressions.

Brackets and Parentheses

Type	LaTeX markup	Renders as
Parentheses; round brackets	`(x+y)`	$(x+y)$
Brackets; square brackets	`[x+y]`	$[x+y]$
Braces; curly brackets	`\{ x+y \}`	$\{x+y\}$
Angle brackets	`\langle x+y \rangle`	$\langle x+y \rangle$
Pipes; vertical bars	`|x+y|`	$\lvert x+y \rvert$
Double pipes	`\\|x+y\\|`	$\lVert x+y \rVert$

```
\[
F = G \left( \frac{m_1 m_2}{r^2} \right)
\]
```

Open this LaTeX fragment in Overleaf

The above example produces the following output:

$$F = G \left(\frac{m_1 m_2}{r^2} \right)$$

Notice that to insert the parentheses or brackets, the `\left` and `\right` commands are used. Even if you are using only one bracket, *both* commands are mandatory. `\left` and `\right` can dynamically adjust the size, as shown by the next example:

```
\[
 \left[  \frac{ N } { \left( \frac{L}{p} \right)  - (m+n) }  \right]
\]
```

Open this LaTeX fragment in Overleaf

The above example produces the following output:

$$\left[\frac{ N } { \left(\frac{L}{p} \right) - (m+n) } \right]$$

`\bigr] \Bigr] \biggr] \Biggr]`	$\bigr] \Bigr] \biggr] \Biggr]$
`\bigl\{ \Bigl\{ \biggl\{ \Biggl\{`	$\bigl\{ \Bigl\{ \biggl\{ \Biggl\{$
`\bigl \langle \Bigl \langle \biggl \langle \Biggl \langle`	$\bigl \langle \Bigl \langle \biggl \langle \Biggl \langle$
`\bigr \rangle \Bigr \rangle \biggr \rangle \Biggr \rangle`	$\bigr \rangle \Bigr \rangle \biggr \rangle \Biggr \rangle$
`\big| \Big| \bigg| \Bigg|`	$\big| \Big| \bigg| \Bigg|$
`\big\\| \Big\\| \bigg\\| \Bigg\\|`	$\big\Vert \Big\Vert \bigg\Vert \Bigg\Vert$
`\bigl \lceil \Bigl \lceil \biggl \lceil \Biggl \lceil`	$\bigl \lceil \Bigl \lceil \biggl \lceil \Biggl \lceil$
`\bigr \rceil \Bigr \rceil \biggr \rceil \Biggr \rceil`	$\bigr \rceil \Bigr \rceil \biggr \rceil \Biggr \rceil$
`\bigl \lfloor \Bigl \lfloor \biggl \lfloor \Biggl \lfloor`	$\bigl \lfloor \Bigl \lfloor \biggl \lfloor \Biggl \lfloor$
`\bigr \rfloor \Bigr \rfloor \biggr \rfloor \Biggr \rfloor`	$\bigr \rfloor \Bigr \rfloor \biggr \rfloor \Biggr \rfloor$

Matrices

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`amsmath` matrix environments

The `amsmath` package provides commands to typeset matrices with different delimiters. Once you have loaded `\usepackage{amsmath}` in your preamble, you can use the following environments in your math environments:

Type	LATEX markup	Renders as
Plain	`\begin{matrix} 1 & 2 & 3\\ a & b & c \end{matrix}`	1a2b3c123abc
Parentheses; round brackets	`\begin{pmatrix} 1 & 2 & 3\\ a & b & c \end{pmatrix}`	(1a2b3c)(123abc)
Brackets; square brackets	`\begin{bmatrix} 1 & 2 & 3\\ a & b & c \end{bmatrix}`	[1a2b3c][123abc]
Braces; curly brackets	`\begin{Bmatrix} 1 & 2 & 3\\ a & b & c \end{Bmatrix}`	{1a2b3c}{123abc}
Pipes	`\begin{vmatrix} 1 & 2 & 3\\ a & b & c \end{vmatrix}`	|||1a2b3c||||123abc|
Double pipes	`\begin{Vmatrix} 1 & 2 & 3\\ a & b & c \end{Vmatrix}`	‖‖‖1a2b3c‖‖‖‖123abc‖

If you need to create matrices with different delimiters, you can add them manually to a plain `matrix`. For example:

LATEX markup	Renders as
`\left\lceil \begin{matrix} 1 & 2 & 3\\ a & b & c \end{matrix} \right\rceil`	⌈1a2b3c⌉⌈123abc⌉

\left\langle \begin{matrix} 1 & 2 & 3\\ a & b & c \end{matrix} \right\rvert	⟨1a2b3c|||⟨123abc|
\left\langle \begin{matrix} 1 & 2 & 3\\ a & b & c \end{matrix} \right\rangle	⟨1a2b3c⟩ ⟨123abc⟩

Inline matrices

When typesetting inline math, the usual `matrix` environments above may look too big. It may be better to use `smallmatrix` in such situations, although you will need to provide your own delimiters.

```
\documentclass{article}
\usepackage{amsmath}
\begin{document}
\noindent Trying to typeset an inline matrix here:
 $\begin{pmatrix}
  a & b\\
  c & d
\end{pmatrix}$,
but it looks too big, so let's try
$\big(\begin{smallmatrix}
  a & b\\
  c & d
\end{smallmatrix}\big)$
instead.
\end{document}
```

Open this `smallmatrix` example in Overleaf

The following image shows the output produced by the example above:

Trying to typeset an inline matrix here: $\begin{pmatrix} a & b \\ c & d \end{pmatrix}$, but it looks too big, so let's try $\big(\begin{smallmatrix} a & b \\ c & d \end{smallmatrix}\big)$ instead.

The `mathtools` package provides `psmallmatrix`, `bsmallmatrix` etc environments for convenience.

Aligning equations with amsmath

Contents

Introduction

The `amsmath` package provides a handful of options for displaying equations. You can choose the layout that better suits your document, even if the equations are really long, or if you have to include several equations in the same line.

The standard LaTeX tools for equations may lack some flexibility, causing overlapping or even trimming part of the equation when it's too long. We can surpass such difficulties by using the `amsmath` package, which can be added to preamble of your document using `\usepackage{amsmath}`.

Let's start with a basic example:

```
\begin{equation} \label{eq1}
\begin{split}
A & = \frac{\pi r^2}{2} \\
 & = \frac{1}{2} \pi r^2
\end{split}
\end{equation}
```

Open this `amsmath` fragment in Overleaf

The following graphic shows the output produced by the LaTeX code:

$$\begin{split} A &= \frac{\pi r^2}{2} \\ &= \frac{1}{2}\pi r^2 \end{split} \tag{1}$$

You have to wrap your equation in the `equation` environment if you want it to be numbered, use `equation*` (with an asterisk) otherwise. Inside the `equation` environment, use the `split` environment to split the equations into smaller pieces, these smaller pieces will be aligned accordingly. The double backslash works as a newline character. Use the ampersand character `&`, to set the points where the equations are vertically aligned.

Writing a single equation

To display a single equation, as mentioned in the introduction, you have to use the `equation*` or `equation` environment, depending on whether you want the equation to be numbered or not. Additionally, you might add a label for future reference within the document.

```
\begin{equation} \label{eu_eqn}
e^{\pi i} + 1 = 0
\end{equation}

The beautiful equation \ref{eu_eqn} is known as the Euler
equation.
```

[Open this `amsmath` fragment in Overleaf]

The following graphic shows the output produced by the LaTeX code:

$$e^{\pi i} + 1 = 0 \tag{1}$$

The beautiful equation 1 is known as the Euler equation

You can also [open a more complete example of the `amsmath` package in Overleaf.]

Displaying long equations

For equations longer than a line use the `multline` environment. Insert a double backslash to set a point for the equation to be broken. The first part will be aligned to the left and the second part will be displayed in the next line and aligned to the right.

Again, the use of an asterisk * in the environment name determines whether the equation is numbered or not.

```
\begin{multline*}
p(x) = 3x^6 + 14x^5y + 590x^4y^2 + 19x^3y^3\\
- 12x^2y^4 - 12xy^5 + 2y^6 - a^3b^3
\end{multline*}
```

[Open this multiline equation `amsmath` fragment in Overleaf]

The following graphic shows the output produced by the LaTeX code:

$$\begin{multline*}
p(x) = 3x^6 + 14x^5y + 590x^4y^2 + 19x^3y^3\\
- 12x^2y^4 - 12xy^5 + 2y^6 - a^3b^3
\end{multline*}$$

You can also open a more complete example of the `amsmath` package in Overleaf.

Splitting and aligning an equation

Split is very similar to *multline*. Use the *split* environment to break an equation and to align it in columns, just as if the parts of the equation were in a table. This environment must be used inside an *equation* environment. For an example check the introduction of this document.

Aligning several equations

If there are several equations that you need to align vertically, the *align* environment will do it:

```
\begin{align*}
2x - 5y &=  8 \\
3x + 9y &=  -12
\end{align*}
```

Open this `amsmath` fragment in Overleaf

The following graphic shows the output produced by the LaTeX code:

$$
\begin{aligned}
2x - 5y &= 8 \\
3x + 9y &= -12
\end{aligned}
$$

Usually the binary operators (`>`, `<` and `=`) are the ones aligned for a nice-looking document.

As mentioned before, the ampersand character `&` determines where the equations align. Let's check a more complex example:

```
\begin{align*}
x&=y           &    w &=z              &   a&=b+c\\
2x&=-y         &    3w&=\frac{1}{2}z   &   a&=b\\
-4 + 5x&=2+y   &    w+2&=-1+w          &   ab&=cb
\end{align*}
```

Open this `amsmath` fragment in Overleaf

The following graphic shows the output produced by the LaTeX code:

$$
\begin{aligned}
x&=y & w &=z & a&=b+c\\
2x&=-y & 3w&=\frac{1}{2}z & a&=b\\
-4 + 5x&=2+y & w+2&=-1+w & ab&=cb
\end{aligned}
$$

Here we arrange the equations in three columns. LaTeX assumes that each equation consists of two parts separated by an `&` and that each equation is separated from the one before by an `&`.

Again, use * to toggle the equation numbering. When numbering is allowed, you can label each row individually.

Grouping and centering equations

If you just need to display a set of consecutive equations, centered and with no alignment whatsoever, use the `gather` environment. The asterisk trick to set/unset the numbering of equations also works here.

```
\begin{gather*}
2x - 5y =  8 \\
3x^2 + 9y =  3a + c
\end{gather*}
```

[Open this `amsmath` fragment in Overleaf]

The following graphic shows the output produced by the LaTeX code:

$$
\begin{gather*}
2x - 5y = 8 \\
3x^2 + 9y = 3a + c
\end{gather*}
$$

Integrals, sums and limits

Integrals

Integral expression can be added using the `\int_{lower}^{upper}` command.

Note, that integral expression may seems a little different in inline and display math mode.

LaTeX code	Output
`Integral \(\int_{a}^{b} x^2 \,dx\) inside text`	Integral $\int_a^b x^2 dx$ inside text

`\[ \int_{a}^{b} x^2 \,dx \]`	$\int_a^b x^2 dx$

Multiple integrals

To obtain double/triple/multiple integrals and cyclic integrals you must use `amsmath` and `esint` (for cyclic integrals) packages.

LaTeX code	Output
`\begin{gather*} \iint_V \mu(u,v) \,du\,dv \\ \iiint_V \mu(u,v,w) \,du\,dv\,dw \\ \iiiint_V \mu(t,u,v,w) \,dt\,du\,dv\,dw \\ \idotsint_V \mu(u_1,\dots,u_k) \,du_1 \dots du_k \end{gather*}`	$\iint_V \mu(u,v)\,du\,dv$ $\iiint_V \mu(u,v,w)\,du\,dv\,dw$ $\iiiint_V \mu(t,u,v,w)\,dt\,du\,dv\,dw$ $\idotsint_V \mu(u_1,\dots,u_k)\,du_1 \dots du_k$
`\[ \oint_V f(s) \,ds \]`	$\oint_V f(s)\,ds$

Sums and products

Like integral, sum expression can be added using the `\sum_{lower}^{upper}` command.

LaTeX code	Output

`Sum $\sum_{n=1}^{\infty} 2^{-n} = 1$ inside text`	Sum $\sum_{n=1}^{\infty} 2^{-n} = 1$ inside text
`\[ \sum_{n=1}^{\infty} 2^{-n} = 1 \]`	$$\sum_{n=1}^{\infty} 2^{-n} = 1$$

In similar way you can obtain expression with product of a sequence of factors using the `\prod_{lower}^{upper}` command.

LATEX code	Output
`Product $\prod_{i=a}^{b} f(i)$ inside text`	Product $\prod_{i=a}^{b} f(i)$ inside text
`\[ \prod_{i=a}^{b} f(i) \]`	$$\prod_{i=a}^{b} f(i)$$

Limits

Limit expression can be added using the `\lim_{lower}` command.

LATEX code	Output
`Limit $\lim_{x\to\infty} f(x)$ inside text`	Limit $\lim_{x\to\infty} f(x)$ inside text
`\[ \lim_{x\to\infty} f(x) \]`	$$\lim_{x\to\infty} f(x)$$

PIECEWISE FUNCTION

```
\usepackage{amsfonts}
```

Latex piecewise function with left operator

```
\begin{equation*}
y = f(x) = \lvert x \rvert = \left\{
        \begin{array}{ll}
            -x & \quad x \leq 0 \\
            x & \quad x \geq 0
        \end{array}
    \right.
\end{equation*}
```

Latex piecewise function with cases environment

```
\begin{equation*}
g(x)=\begin{cases}
          x \quad &\text{if} \, x \in \mathbb{Q} \\
          -x \quad &\text{if} \, x \notin \mathbb{Q} \\
     \end{cases}
\end{equation*}
```

$$y = f(x) = \lvert x \rvert = \left\{ \begin{array}{ll} -x & \quad x \leq 0 \\ x & \quad x \geq 0 \end{array} \right.$$

$$g(x)=\begin{cases} x \quad &\text{if} \, x \in \mathbb{Q} \\ -x \quad &\text{if} \, x \notin \mathbb{Q} \end{cases}$$