# Mathematics in LaTeX

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October 5, 2022

# Introduction

Introduction

Math that is useful everywhere

Displayed math

## Basics

- First of all: put `\usepackage{amsmath}` in the preamble
- Typesetting math is what TeX is created for
- There are two math modes in LaTeX:
  - inline (written between $ signs): this appears as part of the text, like this: $\sum_{n=1}^{\infty} 1/n^2 = \pi^2/6$
  - displayed: these come between paragraphs, like here:

$$\sum_{n=1}^{\infty} 1/n^2 = \frac{\pi^2}{6}$$

    and the simplest way to write one is to put them between `\[` and `\]`
- Two ground rules of math mode:
  - spaces are ignored
  - no blank lines allowed

# Math that is useful everywhere

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# Everyday constructions

- $2(a+b)=2a+2b$: `$2(a+b)=2a+2b$`
- Sometimes we may want $a\cdot b$: `$a\cdot b$` instead of $ab$
- $(a+b)^2=a^2+2ab+b^2$: `$(a+b)^2=a^2+2ab+b^2$`
- $a<0$, $a>0$, $0\leq a^2$, $a^2\geq0$, $x\in A$: `$a<0$`, `$a>0$`, `$0\leq a^2$`, `$a^2\geq0$`, `$x\in A$`
- $a\nless0$, $a\ngtr0$, $0\nleq a^2$, $a^2\ngeq0$, $x\notin A$: `$a\nless0$`, `$a\ngtr0$`, `$0\nleq a^2$`, `$a^2\ngeq0$`, `$x\notin A$`
- Simpler, but doesn't always look good: $a\not<0$, $a\not<0$, $0\not\leq a^2$,...: `$a\not<0$`, `$a\not<0$`, `$0\not\leq a^2$`
- $a_{ij}=-a_{ji}$: `$a_{ij}=-a_{ji}$` (remember blocks?)
- ${a^n}^m=a^{nm}$: `${a^n}^m=a^{nm}$` and not `$a^n^m=a^{nm}$` which will result in a `Double superscript` error. The same applies to subscripts.

## Everyday constructions 2.

- But we can mix superscripts with subscripts: $a_{ij}^n = a_{ji}^n$:
  `$a_{ij}^n=a_{ji}^n$`
- $\frac{a^2-b^2}{a+b} = a - b$: `$\frac{a^2-b^2}{a+b}=a-b$`
- instead of $(\frac{a^2-b^2}{a+b})^2$ we want $\left(\frac{a^2-b^2}{a+b}\right)^2$:
  `$\left(\frac{a^2-b^2}{a+b}\right)^2$`
- $\sqrt{a/b}$, $\sqrt[n]{a/b}$, $\sqrt{1+\sqrt{a/b}}$: `$\sqrt{a/b}$`, `$\sqrt[n]{a/b}$`,
  `$\sqrt{1+\sqrt{a/b}}$`
- $\binom{n}{k} = \frac{n!}{k!(n-k)!}$: `$\binom{n}{k}=\frac{n!}{k!(n-k)!}$`;
- for absolute value, $\lvert a-b\rvert$: `$\lvert a-b\rvert$` is the best choice; if this seems a lot of work, define a new command in the preamble:

  ```
  \newcommand\abs[1]{\lvert#1\rvert}
  ```

  and then use `\abs{a-b}`

# Everyday constructions 3.

- $a\mid b$, $a\nmid b$: `$a\mid b$`, `$a\nmid b$`
- $a\bmod b = c \iff a\equiv c\pmod b (\iff a\equiv c\mod b)$: `$a\bmod b = c \iff a\equiv c\pmod b (\iff a\equiv c\mod b)$`
- $x^2-1=0\iff x=\pm1$: `$x^2-1=0\iff x=\pm1$`
- $\mathbf{a}\times \mathbf{b}\perp \mathbf{a}$, $\vec{a}\parallel \overrightarrow{BC}$: `$\mathbf{a}\times \mathbf{b}\perp \mathbf{a}$`, `$\vec{a}\parallel \overrightarrow{BC}$`
- Greek letters: $\alpha$, $\beta$, $\gamma$, $\pi$, $\Delta$, $\Sigma$, $\Pi$: `$\alpha$`, `$\beta$`, `$\gamma$`, `$\pi$`, `$\Delta$`, `$\Sigma$`, `$\Pi$`
- Famous sets of numbers: $\mathbb{N}$, $\mathbb{Z}$, $\mathbb{R}$, $\mathbb{C}$: `$\mathbb{N}$`, `$\mathbb{Z}$`, `$\mathbb{R}$`, `$\mathbb{C}$`
- $\lim_{n\to\infty}(1+1/n)^n=e$: `$\lim_{n\to\infty}(1+1/n)^n=e$`
- $\sin'x=\cos x$: `$\sin'x=\cos x$`; the apostrophe ($'$) gets automatically superscripted. Because of this, we can't write `$f'^2$`, but either this: `${f'}^2$` (which doesn't look quite right: ${f'}^2$) or this `$f^{\prime 2}$` (which does: $f^{\prime 2}$).

# Everyday constructions 4.

- $A\cap (B\cup C)= (A\cap B)\cup (A\cap C)$:
  `$A\cap (B\cup C)= (A\cap B)\cup (A\cap C)$`
- $\emptyset\subseteq A$: `$\emptyset\subseteq A$`
- $A\supseteq B\iff B\subseteq A$: `$A\supseteq B\iff B\subseteq A$`
- $A\setminus A=\emptyset$: `$A\setminus A=\emptyset$`
- $A\subseteq B\iff \forall x(x\in A \implies x\in B)$:
  `$A\subseteq B\iff \forall x(x\in A \implies x\in B)$`
- $A\subsetneq B\iff A\subseteq B \mathrel{\&} \exists x(x\in B \mathrel{\&} x\notin A)$:
  `$A\subsetneq B\iff A\subseteq B\And`
  `\exists x(x\in B \And x\notin A)$`
- $\pi_0\langle\,a,b\,\rangle = a$: `$\pi_0\langle\,a,b\,\rangle = a$`; without the extra `\,` ("thin horizontal space"), it doesn't look quite right: $\langle a,b\rangle$

# Everyday constructions 5.

- $\sum_{n=1}^\infty 1/n^2=\pi^2/6$: `$\sum_{n=1}^\infty1/n^2=\pi^2/6$`;
- $\prod_{n=1}^{10}n=362880$: `$\prod_{n=1}^{10}n=362880$`;
- integrals need a little fine tuning: $\int_0^{\pi/2}\sin^2x\,dx=\pi/4$: `$\int_0^{\pi/2}\sin^2x\,dx=\pi/4$`; without the extra `\,` it looks bad: $\int_0^{\pi/2}\sin^2xdx=\pi/4$.
- thin horizontal space is used here, too:
  $\{\,n\in\mathbb{N}\mid \text{$n$ has at least $3$ different prime divisors}\,\}$:

  ```
  $\{\,n\in\mathbb{N}\mid \text{$n$ has
           at least $3$ different prime divisors}\,\}$
  ```
- $\int_a^bf(x)\,dx = F(x)\bigr|_a^b$: `$\int_a^bf(x)\,dx = F(x)\bigr|_a^b$`
- or even $\int_a^bf(x)\,dx = F(x)\Bigr|_a^b$: `$\int_a^bf(x)\,dx = F(x)\Bigr|_a^b$` which looks probably better in displayed formulas

## Some finer points

- This is how to write ${}^k a^i_j$: `${}^k a^i_j$`
- Text mode knows about spacing around a comma, math mode doesn't; so
  - write $a$, $b \in B$ like this: `$a$, $b \in B$` and not like this: `$a, b \in B$`
  - similarly, "for $i = 1$, $2$, $\dots$, $n$" should be written like this: `for $i = 1$,~$2$, \dots,~$n$`
  - but not in the middle of a formula: $\{\,2i \mid i=1,2,\dots,n\,\}$: `$\{\,2i \mid i=1,2,\dots,n\,\}$`
- LaTeX is clever here: $1+2+\dots+n=\frac{n(n+1)}2$: `$1+2+\dots+n=\frac{n(n+1)}2$`
- but when it's not, we can use `\ldots` and `\cdots`

# Displayed math

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# Displayed formulas

- Notice that

$$\sum_{n=1}^{\infty} 1/n^2 = \pi^2/6$$

(written as `\[\sum_{n=1}^\infty1/n^2=\pi^2/6\]`) looks a little different from its inline version $\sum_{n=1}^{\infty} 1/n^2 = \pi^2/6$

- We can label displayed formulas manually, as in

$$\sum_{n=1}^{\infty} 1/n^2 = \pi^2/6, \tag{$\dagger$}$$

which is written

`\[\tag{$\dagger$} \sum_{n=1}^\infty1/n^2=\pi^2/6,\]`

- and refer to it as "the equation (†)":
  `‘‘the equation \thetag{$\dagger$}’’`
- for automatic labelling we need to use some other environment, such as `\begin{equation} ... \end{equation}`

## Displayed formulas 2.

- Sometimes we want to put extra space between formulas on the same line:

$$sin(x+y) = \sin x\cos y+ \cos x\sin y, \qquad cos(x+y) = \cos x\cos y - \sin x\sin y$$

- `\[ sin(x+y) = \sin x\cos y+ \cos x\sin y, \qquad cos(x+y) = \cos x\cos y - \sin x\sin y \]`
- We may prefer to write it this way:

$$sin(x+y) = \sin x\cos y+ \cos x\sin y \quad\text{and}\quad cos(x+y) = \cos x\cos y - \sin x\sin y$$

- `\[ sin(x+y) = \sin x\cos y+ \cos x\sin y \quad\text{and}\quad cos(x+y) = \cos x\cos y - \sin x\sin y \]`
- Another example:

$$a_1 = \frac12,\quad a_2 = \frac23,\quad\dots\quad a_n=\frac{n}{n+1}$$

- `\[a_1 = \frac12,\quad a_2 = \frac23, \quad\dots\quad a_n=\frac{n}{n+1}\]`

# Displayed formulas 3.

- To help the reader (or our later self) this is sometimes useful:

$$r_1r_2(\overbrace{\cos\varphi_1\cdot\cos\varphi_2-\sin\varphi_1\cdot\sin\varphi_2}^{\cos(\varphi_1+\varphi_2)}+j(\underbrace{\cos\varphi_1\cdot\sin\varphi_2 + \sin\varphi_1\cdot\cos\varphi_2}_{\sin(\varphi_1+\varphi_2)}))$$

- ```
  \[r_1r_2(\overbrace{\cos\varphi_1\cdot\cos\varphi_2-
    \sin\varphi_1\cdot\sin\varphi_2}^{\cos(\varphi_1+\varphi_2)}+
    j(\underbrace{\cos\varphi_1\cdot\sin\varphi_2 +
    \sin\varphi_1\cdot\cos\varphi_2}_{\sin(\varphi_1+\varphi_2)}))
  ```
- Another kind of help:

$$s=\lim f(a_{n_i}) \overset{(3)}{=} \lim_b f \overset{\text{cont.}}{=} f(b).$$

```
\[s=\lim f(a_{n_i}) \overset{(3)}{=}
  \lim_b f \overset{\text{cont.}}{=} f(b).\]
```
```

## Multiline formulas

If our formula is too long:

$$\frac{r_1(\cos\varphi_1 + j\sin\varphi_1)}{r_2(\cos\varphi_2 + j\sin\varphi_2)} \\ = \frac{r_1(\cos\varphi_1 + j\sin\varphi_1)r_2(\cos-\varphi_2 + j\sin-\varphi_2)}{r_2^2} \\ = \frac{r_1}{r_2}\bigl(\cos(\varphi_1-\varphi_2) + j\sin(\varphi_1 - \varphi_2)\bigr)$$

which is written like this:

```
\begin{multline*}\frac{r_1(\cos\varphi_1 +
    j\sin\varphi_1)}{r_2(\cos\varphi_2 + j\sin\varphi_2)} \\
  = \frac{r_1(\cos\varphi_1 + j\sin\varphi_1)r_2(\cos-\varphi_2 +
    j\sin-\varphi_2)}{r_2^2}  \\
  = \frac{r_1}{r_2}\bigl(\cos(\varphi_1-\varphi_2) +
  j\sin(\varphi_1 - \varphi_2)\bigr)
\end{multline*}
```

# Multiline formulas 2.

- The $*$ is here to avoid automatic labelling. This works with all other named environments for displaying math, too.
- Always break (with `\\`) a long formula *before* a binary relation or binary operation
- Don't write `\\` after the last line
- With most multiline environments, every line is labelled automatically, unless one writes `\notag` on the line.

## Multiline formulas 3.

$$\sin^2 x + \cos^2 x = 1 \tag{1}$$
$$sin(x + y) = \sin x \cos y + \cos x \sin y$$
$$cos(x + y) = \cos x \cos y - \sin x \sin y \tag{2}$$

is written like this:

```
\begin{gather}
\sin^2x + \cos^2x = 1\\
\sin(x+y) = \sin x\cos y + \cos x\sin y \notag\\
\cos(x+y) = \cos x\cos y - \sin x\sin y
\end{gather}
```

## Multiline formulas 4.

We may want to align the equations:

$$\begin{align} \sin^2 x + \cos^2 x &= 1 \tag{3}\\ sin(x+y) &= \sin x\cos y + \cos x\sin y \notag\\ cos(x+y) &= \cos x\cos y - \sin x\sin y \tag{4} \end{align}$$

written like this:

```
\begin{align}
  \sin^2x + \cos^2x & = 1\\
  sin(x+y) & = \sin x\cos y+ \cos x\sin y \notag\\
  cos(x+y) & = \cos x\cos y - \sin x\sin y
\end{align}
```

## Multiline formulas 5.

or like this, with three columns

$$\sin^2 x + \cos^2 x = 1 \qquad \text{easy} \qquad (5)$$

$$sin(x+y) = \sin x \cos y + \cos x \sin y \qquad \text{hard}$$

$$cos(x+y) = \cos x \cos y - \sin x \sin y \qquad \text{hard} \qquad (6)$$

written like this:

```
\begin{align}
  \sin^2x + \cos^2x & = 1 && \text{easy} \\
  sin(x+y) & = \sin x\cos y+ \cos x\sin y && \text{hard}\notag\\
  cos(x+y) & = \cos x\cos y - \sin x\sin y && \text{hard}
\end{align}
```

"The align environment is used for two or more equations when vertical alignment is desired; usually binary relations such as equal signs are aligned [...] To have several equation columns side-by-side, use extra ampersands to separate the columns." (`amsldoc`)

# Multiline formulas 6.

There are a million other environments like these (Google `amsldoc` and see §3). But one that comes up often is this:

$$f(x)=\begin{cases}
1 &\text{if $x\in\mathbb{Q}$} \\ 0 &\text{otherwise.}
\end{cases}$$

```
\[f(x)=\begin{cases}
1 &\text{if $x\in\mathbb{Q}$} \\ 0 &\text{otherwise.}
\end{cases}
\]
```

## Matrices

- Matrix:

$$\begin{pmatrix}
a + b + c & uv & x - y & 27\\
a + b & u + v & z & 1340\\
a & & uz & 93
\end{pmatrix}$$

```
\[\begin{pmatrix}
a + b + c & uv & x - y & 27\\
a + b & u + v & z & 1340\\
a & & uz & 93
\end{pmatrix}\]
```

- The same in brackets:

$$\begin{bmatrix}
a + b + c & uv & x - y & 27\\
a + b & u + v & z & 1340\\
a & & uz & 93
\end{bmatrix}$$

```
\[\begin{bmatrix}
a + b + c & uv & x - y & 27\\
a + b & u + v & z & 1340\\
a & & uz & 93
\end{bmatrix}\]
```

# Matrices 2.

- There are also `vmatrix`, `Vmatrix`, and `Bmatrix` with different delimiters (try them!), and `matrix` with none.
- The latter is useful in situations like this:

$$\left(\begin{matrix} a+b+c & uv & x-y & 27\\ a+b & u+v & z & 1340\\ a & & uz & 93 \end{matrix}\right]$$

```
\[\left(
  \begin{matrix}
    a + b + c & uv & x - y & 27\\
    a + b & u + v & z & 1340\\
    a & & uz & 93
  \end{matrix}
  \right]
  \]
```

that should never arise.

# Matrices 3.

$$\begin{vmatrix}
a_{1,1} & a_{1,2} & \dots & a_{1,n}\\
a_{2,1} & a_{2,2} & \dots & a_{2,n}\\
\vdots & \vdots & \ddots & \vdots \\
a_{n,1} & a_{n,2} & \dots & a_{n,n}
\end{vmatrix}$$

```
\[\begin{vmatrix}
a_{1,1} & a_{1,2} &\dots & a_{1,n}\\
a_{2,1} & a_{2,2} &\dots & a_{2,n}\\
\vdots & \vdots & \ddots & \vdots \\
a_{n,1} & a_{n,2} &\dots & a_{n,n}
\end{vmatrix} \]
```

# Matrices 4.

$$\begin{pmatrix} a_{1,1} & a_{1,2} & \dots & a_{1,n} \\ a_{2,1} & a_{2,2} & \dots & a_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m,1} & a_{m,2} & \dots & a_{m,n} \end{pmatrix} \cdot \begin{pmatrix} b_{1,1} & b_{1,2} & \dots & b_{1,m} \\ b_{2,1} & b_{2,2} & \dots & b_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n,1} & b_{n,2} & \dots & b_{n,m} \end{pmatrix}$$

$$= \begin{pmatrix} \sum_{i=1}^{n} a_{1,i} b_{i,1} & \sum_{i=1}^{n} a_{1,i} b_{i,2} & \dots & \sum_{i=1}^{n} a_{1,i} b_{i,m} \\ \sum_{i=1}^{n} a_{2,i} b_{i,1} & \sum_{i=1}^{n} a_{2,i} b_{i,2} & \dots & \sum_{i=1}^{n} a_{2,i} b_{i,m} \\ \vdots & \vdots & \ddots & \vdots \\ \sum_{i=1}^{n} a_{m,i} b_{i,1} & \sum_{i=1}^{n} a_{m,i} b_{i,2} & \dots & \sum_{i=1}^{n} a_{m,i} b_{i,m} \end{pmatrix}$$

# Matrices 5.

```
\begin{multline*}
\begin{pmatrix}
a_{1,1} & a_{1,2} &\dots & a_{1,n}\\
a_{2,1} & a_{2,2} &\dots & a_{2,n}\\
\vdots & \vdots & \ddots & \vdots\\
a_{m,1} & a_{m,2} &\dots & a_{m,n}
\end{pmatrix} \cdot
\begin{pmatrix}
b_{1,1} & b_{1,2} &\dots & b_{1,m}\\
b_{2,1} & b_{2,2} &\dots & b_{2,m}\\
\vdots & \vdots & \ddots & \vdots\\
b_{n,1} & b_{n,2} &\dots & b_{n,m}
\end{pmatrix} \\
=
\begin{pmatrix}
\sum_{i=1}^n a_{1,i}b_{i,1} & \sum_{i=1}^n a_{1,i}b_{i,2}
   &\dots & \sum_{i=1}^n a_{1,i}b_{i,m}\\
\sum_{i=1}^n a_{2,i}b_{i,1} & \sum_{i=1}^n a_{2,i}b_{i,2}
   &\dots & \sum_{i=1}^n a_{2,i}b_{i,m}\\
\vdots & \vdots & \ddots & \vdots\\
\sum_{i=1}^n a_{m,i}b_{i,1} & \sum_{i=1}^n a_{m,i}b_{i,2}
   &\dots & \sum_{i=1}^n a_{m,i}b_{i,m}\\
\end{pmatrix}
\end{multline*}
```