Hardcore $\LaTeX$ Math

RSI 2011 Staff

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Part I: basic features

- Review

- Theorems and proofs such
Entering math mode

Use $...$ or \((...\)) for text math mode and \([...\]) or $$...$$ for display math mode:

This sentence refers to integers $n$ and $(m)$ and reminds you that
\[
\int_0^\infty e^{-t} \, dt = 1.
\]

This sentence refers to integers $n$ and $m$ and reminds you that
\[
\int_0^\infty e^{-t} \, dt = 1.
\]

It’s probably better to use $...$ than \((...\)), because dollar signs are more traditional, and thus easier to read. But for displayed equations, \([...\]) is preferable.
Punctuation

Inline equations should not contain punctuation belonging to the sentence.

Because the ideal $I$ contains $x$, ...

Displayed equations that end sentences should contain a period.

Therefore, the value of the integral is
\[
\int_0^\infty e^{-t} \, dt = 1. \]
Numbered equations

Use the equation environment to create a numbered equation. Put a label inside it using \label{foo} and then use \ref{foo} to typeset the equation number. Preferred: You can type \eqref{foo} to add parentheses automatically.

It follows that
\begin{equation}
\label{verywrong}
6 \times 9 = 42.
\end{equation}
From \eqref{verywrong} we can deduce we screwed up somewhere.

It follows that

\[ 6 \times 9 = 42. \quad (1) \]
From (1) we can deduce we screwed up somewhere.
**Variables**

For most variables with one-character names, just type the character in math mode: $x + y$ for $x + y$.

For Greek letters, backslash their names: $\alpha, \beta, \Gamma$ for $\alpha, \beta, \Gamma$. (There is no $\Alpha$; simply use $A$.)

For long names, there are two tasteful options:

\[
[ \mathit{long\_variable\_name} + \text{roman name} = 240 \]

\[
\text{long\_variable\_name} + \text{roman name} = 240
\]

Don't just type a long name into math mode or you'll get

\[
\text{long\_variable\_name}.
\]
Variables in other fonts

\[ A \ \texttt{\textbackslash mathbf\{A\}} \]
\[ \mathcal{F} \ \texttt{\textbackslash mathcal\{F\}} \ (\text{capitals only}) \]
\[ \mathbb{Z} \ \texttt{\textbackslash mathbb\{Z\}} \ (\text{capitals only}) \]
\[ ab \ \texttt{\textbackslash mathfrak\{ab\}} \]
\[ \mathscr{L} \ \texttt{\textbackslash mathscr\{L\}} \ (\text{capitals only}; \text{requires \texttt{mathrsfs} package}) \]

Put only the variable inside the font-changing command:

\[ [ \ \texttt{\textbackslash mathfrak\{c\}\{\textbackslash mathfrak\{a\} + \textbackslash mathfrak\{b\}\}} \ ] \]

\[ c(a + b) \]
Roman operators

Many notations like $\sin(x)$ and $\log(x)$ are typeset in upright characters. Say $\sin(x)$, $\log(x)$, etc. For comparison, $\sin(x)$ produces $sin(x)$, which is italicized.

For the condition under $\lim$, $\max$, or the like, use a subscript:

\[
\lim_{x \to \infty} \frac{1}{x} = 0
\]

(Note that subscripts and superscripts which are more than one character need brackets. For instance, $10^{-10}$ appears as $10^{10}$.)
Defining your own operators

To define your own, say

\DeclareMathOperator{\spec}{Spec}

in preamble.tex and then use $\spec A[x]$ for Spec $A[x]$. You can also type $\operatorname{Spec} A[x]$ to get the same result without defining a command.
Big operators

For big operators such as sums (\sum), products (\prod), and integrals (\int), use subscripts and superscripts to get the limits:

\[ \int_{1}^{\infty} \frac{dx}{x^2} = 1. \]

\[ \sum_{k=1}^{\infty} \frac{1}{k^2} = \frac{\pi^2}{6}. \]
Theorems and such

After a couple of declarations, you can do this:

\begin{theorem}
Herding cats is hard.
\end{theorem}

**Theorem 1.** *Herding cats is hard.*

\begin{lemma}[Smith, 1972]
Herding alligators is harder, and much more dangerous besides.
\end{lemma}

**Lemma 1** (Smith, 1972). *Herding alligators is harder, and much more dangerous besides.*
Creating theorem types

Before using theorem and lemma, I had to do this:

\newtheorem{theorem}{Theorem}
\newtheorem{lemma}{Lemma}

The first argument is the internal name, so the word you put in the \begin{} and \end{} statements. The second argument is the external name, so it appears in the document before the number.

Each theorem type has its own counter (hence Theorem 1 and Lemma 1 in the previous example).

Put these declarations in preamble.tex.
Several types, one counter

\newtheorem{prop}{Proposition}
\newtheorem{propdef}[prop]{Proposition-Definition}

The optional argument [prop] says that Proposition-Definitions should be numbered in the same series as Propositions.

\begin{prop}[Lucas, 1977]
Swordplay obviates acting.
\end{prop}

\begin{propdef}[Lucas, 1999]
There exist painfully inane characters. A maximal such character in a film is \textit{of Jar-Jar type}.
\end{propdef}
Several times, one counter (continued)

Proposition-Definitions and Propositions are not numbered separately:

**Proposition 1** (Lucas, 1977). *Swordplay obviates acting.*

**Proposition-Definition 2** (Lucas, 1999). *There exist painfully inane characters. A maximal such character in a film is of Jar-Jar type.*

Note also that we used `emph` instead of `textit`. 
Counting within sections, subsections, etc.

You can do

\newtheorem{remark}{Remark}[section]

to make Remarks numbered separately within each section ("Remark 5.3" for the third Remark in Section 5).

Similarly \newtheorem{remark}{Remark}[subsection] would make "Remark 5.2.1" and the like.
More with theorems: styles and numbering

You can use three built-in “styles” to specify how you want your theorem heading to appear. You can also define your own if these aren’t enough. Additionally, using an * makes a theorem type unnumbered.

\theoremstyle{plain}% default
\newtheorem{thm}{Theorem}[section]
\newtheorem{lem}[thm]{Lemma}
\newtheorem{prop}[thm]{Proposition}
\newtheorem*{cor}{Corollary}
\newtheorem*{KL}{Kleins Lemma}
More with theorems (continued)

\theoremstyle{definition}
\newtheorem{defn}{Definition}[section]
\newtheorem{conj}{Conjecture}[section]
\newtheorem{exmp}{Example}[section]

\theoremstyle{remark}
\newtheorem*{rem}{Remark}
\newtheorem*{note}{Note}
\newtheorem{case}{Case}
The proof environment automatically places a QED symbol at the end of your proof:

\begin{proof}[Proof of the Main Theorem]
Combining Lemma \ref{lem:smith} and Definition \ref{def:smith}, we see that $\mu(x) = 17$.
\end{proof}

*Proof of the Main Theorem.* Combining Lemma 1 and Definition 3, we see that $\mu(x) = 17$.

For some reason, amsmath doesn’t appear to contain the proof environment, so you might need to add \texttt{\textbackslash usepackage\{amsthm\}} to \texttt{preamble.tex}.
Moving the QED

Sometimes, the box appears on an empty line:

Proof.

\[ G(t) = L\gamma! t^{-\gamma} + t^{-\delta} \eta(t) \]

\begin{proof}
\begin{equation*}
G(t) = L\gamma! t^{-\gamma} + t^{-\delta} \eta(t) \quad \square
\end{equation*}
\end{proof}

Proof.

\[ G(t) = L\gamma! t^{-\gamma} + t^{-\delta} \eta(t) \quad \square \]
Part II: breaking and stacking

- \texttt{multline}, for breaking lines in long equations

- \texttt{gather} and \texttt{align}, for several equations in one display

- \texttt{pmatrix} and variants, for matrices

- \texttt{\substack}, for stacking conditions under big operators
Breaking lines in displayed equations

Don’t try to use `\` to force a line break in a displayed equation. It won’t work. Instead, use the `multline` environment:

\begin{multline}
X = a + b + c + d + e + f + g \\
+ h + i + j + k + l
\end{multline}

\[ X = a + b + c + d + e + f + g + h + i + j + k + l + m \\
+ n + o + p + q + r + s + t + u \] (2)

The variant `multline*` gives an unnumbered equation.

In a display, always break the line before a binary operator.
More lines in \texttt{multline}

More than two lines are allowed. The first is flushed left; the last is flushed right; the others are centered.

\begin{multline*}
x = a + b + c + d + e + f + g + h + i + j + k + l + m \\
+ n + o + p + q + r + s + t + u + v \\
+ w + x + y + z + 1 + 2 + 3 + 4 + 691
\end{multline*}

\begin{align*}
x &= a + b + c + d + e + f + g + h + i + j + k + l + m \\
&
+ n + o + p + q + r + s + t + u + v \\
&
+ w + x + y + z + 1 + 2 + 3 + 4 + 691
\end{align*}
Rejustifying `multline`

Put a line in `\shoveleft{...}` or `\shoveright{...}` to change the justification.

```
\begin{multline*}
X = a + b + c + d + e + f + g + h + i + j + k + l + m \\
\shoveright{+ n + o + p + q + r + s + t + u + v} \\
+ w + x + y + z + 1 + 2 + 3 + 4 + 691
\end{multline*}
```

\[
X = a + b + c + d + e + f + g + h + i + j + k + l + m \\
+ n + o + p + q + r + s + t + u + v \\
+ w + x + y + z + 1 + 2 + 3 + 4 + 691
\]
Several equations in one display

You can use the \texttt{gather} (numbered) or \texttt{gather*} (unnumbered) environments to put several equations in a display, each centered independently of the others.

\begin{gather}
\label{foo} x + y = z \\
\label{bar} a = b + c + d + e + f
\end{gather}

\begin{align*}
x + y &= z & (3) \\
a &= b + c + d + e + f & (4)
\end{align*}

But it is usually more tasteful to align your equations.
Aligned equations

To align several equations in one display, use \texttt{align} (numbered) or \texttt{align*} (unnumbered).

\begin{align}
  f(x) &= g(x^2) \\
  a + b + c &= d + e + f
\end{align}

\begin{align*}
  f(x) &= g(x^2) \\
  a + b + c &= d + e + f
\end{align*}

\begin{align}
  f(x) &= g(x^2) & \text{(5)} \\
  a + b + c &= d + e + f & \text{(6)}
\end{align}
Multicolumn align

You can have several aligned columns; use extra ampersands to separate them.

\begin{align}
  x + y &= z + w & a + b &= c + d \\
  X + Y &= Z + W & A + B &= C + D \\
\end{align}

\begin{equation}
  x + y = z + w \quad a + b = c + d \quad (7)
\end{equation}

\begin{equation}
  X + Y = Z + W \quad A + B = C + D \quad (8)
\end{equation}
Align: making only some lines numbered

Option 1: Use \begin{align} with \notag just before the \\ on the lines you do not want numbered.

Option 2: Use \begin{align*} with \tag{} just before the \\ on the lines you do want numbered.

\begin{align*}
x+1 &= 18 \\
x &= 17 \tag{1}\label{result}
\end{align*}

We can see from \eqref{result} that...

\[ x + 1 = 18 \]
\[ x = 17 \]

We can see from (1) that...
Cases constructions

\begin{equation}
F_n = \begin{cases}
0 & \text{if } n = 0; \\
1 & \text{if } n = 1; \\
F_{n - 1} + F_{n - 2} & \text{if } n > 0.
\end{cases}
\end{equation}

\begin{align*}
F_n &= \begin{cases}
0 & \text{if } n = 0; \\
1 & \text{if } n = 1; \\
F_{n-1} + F_{n-2} & \text{if } n > 1.
\end{cases} \quad (9)
\end{align*}
Matrices

\[
\begin{pmatrix}
2 & 3 & 4 \\
5 & 6 & 7 \\
8 & 9 & 10
\end{pmatrix} v = 0
\]

\[
\begin{pmatrix}
2 & 3 & 4 \\
5 & 6 & 7 \\
8 & 9 & 10
\end{pmatrix} v = 0
\]

For square brackets use \texttt{bmatrix}. For single or double vertical lines use \texttt{vmatrix} or \texttt{Vmatrix} respectively.

For small matrices in running text like \[
\begin{pmatrix}
2 & 3 \\
4 & 5
\end{pmatrix}
\]:

\[
\bigl( \begin{smallmatrix}
2 & 3 \\
4 & 5
\end{smallmatrix} \bigr)
\]
The \substack command

\substack lets you stack expressions in subscripts.

\[
\min_{\substack{ x \in S \\ x \ge 20 }} f(x)
\]

\[
\sum_{\substack{ a + b + c = 20 \\ a,b,c \ge 0 \\ a + 2b \ge 5 }} abc
\]
Part III: the fine points of looking good

- Math in text
- Dots
- Big delimiters
- Spacing tricks
- Common ugly constructions
Putting it all in math mode

A common mistake:

We see that $x$ $+$ $y$ $=$ $z$ $+$ $23$.

We see that $x + y = z + 23$.

Put the entire equation or expression in math mode:

We see that $x + y = z + 23$.

We see that $x + y = z + 23$. 
Punctuation around formulae

In text math mode, commas and periods that are part of the sentence should be outside math mode:

Because $f(a,b) = 0$, it follows that $f(2a, b-a) = 4$.

Because $f(a,b) = 0$, it follows that $f(2a, b-a) = 4$.

In display math mode, there should (usually) be a comma, semicolon, or period inside the display.

We find therefore that \[ x^n + y^n \neq z^n. \]

We find therefore that

$$ x^n + y^n \neq z^n. $$
The AMS packages have introduced convenient abbreviations for different kinds of dots in math mode. This is a good idea, since then it is possible to change all of the style consistently throughout a document by adding a single line to the preamble (instead of doing a search and replace potentially across several files). Here they are:

- \dotsc for dots with commas, as in $a_1, \dotsc, a_n$ for $a_1, \ldots, a_n$;

- \dotsm for dots with multiplication, as in $1 \cdot 2 \dotsm n$ for $1 \cdot 2 \cdots n$;
More dots

• \texttt{\textbackslash dotsb} for dots with binary operators or relations, as in
  \[1 + \ldotsb + n\] for \(1 + \cdots + n\);

• \texttt{\textbackslash dotsi} for dots with integrals, as in
  \[
  \int_A \int_B \ldotsi \int_Z
  \]
  for
  \[
  \int_A \int_B \cdots \int_Z;
  \]

• \texttt{\textbackslash dotso} for “other.”
Even more dots

- In text mode just use $\ldots$; it’ll make something like this...

- To force low horizontal dots in math mode, use $\ldots$.

- To force centered horizontal dots in math mode, use $\cdots$.

- In matrices with rows or columns left out, you may need $\vdots$ (…) and $\ddots$ (…) as well.
Dots in a matrix

\[
\begin{matrix}
a_{11} & \cdots & a_{1n} \\
\vdots & \ddots & \vdots \\
a_{n1} & \cdots & a_{nn}
\end{matrix}
\]
Delimiter height, part 1: automatic expansion

Using \texttt{\textbackslash left} and \texttt{\textbackslash right} in front of delimiters (parentheses, brackets, etc.) makes them expand to enclose a tall expression (fraction, sum, integral, etc.).

Thus $\texttt{\textbackslash left}(\frac{x^2}{y^2}\texttt{\textbackslash right})$ gives $\left(\frac{x^2}{y^2}\right)$.

By contrast $(\frac{x^2}{y^2})$ gives $\left(\frac{x^2}{y^2}\right)$.

\texttt{\textbackslash left} and \texttt{\textbackslash right} must be properly nested.
You can (and sometimes should) choose the size yourself:

\(\ldots\)

\(\bigl(\ldots\bigr)\)

\(\Bigl(\ldots\Bigr)\)

\(\biggl(\ldots\biggl)\)

\(\begin{array}{c}
\end{array}\)

These need not be properly nested (so be careful).
Delimiter height, part 3: examples

\[ f \left( (x + 1)^4 + 1 \right) \]

\[ \left( \sum_{n \geq 1} a_n n^{-s} \right)^2 \]
Spacing adjustments

Normally \LaTeX \text{ puts tasty amounts of whitespace into expressions without your help. In certain situations, though, you can make formulae look neater by adding or deleting space.}

- \, — thin space (\(a\,b\) is \(ab\))
- \! — thin backspace (\(a\!b\) is \(ab\))

\textit{Example.} The code $x^{n}/n!$ gives $x^n/n!$, with an apparent gap between the exponent and slash. Better is $x^{n}\!/n!$, which gives $x^n/n!$. 
Spacing adjustments in integrals

Multiple integrals sometimes look bad without a bit of backspacing (\!). A thin space (\,) before a differential is often tasteful.

\[ \int_{0}^{2\pi} \! \int_{0}^{\infty} e^{-r^2}r\,dr\,d\theta = \pi \]

\[ \int_{0}^{2\pi} \int_{0}^{\infty} e^{-r^2} r \, dr \, d\theta = \pi \]
Ugly mistakes

• Italicizing text by putting it in math mode. This looks *awful*. Use \textit{...} instead: *awful*.

• Writing long variable names without \textit{...} or \text.

• Putting two displayed equations one after the other. Use an alignment to line up the equality signs and space more tastefully.

• Forgetting to use \texttt{\texttt{left} and \texttt{right}} or explicit resizing commands when you put parentheses around a tall formula.