Ph3 LaTeX Week 5:
More Math

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1 Modes

As latex compiles your source code, it operates in one of three *modes*. The default mode is *paragraph*, which is used for processing text, like this paragraph. In paragraph mode letters string together into words. Spacing between words and sentences is adjusted as necessary, regardless of how many spaces you put in the source code. Lines are wrapped to fit on the page. Words are broken across lines when they need to be. Figures are floated to convenient places, and text is arranged around them.

Math mode is a different animal. There, letters are treated as variables and are strung together as products of several variables, not words, and spaces are ignored. Special symbols are available in math mode that aren't in paragraph mode, as are special constructions like fractions, as we've seen before. You cause the latex compiler to enter math mode when you declare a math environment, and there are several types of math environments for different types of equations and formulae. We've covered two of those environments so far, *math* for in-line and *equation* for stand-alone equations, and this week we'll cover some more.

The third mode is called *left-to-right*, or LR for short, and is very similar to paragraph mode. We'll come back to LR mode later. For now just remember that paragraph mode and math mode are very different, and many commands will be available in one mode but not the other.

2 Symbols

2.1 Symbols available in paragraph and LR modes

Special symbols are usually mode-specific. The umlaut in Schrödinger we saw in an earlier lesson, for example, is only available in paragraph mode, and it is typeset like so, `Schro\"{o}dinger`. Other accents are listed in Lamport [1], and I will reproduce a few of the most useful ones at the end of this document. Lamport's book is worth getting for the tables of special symbols alone.

2.2 Symbols available in math mode

Most mathematical symbols are only available in math mode. Lamport, of course, lists many more than I care to reproduce here, and for a comprehensive list I will direct you to his book [1]. I will list all the Greek letters, plus a few commonly-used symbols at the end of this document, but you don't need to memorize those commands if you remember that the way to produce a symbol is usually with a backslash, followed by the name of the symbol, *e.g.* `\alpha`.

2.3 Symbols available in all modes

Special symbols that would otherwise be used for formatting can be produced by adding a backslash (\) in front of them. The symbols # $ % & _ { and } are displayed with the source code `\# \$ \% \& \_ \{` and `\}`. These commands work in either paragraph or math mode.

3 Roots and fractions

We've already covered fractions, but it bears repeating here. In-line fractions generally look best done the simplest way, like this 1/4 (`$1/4$`), but they can be formatted like this, $\frac{1}{4}$ (`$\frac{1}{4}$`). Standalone fractions almost always look best when formatted with the `\frac{}{}` command.

Square roots are similar. The command is \sqrt{*argument*}, where *argument* is whatever you want to go inside the radical. For example,

$$\sqrt{b^2 - 4ac}$$

is formatted `\sqrt{b^2 - 4ac}`. Higher-order roots put the order in an option before the argument. For example, you make $\sqrt[3]{5}$ with `\sqrt[3]{5}`.

4 Arrays

By now it will probably not surprise you that you make arrays using the *array* environment, which works in math mode. There is an extra argument to the command to begin this environment that tells latex how many columns you want and whether the elements in those columns should be centered (`c`), left-justified (`l`), or right-justified (`r`). To fill the array you type in each element one at a time, using & signs to separate columns an double backslashes (\\) to start new rows. For example, to typeset a three-by-three identity matrix with the elements in all three columns centered you would use the following source code.

```
\begin{equation}
\label{eq:3x3_identity}
I = \left[
            \begin{array}{ccc}
```

```
            1 & 0 & 0 \\
            0 & 1 & 0 \\
            0 & 0 & 1
            \end{array}
       \right]
\end{equation}
```

Note that you don't need double backslashes after the last row, since there is no new row to start after that. The output looks like this.

$$I = \left[\begin{array}{ccc} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{array} \right] \tag{1}$$

5 Multi-line equations

You can make a multi-line equation with the array environment by setting one of the columns to hold equal signs and leaving blank the elements you don't need. For example, this

$$\begin{array}{rcl} y & = & (x+a)^3 \\ & = & (x+a)(x^2+2xa+a^2) \\ & = & x^3+3x^2a+3xa^2+a^3 \end{array} \tag{2}$$

would be coded like this.

```
\begin{equation}
\label{eq:expanding_cubic}
\begin{array}{rcl}
y & = & (x + a)^3 \\
  & = & (x + a)(x^2 + 2xa + a^2) \\
  & = & x^3 + 3x^2a + 3xa^2 + a^3
\end{array}
\end{equation}
```

6 Numbered vs. unnumbered equations

We have seen how to format math inside a line of text using the math environment, and we have seen a shorthand for beginning and ending that environment with dollar sign symbols, $ to begin the environment and another $ to end it. You can also begin the in-line math environment with \(and end it with \), which can be easier to read when the formula is long. Dollar signs don't give you any immediate indication whether they are meant to begin or end the environment. So, the three ways to begin and end in-line math mode are

```
\begin{math}  E = m c^2  \end{math}
\(  E = m c^2  \)
$   E = m c^2  $
```

We have also seen how to begin and end standalone equations using the equation environment, which also numbers the equations and allows you to label them and refer back to them by those numbers in the text.

```
\begin{equation}
    E = m c^2
    \label{eq:mass_energy_equivalence}
\end{equation}
```

You can make un-numbered standalone equations using the *equation** environment, which has the shortcut \[to begin and \] to end. The following two examples produce exactly the same output.

```
\begin{equation*}
    E = m c^2
\end{equation*}

\[
    E = m c^2
\]
```

7 Exercises

1. Typeset the Pauli matrices, given below, making sure the delimiters (big parentheses) come out as shown.

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \; \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \; \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

   Hint:. Remember how we forced the correct spacing after a period inside a sentence ("Dr. Sadler, Dr. Malcom, if you please…")? You can use the same command to force a space between equations in math mode too.

2. Format and cite the following. Make the ellipsis with the command listed in Table 6, and make sure your single quotation marks are oriented correctly. Use the *quotation* environment to indent your passage, as I have done.

> 'Gúthwinë!' cried Éomer. 'Gúthwinë for the Mark!'
> …
> But a small dark figure that none had observed sprang out of the shadows and gave a hoarse shout: *Baruk Khazâd! Khazâd ai-mênu!* [2]

3. Format the following [4]. Is it right?

$$\begin{aligned}\sqrt{3-2\sqrt{2}} &= \sqrt{1+2-2\sqrt{2}} \\ &= \sqrt{1+\left(\sqrt{2}\right)^2-2\sqrt{2}} \\ &= \sqrt{\left(1-\sqrt{2}\right)^2} \\ &= 1-\sqrt{2}\end{aligned}$$

4. Format the following [3]. Use `\mathcal{H}` to make the script-H for the Hamiltonian. There is a mathcal version of each capitol letter like this. See Appendix A for any symbols not covered in the body of this handout.

$$\begin{aligned}\dot{q}_i &= \{q_i, \mathcal{H}\} \\ \dot{p}_i &= \{p_i, \mathcal{H}\} \\ \dot{\bar{q}}_i &= \partial\mathcal{H}/\partial\bar{p}_i \\ \dot{\bar{p}}_i &= -\left(\partial\mathcal{H}/\partial\bar{q}_i\right)\end{aligned}$$

5. Sometimes you want boldface characters in your formulae, to denote vectors, for example, and you can get them with the `\mathbf{}` command. With this in mind, typeset the formula for the Hamiltonian of a charged particle in an electromagnetic potential, including the vector potential $\mathbf{A}$.

$$\mathcal{H}_{e\cdot m} = \frac{\left|\left(\mathbf{p} - q\mathbf{A}/c\right)\right|^2}{2m} + q\phi$$

References

[1] Lamport, Leslie *LaTeX: A Document Preparation System User's Guide and Reference Manual 2ed.*, Addison-Wesley Publishing Company 1994.

[2] Tolkien, J. R. R., *The Two Towers, Second Edition*, Houghton Mifflin Company, Boston (1954), p. 139.

[3] Shankar, Ramamurti, *Principles of Quantum Mechanics*, Plenum Press, New York (1980), pp. 98-99.

[4] Gelfand, Israel M., and Shen, Alexander, *Algebra*, Springer Science+Business Media New York (2004), p. 51. If you aren't familiar with this book, you should be.

A Tables of symbols and commands

ó \'{o}	õ \~{o}	ǒ \v{o}	o̧ \c{o}
ò \`{o}	ō \={o}	ő \H{o}	ọ \d{o}
ô \^{o}	ȯ \.{o}	o͡o \t{oo}	o̲ \b{o}
ö \"{o}	ŏ \u{o}		

Table 1: Accents available in paragraph mode and the source codes that produce them. This reproduces Lamport's Table 3.1 [1], and he has many more tables like this.

α \alpha	θ \theta	o o	τ \tau
β \beta	ϑ \vartheta	π \pi	υ \upsilon
γ \gamma	ι \iota	ϖ \varpi	ϕ \phi
δ \delta	κ \kappa	ρ \rho	φ \varphi
ϵ \epsilon	λ \lambda	ϱ \varrho	χ \chi
ε \varepsilon	μ \mu	σ \sigma	ψ \psi
ζ \zeta	ν \nu	ς \varsigma	ω \omega
η \eta	ξ \xi		
Γ \Gamma	Λ \Lambda	Σ \Sigma	Ψ \Psi
Δ \Delta	Ξ \Xi	Υ \Upsilon	Ω \Omega
Θ \Theta	Π \Pi	Φ \Phi	

Table 2: The Greek alphabet available in math mode and the source code to produce it. This reproduces Lamport's Table 3.3 [1].

# \#	$ \$	% \%	_ _
& \&	{ \{	} \}	

Table 3: Commands to display special symbols that are normally used as commands themselves are the symbol preceded by a backslash (\). These work in both paragraph and math mode.

$+$ `+`	$-$ `-`	$\times$ `\times`	$\div$ `\div`
$\pm$ `\pm`	$\mp$ `\mp`	$\cdot$ `\cdot`	

Table 4: Commonly-used operations (math mode).

$=$ `=`	$\neq$ `\neq`	$\simeq$ `\simeq`
$\sim$ `\sim`	$\propto$ `\propto`	
$<$ `<`	$\ll$ `\ll`	$\leq$ `\leq`
$>$ `>`	$\gg$ `\gg`	$\geq$ `\geq`
$\equiv$ `\equiv`	$\in$ `\in`	$\notin$ `\notin`

Table 5: Some relational symbols. These are mostly available only in math mode, except for the straightforward characters that don't require commands, such as =. Those work in any mode. You can make a slash through (negative of) any of these symbols by adding $\backslash not$ to the beginning of the command. For example $\not\leq$ is just \not\leq.

$\hbar$ `\hbar`	$\imath$ `\imath`	$\jmath$ `\jmath`	ℓ `\ell`
∇ `\nabla`	∂ `\partial`	∞ `\infty`	
$\ldots$ `\ldots`	$\cdots$ `\cdots`	$\vdots$ `\vdots`	$\ddots$ `\ddots`
$\perp$ `\perp`	$\parallel$ `\parallel`	$\angle$ `\angle`	$\circ$ `\circ`
$\rightarrow$ `\rightarrow`	$\Rightarrow$ `\Rightarrow`	$\Leftarrow$ `\Leftarrow`	$\leftarrow$ `\leftarrow`
$\forall$ `\forall`	$\exists$ `\exists`	$\emptyset$ `\emptyset`	

Table 6: Some more useful symbols. Most of these are only available in math mode, but \ldots, which is called an *ellipsis* can be used in all modes.

$\hat{a}$ `\hat{a}`	$\vec{a}$ `\vec{a}`	$\bar{a}$ `\bar{a}`
$\dot{a}$ `\dot{a}`	$\ddot{a}$ `\ddot{a}`	$\overline{xy}$ `\overline{xy}`

Table 7: Some accents in math mode. These come in useful if, for example, you want to typeset the unit vectors $\hat{\imath}$, $\hat{\jmath}$, and $\hat{k}$. Use overline when you want to draw a line over multiple symbols or entire formulae.

$\sum$ `\sum`	$\int$ `\int`	$\prod$ `\prod`	$\oint$ `\oint`

Table 8: And of course the ever-useful sum, integral, and product symbols, available in math mode.