IBTEX

A Template for Writing the IB Extended Essay and Internal Assessments.

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Contents

1 Typesetting Mathematics

This chapter will focus on inserting mathematics into your paper. LaTeX comes with basic mathematics support out of the box, so we will need to incorporate some additional packages to enhance the range of formulas that can be included in our document. You can think of it as adding the functionality of an equation editor into your current word processor. As you become more familiar with the syntax, you will quickly appreciate being able to type your formulas with the same ease you write text.

LaTeX comes with two modes that are of interest to us:

1. normal and
2. math, which has the two styles
    a) inline and
    b) display.

Normal mode is the default mode and where you will write the non-mathematical text of your document. If you want to include expressions and equations, then you are going to need to use either an inline or display math mode, which are environments specific for mathematics. However, we are going to want to include more advanced mathematical formatting such as multiline equations and for this we are going to include some additional packages including those from the $\mathcal{AMS}$, American Mathematics Society, and the mathtools[2] packages which will bring some enhancements to the $\mathcal{AMS}$ math package[1]. Don't worry, these packages are loaded by default when using this style file; however, you should be aware which packages are being used so that you know which documentation to reference for help beyond this quick start up guide.

To get us started, I am going to briefly introduce both the inline and display math environments that are available. Then I will provide some of the more common features available from the $\mathcal{AMS}$ math package. Once we have established the environments in which we can write mathematics, we can look at how we can format special characters and symbols such as operators, operands and function names. To make our lives a bit easier, we will include some additional packages along the way and I will share some of the custom macros that are available through the mhomath.sty file.

§1.1 Inline Mathematics

In order for the code that you write to be interpreted by the compiler as mathematics, you need to toggle between **normal mode** and **inline math mode** by using the math environment.

```
\begin{math}
  ⟨mathematics content goes here⟩
\end{math}
```

```
Solve all equations of the form
\begin{math}
  ax^2 + bx + c = 0
\end{math}
for
\begin{math}
  x \in \mathbb{R}
\end{math}
by completing the square.
```

Solve all equations of the form $ax^2 + bx + c = 0$ for $x \in \mathbb{R}$ by completing the square.

From the above example, we can see that the code is verbose and difficult to read. Thankfully, this environment has a shortcut notation that should **ALWAYS** be used. The macro `\(` is used to toggle into inline math mode and the macro `\)` is used to toggle back to normal mode.

```
< normal mode text > \( < math environment code > \) < normal mode text >
```

We can now revisit our original example using this simplified notation.

```
Solve all equations of the form \( ax^2 + bx + c = 0 \)
for \( x \in \mathbb{R} \) by completing the square.
```

Solve all equations of the form $ax^2 + bx + c = 0$ for $x \in \mathbb{R}$ by completing the square.

It is helpful to know that spaces in math mode are ignored by the compiler, which means we can be generous with how we use spaces to format our code such that it is easier to parse. As your expressions become more complex, the additional spaces in your code should improve its legibility. Well, at least that has been my experience. Let's consider our example without the extra spaces.

```
Solve all equations of the form \(ax^2+bx+c=0\) for
\(x\in\mathbb{R}\) by completing the square.
```

Solve all equations of the form $ax^2 + bx + c = 0$ for $x \in \mathbb{R}$ by completing the square.

The shortcut inline math environment, `\(`⟨*math environment code*⟩`\)`, that we have been using is from LaTeX. However, there is a plain TeX shortcut for the math environment that remains popular today which is using the dollar sign character as the delimiter.

```
< normal mode text > $ < math environment code > $ < normal mode text >
```

I prefer the `\(` ⟨*math environment code*⟩ `\)` notation as it can be helpful in resolving errors. However, if you are new to using LaTeX, then you might want to use the dollar sign delimiters as they have the advantage of making your code slightly easier to read and faster to type. At this point in the development of LaTeX as a language, it is really a matter of personal preference. Just be consistent!

```
Solve all equations of the form $ ax^2 + bx + c = 0 $ for
$ x \in \mathbb{R} $ by completing the square.
```

Solve all equations of the form $ax^2 + bx + c = 0$ for $x \in \mathbb{R}$ by completing the square.

A small thought on changing between the two different shortcut notations. It would be possible to do a quick search and replace from the LaTeX notation to the TeX notation, but not vice-versa.

§1.2 Display Style Math Mode

There will be times when you will want to emphasize or isolate an expression by centering it on the page and for this we are going to be using the **display style math mode** environment. This environment is restricted to a single line of output like an equation.

```
\begin{displaymath}
  ⟨mathematics content goes here⟩
\end{displaymath}
```

```
All the real number values of \( x \) that satisfy the quadratic equations
of the form \( ax^2 + bx + c = 0 \) where \( a, b, c \in \mathbb{R} \)
can be found using the quadratic formula,
\begin{displaymath}
  x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.
\end{displaymath}
```

All the real number values of x that satisfy the quadratic equations of the form $ax^2 + bx + c = 0$ where $a, b, c \in \mathbb{R}$ can be found using the quadratic formula,

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.$$

Just like the inline math environment, you would **ALWAYS** use the LaTeX pair of `\[` ⟨*math environment code*⟩ `\]` delimiters as the shortcut. Rather than write the delimiters and mathematical expression on the same line as we did in inline math mode, we give each delimiter it's own line and place the math on the line in between the delimiters. We could express the quadratic formula from our previous examples as:

```
\[
  x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.
\]
```

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.$$

It is very likely that you will come across the the double dollar sign shortcut notation for the display math environment, but it should **NEVER** be used as it will most likely bring up issues at some point.

```
$$
  x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.
$$
```

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.$$

If you are looking to include multiple lines in display math mode, then you might be tempted to use consecutive display style math mode environments, but you must resist as a better solution is available. In summary, you should **NEVER** use consecutive display math mode environments, which means you should never write something like:

```
\[
  2x^2 + 14x + 24 = 2( x^2 + 7x + 12 )
\]
\[
  = 2(x + 3)(x + 3)
\].
```

$$2x^2 + 14x + 24 = 2(x^2 + 7x + 12)$$
$$= 2(x + 3)(x + 3)$$

.

§1.3 Multiline Math Environments

Like I said, there are specific environments that you can use to achieve multiline equations. This style file includes the package mathtools, which will give us multiple environments to achieve multiline equations and more. The mathtools package imports the $\mathcal{AMS}$ math package and enhances its functionality. This means if we are using mathtools, then there is no need to import $\mathcal{AMS}$ math.

For complete documentation I suggest you check the official documentation:

- User's Guide for the amsmath Package
- The mathtools package

Before we look at the using multiline equation environments, I want to point out the single line math environment called equation, which is similar to the LaTeX display math environment

```
\begin{equation}
  ⟨mathematics content goes here⟩
\end{equation}
```

The first environment that we are going to consider is very similar to the the LaTeX display math environment, but it also supports multiline equations. By default the equations will be numbered.

```
\begin{equation}
  x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.
\end{equation}
```

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}. \tag{1.1}$$

In fact, we get something very close to the LaTeX display math environment with the star version of this equation environment as the equation numbers are suppressed. All these structured math environments have a star version that suppresses numbering, so I will only include an example for the equation environment.

```
\begin{equation*}
  ⟨mathematics content goes here⟩
\end{equation*}
```

```
\begin{equation*}
  x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.
\end{equation*}
```

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.$$

It's time to take a look at some of the multiline equation environments that are available for us to use in our work. To change the form of the expression $2x^2+14x+24$ using the equation environment.

```
\begin{equation*}
  2x^2 + 14x + 24 = 2( x^2 + 7x + 12 ) = 2(x + 3)(x + 3)
  \end{equation*}
```

$$2x^2 + 14x + 24 = 2(x^2 + 7x + 12) = 2(x + 3)(x + 3)$$

However, this might be easier to read if it was expressed using a multiline math environment.

It is possible include a split environment within the equation environment to achieve a multiline equation with the option to include expression splitting as well.

```
\begin{split}
  ⟨mathematics content goes here⟩
\end{split}
```

We will use the & character to vertically *align* each equation at the equal sign and two consecutive double backslash characters, \\ break to the next line.

```
\begin{equation*}
  \begin{split}
    2x^2 + 14x + 24
    &= 2( x^2 + 7x + 12 ) \\
    &= 2(x + 3)(x + 3)
  \end{split}
\end{equation*}
```

$$\begin{aligned} 2x^2 + 14x + 24 &= 2(x^2 + 7x + 12) \\ &= 2(x + 3)(x + 3) \end{aligned}$$

It is even possible to split up long expressions! The \quad macro is used to include 4 spaces.

```
\begin{equation*}
  \begin{split}
    a
    &= b - c + d - e + f \\
    & \quad - g + h - i + k \\
    &= l + m \\
    &= n
  \end{split}
\end{equation*}
```

$$\begin{aligned} a &= b - c + d - e + f \\ &\quad - g + h - i + k \\ &= l + m \\ &= n \end{aligned}$$

It might be the case that you have one very long expression that you would like to break up and this can be done with the multline environment. Notice that this does not require to be embedded in the equation environment.

```
\begin{multiline}
  ⟨mathematics content goes here⟩
\end{multiline}
```

```
\begin{multline*}
    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 \\
    - (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 )
\end{multline*}
```

$$\begin{multline} a+b+c+d+e+f+g+h+i+j+k+l+m+n+o+p+q+r+s+t+u+v+w+x+y+z \\ -(a+b+c+d+e+f+g+h+i+j+k+l+m+n+o+p+q+r+s+t+u+v+w+x+y+z) \end{multline}$$

My preference is to have my equations to be vertically aligned at the equal sign. However, you might want your equations to be centered on the page. The gather environment will take care of this for you.

```
\begin{gather}
  ⟨mathematics content goes here⟩
\end{gather}
```

```
\begin{gather*}
    a = b + c + d + e \\
    a = f + g \\
    a = h
\end{gather*}
```

$$a = b + c + d + e$$
$$a = f + g$$
$$a = h$$

Notice that there is not & character being used for alignment in this environment.

It is now time to introduce the environment that I use for about 95 % of the multiple line expressions needed in my work and it is called align.

```
\begin{align*}
  ⟨mathematics content goes here⟩
\end{align*}
```

```
\begin{align*}
  2x^2 + 14x + 24
  &= 2( x^2 + 7x + 12 ) \\
  &= 2(x + 3)(x + 3).
\end{align*}
```

$$\begin{aligned} 2x^2 + 14x + 24 &= 2(x^2 + 7x + 12) \\ &= 2(x + 3)(x + 3). \end{aligned}$$

This environment allows you to comment you work using tags

```
\begin{align*}
  2x^2 + 14x + 24
  &= 2( x^2 + 7x + 12 ) \tag{factoring two}\\
  &= 2(x + 3)(x + 3). \tag{factoring the quadratic}
\end{align*}
```

$$\begin{aligned} 2x^2 + 14x + 24 &= 2(x^2 + 7x + 12) && \text{(factoring two)} \\ &= 2(x + 3)(x + 3). && \text{(factoring the quadratic)} \end{aligned}$$

There is no need for multiple align environments in a sentence since there is the `\intertext` macro. If you want less space between the lines, then I can suggest that you use the `\shortintertext` macro instead.

```
Given \( x = \cos x \) and \( y = \sin x \), we can show
\begin{align*}
  \shortintertext{using the Pythagorean identity}
  x^2 + y^2 &= 1 \\
  \intertext{substituting \(x \) and \(y \)}
  \left( \cos x \right)^2 + \left( \sin x \right)^2 &= 1 \\
  \shortintertext{alternative function squared form}
  \cos^2 x + \sin^2 &= 1.
\end{align*}
```

Given $x = \cos x$ and $y = \sin x$, we can show

using the Pythagorean identity

$$x^2 + y^2 = 1$$

substituting x and y

$$(\cos x)^2 + (\sin x)^2 = 1$$

alternative function squared form

$$\cos^2 x + \sin^2 = 1.$$

It is also possible to include two columns of equations

```
\begin{align*}
  a_{11}
  & =b_{11}
  &
  a_{12}
  & =b_{12}\\
  a_{21}
  & =b_{21}
  &
  a_{22}
  & =b_{22}+c_{22}
\end{align*}
```

$$a_{11} = b_{11} \qquad a_{12} = b_{12}$$
$$a_{21} = b_{21} \qquad a_{22} = b_{22} + c_{22}$$

If you would like the columns to be fully justified, then there is an alternative environment called flalign.

```
\begin{flalign*}
  ⟨mathematics content goes here⟩
\end{flalign*}
```

```
\begin{flalign*}
    a_{11}
    & =b_{11}
    &
    a_{12}
    & =b_{12}\\
    a_{21}
    & =b_{21}
    &
    a_{22}
    & =b_{22}+c_{22}
\end{flalign*}
```

$$a_{11} = b_{11} \qquad a_{12} = b_{12}$$
$$a_{21} = b_{21} \qquad a_{22} = b_{22} + c_{22}$$

§1.4 Cases Environment

There are a couple cases where you might want to treat some part of your formula as a block on the same line and the cases environment get the job done.

```
\begin{cases}
  ⟨mathematics content goes here⟩
\end{cases}
```

```
\[
\abs{x}=\begin{cases}
  x & \text{ if \( x \ge 0 \) } \\
  -x & \text{ if \( x < 0 \) }
\end{cases}
\]
```

$$|x| = \begin{cases} x & \text{if } x \geq 0 \\ -x & \text{if } x < 0 \end{cases}$$

This can also be used for systems of equations.

```
Solve the following system of equations for \( x \) and \( y \).
  \[
  \begin{cases}
    x + y = 12 \\
    2x - 3y = 9
  \end{cases}
  \]
```

Solve the following system of equations for x and y.

$$\begin{cases} x + y = 12 \\ 2x - 3y = 9 \end{cases}$$

2 Figures & Images

§2.1 Storing Images

Images can be easily included in your document by using the `\includegraphics` macro included with the graphics package. Before we include our first image, we should probably create a folder to hold all our images to keep our directory lean in terms of the number of files. My personal preference is to keep my images in the folder called `~/assets`, which is relative to the directory of my main file. Rather than have to provide the path of where your images are located there is a `\graphicspath` macro that you can place in the preamble that allows you to assign one or more locations for LaTeX to look for image files.

```
\graphicspath{{/assets/}}
```

Or if you have more than one directory

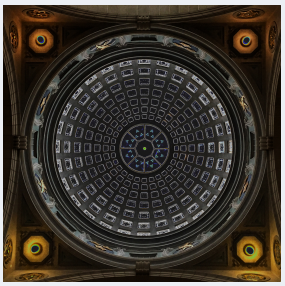
```
\graphicspath{{/assets/}{/images/}{/pdfs/}}
```

This will save you a lot of extra typing and worry about where your images are being stored.

§2.2 Including Images

To include an image we will be using the `\includegraphics` macro, which accepts the path and file name as its argument and can take multiple options. If you made use of the `\graphicspath` macro, made available by default for this template, then the argument is the file name. The file extension is optional, unless you have multiple files with the same name, but with different extensions. Let's scale an image such that it's width is a quarter of the textwidth and center it by placing it in a center environment.

```
\begin{center}
\includegraphics[width = 0.25\textwidth]{image.jpg}
\end{center}
```



§2.3 Figure Environment

You will probably want to reference your image at some point in your text and will most likely want to provide it with a caption. For this we are going to use the figure environment, which will calculate the best position to place your image within the document. Don't worry, there are ways to manually place the image where you would like it to appear.

```
\begin{figure}[⟨h, t⟩]
  ⟨image content goes here⟩
\end{figure}
```

```
\begin{center}
\includegraphics[width = 0.25\textwidth]{image.jpg}
\end{center}
\caption{Here is my excellent image.}
\label{fig:img###}
```

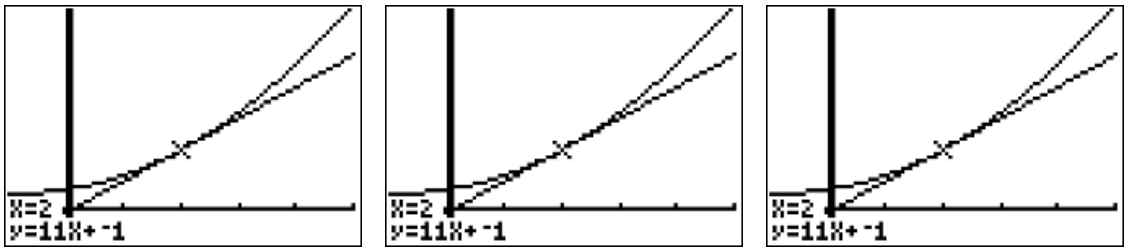
Figure 2.1: Here is my excellent image.

This would generate figure 2.1.

§2.4 Multiple Horizontally Aligned Images

Quite often it is the case that we want to include multiple horizontally aligned images. The figure environment is not well equipped for this task, so we care going to make use of the subfigure package which will give us the subfigure environment that we can embed in our figure environment. This will enable us to assign both a caption and a label to each image separately.

```
\begin{subfigure}
  ⟨image content goes here⟩
\end{subfigure}
```



(a) Step 1 (b) Step 2 (c) Step 3

Figure 2.2: The Steps Shown

```
\begin{figure}
    \begin{center}
    \begin{subfigure}[b]{0.3\textwidth}
        \includegraphics[width=\textwidth]{20170509-123642}
        \caption{Step 1}
        \label{fig:step1a}
    \end{subfigure}
    ~   % > > > Add desired spacing between images, e. g. ~, \quad, \qquad,
              % \hfill etc. (or a blank line to force the subfigure onto
              % a new line)
    \begin{subfigure}[b]{0.3\textwidth}
        \includegraphics[width=\textwidth]{20170509-123642.png}
        \caption{Step 2}
        \label{fig:step2a}
    \end{subfigure}
    ~   % > > > Add desired spacing between images, e. g. ~, \quad, \qquad,
              % \hfill etc. (or a blank line to force the subfigure onto
              % a new line)
    \begin{subfigure}[b]{0.3\textwidth}
        \includegraphics[width=\textwidth]{20170509-123642.png}
        \caption{Step 3}
        \label{fig:step3a}
    \end{subfigure}
    \caption{The Steps Shown}\label{fig:threestepsa}
    \end{center}
\end{figure}
```

3 Theorem Environments

§3.1 Definition

Definition 1 (Definition Of Subtraction)**.** Given a and b are real numbers, then[4] [3]

$$a + (-b) = a - b.$$

§3.2 Examples

Example 1. Solve the equation $x + 4 = 7$ for all $x \in \mathbb{Z}$.

Solution. The solution set is $x = \{3\}$. □

§3.3 Theorems

Axiom 1 (Axiom Of Simple Mathematical Induction)**.** Let $P(n)$ be a proposition, where $n \in \mathbb{Z}^+$. If we can

1. show the basis step is TRUE by showing $P(1)$ is TRUE and
2. show the inductive step is TRUE by showing for each $r \in \mathbb{Z}^+$, whenever $P(r)$ is TRUE , then $P(r + 1)$ is TRUE, where $P(r)$ is called the **induction hypothesis**,

then by the **axiom of mathematical induction** the proposition is proved.

The axiom of simple mathematical induction cannot be proven as it is part of the definition of $\mathbb{Z}^+$.

The axiom of simple mathematical induction1 cannot be proven as it is included as part of the definition of the set of positive integers, $\mathbb{Z}^+$.

Proposition 1 (Product of Common Base Powers)**.** Given b^m and b^n, then

$$b^m \cdot b^n = b^{m+n}.$$

Proof. Coming Soon! ■

Theorem 1 (Pythagorean Theorem)**.** Given a right-angled triangle ABC with sides a, b

and c, where c is the hypotenuse, then

$$a^2 + b^2 = c^2.$$

Proof. Someday soon! ■

References

[1] *CTAN: User's Guide for the amsmath Package (Version 2.1)*. American Mathematical Society, LATEX Project, LaTeX project. 2020. URL: https://ftpmirror1.infania.net/mirror/CTAN/macros/latex/contrib/mathtools/mathtools.pdf (visited on 07/02/2021).

[2] Lars Madsen Morten Hogholm. *CTAN: The mathtools package*. LaTeX3 project. 2021. URL: https://ftpmirror1.infania.net/mirror/CTAN/macros/latex/contrib/mathtools/mathtools.pdf (visited on 07/02/2021).

[3] Mark Olson. *02AQ - How to Factor a Quadratic Expression*. 2021. URL: https://youtu.be/3ftBMUrSJtg (visited on 06/08/2021).

[4] Eric W. Weisstein. *List*. From MathWorld–A Wolfram Web Resource. Wolfram Research, Inc. Aug. 5, 2003. URL: https://mathworld.wolfram.com/List.html (visited on 07/31/2020).