

The Book of Math (Notes)

Kevin Kuo

November 19, 2020

Forward and Disclaimer

These are math notes made by a student (with a physics major and math minor) based off text books. It may contain misconceptions and misinterpretations, thus should not be viewed in the same light of a text book. Use at your own risk and mental sanity.

Symbols

Logic

Name	Symbol	Comment
Exists	\exists	There exists at least one
For all	\forall	
Not exists	\nexists	There does not exist
Exists one	$\exists!$	There only exists one and only one
And	\wedge	
Or	\vee	Inclusive or
Not	\neg	
Logically implies	\implies	If
Logically implied by	\impliedby	Only if
Logically equivalent	\iff	If and only if
Implies	\longrightarrow	
Implied by	\longleftarrow	
Double Implication	\longleftrightarrow	

Set Notation

Name	Symbol	Comment
Empty Set	\emptyset	The set that is empty
Natural Numbers	\mathbb{N}	Set of natural numbers not containing 0, equivalent to the set of positive integers
Integers	\mathbb{Z}	Set of integers
Rational Numbers	\mathbb{Q}	
Algebraic Numbers	\mathbb{A}	
Real Numbers	\mathbb{R}	
Complex Numbers	\mathbb{C}	
In	\in	
Not in	\notin	
Owns	\ni	Has an element
Proper Subset	\subset	Subset that is not itself
Subset	\subseteq	
Superset	\supset	Superset that is not itself
Proper Superset	\supsetneq	

Power set	\wp
Union	\cup
Intersection	\cap
Difference	\setminus

Relationships

Name	Symbol	Comment
Defined	\doteq	
Approximate	\approx	
Equivalent	\equiv	Isomorphic (Group Theory)
Congruent	\cong	Homomorphic (Group Theory)
Proportional	\propto	

Operators

Name	Symbol	Comment
	\oplus	
	\otimes	
	\odot	
	\circ	Convolution
Dagger	\dagger	Complex conjugate transpose of a matrix

Arrows

Name	Symbol	Comment
Maps to	\mapsto	

Hebrew

Name	Symbol	Comment
Aleph	\aleph	Carnality of infinite sets that can be well ordered

Other

Name	Symbol	Comment
Real part	\Re	Real part of a number
Imaginary part	\Im	Imaginary part of a number

Book Constitution

Intents and Purpose

The goal of this book is to organize mathematical knowledge of topics related to the study of physics or the author's interest. It is meant to be used as a source of for future reference, not as a textbook for students new to the topics. It is a notebook of a student, thus should be treated as one and not as a textbook. At most, it could be used as a study guide along side a textbook. Definitely not as the main source for acquiring knowledge.

Layout and Organization

The book is split into parts each containing a field of study mathematics, or a topic large enough to justify giving it its own part. Each part contains chapters that focuses on a particular topic required to understand the field, with sections dedicated to describing a particular knowledge required for the topic.

As axioms, definitions, theorems, corollary, and proofs are integral and abundant to the study of mathematics, each will have a unique style. Each environment and its styles are displayed as follows:

Axiom 0.1: Axiom name

Example Axiom Axioms are the “ground rules” of the set.

Theorem 0.0.1: Theorem name or citation

Example Theorem An important logical result from the axioms, with proof.

Conjecture 0.0.1: Name of conjecture or citation

Example Conjecture A hypothesis, without proof.

Corollary 0.0.1.1:

Example Corollary An implication as a result of a theorem.

Lemma 0.0.1.1:

Example Lemma Small theorems that build up to a larger theorem.

Proposition 0.0.1.1:

Example Proposition Example proposition.

Proof: Logical deductions that results in a theorem. Proofs I've written will be in grey, which may or may not be correct. □

Definition 0.0.1: Word

Example Definition The definition of a word.

Example 0.0.1. *An example.*

Remark. *Remark A comment by the author in the textbooks used.*

Observation. *Example Observation A remark by me.*

Question. *Example Question A question from me for a mystery to be answered later.*

Contents

I	Logic	1
1	Proofs	3
II	Numbers	5
2	Natural \mathbb{N}	7
3	Integers \mathbb{Z}	9
4	Rationals \mathbb{Q}	11
5	Constructible	13
6	Algebraic \mathbb{A}	15
7	Reals \mathbb{R}	17
8	Complex \mathbb{C}	19
III	Real Analysis	21
9	Metric Spaces	23
IV	Complex Analysis	25
10	Basics	27
10.1	Complex Numbers	27

10.2 Triangle Inequality	28
10.3 Polar and Exponential Form	29
10.4 Complex Conjugates	30
11 Conformal Mapping	33
V Ordinary Differential Equations	35
VI Nonlinear Dynamics	37
VII Partial Differential Equations	39
VIII Integral Equations	41
IX Linear Algebra	43
12 Markov Chains	45
X Tensors	47
XI Riemann Geometry	49
XII Abstract Algebra	51
13 Groups	53
14 Rings	55
14.1 Ideals	55
15 Integral Domains	57
16 GCD Domains	59

17 Unique Factorization Domains	61
18 Principal Ideal Domains	63
19 Fields	65
XIII Galois Theory	67
XIV C-Star Algebra	69
XV Set Theory	71
XVI Model Theory	73
XVII Statistics	75
XVIII Tips and Tricks	77
20 Integration Techniques	79
20.1 DI Method (Integration Table)	79
20.2 Feynman Integration	79
XIX Index	81
XX Bibliography	83

Part I

Logic

Chapter 1

Proofs

Part II

Numbers

Resources used in part II

content...

Chapter 2

Natural \mathbb{N}

Chapter 3

Integers \mathbb{Z}

Chapter 4

Rationals \mathbb{Q}

Chapter 5

Constructible

Chapter 6

Algebraic \mathbb{A}

Chapter 7

Reals \mathbb{R}

Chapter 8

Complex \mathbb{C}

Part III

Real Analysis

Resources used in part III

1. Kenneth A. Ross - Elementary Analysis (2nd Ed.) [1]

Chapter 9

Metric Spaces

Part IV

Complex Analysis

Resources used in part IV

1. Brown and Churchill - Complex Variables and Applications [2]

Chapter 10

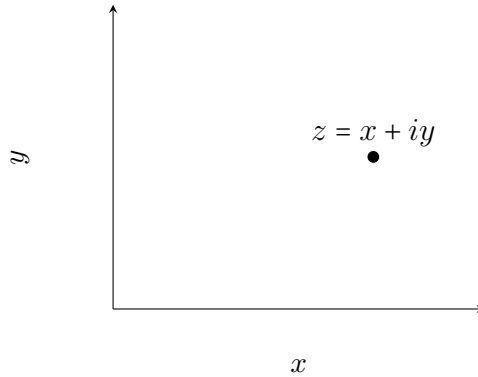
Basics

10.1 Complex Numbers

$$\mathbb{C} = \{x + iy \mid x, y \in \mathbb{R}, i = \sqrt{-1}\}$$

Complex numbers are elements of the complex field (\mathbb{C}), therefore, they obey all the properties of a field.

We will denote complex numbers by $z = x + iy$ with $x, y \in \mathbb{R}$, and refer the real part as $\Re(z) = \text{Re}(z) = x$ and imaginary part as $\Im(z) = \text{Im}(z) = y$. Complex numbers can also be defined as an ordered pair $z = (x, y)$ which is interpreted as points in the complex plane. $(x, 0)$ are points on the real axis while $(0, y)$ are points in the imaginary axis.



We add and multiply complex numbers in the usual way:

$$\begin{aligned} z_1 + z_2 &= (x_1 + iy_1) + (x_2 + iy_2) & z_1 z_2 &= (x_1 + iy_1)(x_2 + iy_2) \\ &= (x_1 + x_2) + i(y_1 + y_2) & &= (x_1 x_2 - y_1 y_2) + i(x_1 y_2 + x_2 y_1) \end{aligned}$$

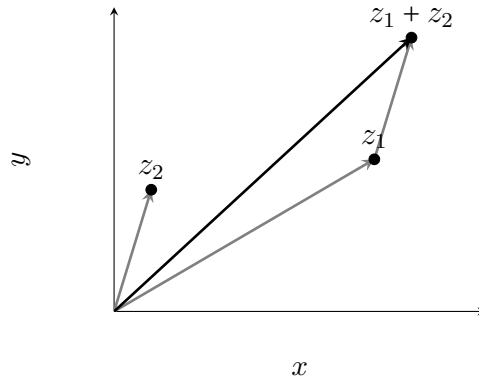
$\forall z \in \mathbb{C}$, there is an unique additive inverse $(-z)$ and $\forall z \in \mathbb{C} \setminus \{0\}$, there is an unique

multiplicative inverse (z^{-1}) such that

$$\begin{aligned}
 z + (-z) &= 0 & zz^{-1} &= 1 \\
 \implies -z &= -x - iy & \implies (x_1x_2 - y_1y_2) &= 1 \wedge (x_1y_2 + x_2y_1) = 0 \\
 & & \implies z^{-1} &= \frac{x_1}{x_1^2 + y_1^2} - i \frac{y_1}{x_1^2 + y_1^2}
 \end{aligned}$$

The existence and uniqueness of the inverses can be easily proven.

The addition of complex numbers may also be interpreted as akin to vector addition.



Likewise, this naturally extends to the definition of a modulus of a complex number.

Definition 10.1.1: Modulus

The absolute value of a real number: $|z| = \sqrt{x^2 + y^2}$

It is obvious why the definition is not $|z| = \sqrt{x^2 + (iy)^2}$ as problems arise when $x = y$. The modulus is the distance of z from $(0,0)$.

10.2 Triangle Inequality

It is not analysis without a section dedicated to the triangle inequality.

Theorem 10.2.1: Triangle Inequality

$$\forall z_1, z_2 \in \mathbb{C} [|z_1 + z_2| \leq |z_1| + |z_2|]$$

From the theorem, we can derive a similar inequality:

$$|z_1| = |z_1 + z_2 - z_2| \leq |z_1 + z_2| + |-z_2| \implies |z_1| - |z_2| \leq |z_1 + z_2|$$

An important property of polynomials is observed when theorem 10.2.1 is applied to polynomials.

Corollary 10.2.1.1:

Consider the polynomial $P(z)$ where $a_n \in \mathbb{C}$, $n \in \mathbb{N}$, $a_0 \neq 0$, and $z \in \mathbb{C}$.

$$P(z) = a_0 + a_1 z + a_2 z^2 + \dots + a_n z^n$$

Then $\forall z, \exists R \in \mathbb{R}_{>0}, |z| < R$ such that

$$\left| \frac{1}{P(z)} \right| < \frac{2}{|a_n| R^n}$$

Proof: Consider

$$\begin{aligned} w &= \frac{P(z)}{z^n} - a_n = \frac{a_0}{z^n} + \frac{a_1}{z^{n-1}} + \dots + \frac{a_{n-1}}{z} & z \neq 0 \\ \implies w z^n &= a_0 + a_1 z + \dots + a_{n-1} z^{n-1} \\ \implies |w| |z|^n &\leq |a_0| + |a_1| |z| + \dots + |a_{n-1}| |z|^{n-1} \\ \implies |w| &\leq \frac{|a_0|}{|z|^n} + \frac{|a_1|}{|z|^{n-1}} + \dots + \frac{|a_{n-1}|}{|z|} \\ \implies |w| &< n \frac{|a_n|}{2n} = \frac{|a_n|}{2} & \exists \text{ sufficiently large } R < |z| \text{ s.t.} \\ & & \forall m, 0 \leq m \leq n-1, \frac{|a_m|}{|z|^{n-m}} < \frac{|a_n|}{2n} \\ \implies |a_n + w| &\geq ||a_n| - |w|| > \frac{|a_n|}{2} & R < |z| \\ \implies |P_n(z)| = |a_n + w| |z|^n &> \frac{|a_n|}{2} |z|^n > \frac{|a_n|}{2} R^n & R < |z| \\ \implies \left| \frac{1}{P(z)} \right| &< \frac{2}{|a_n| R^n} \end{aligned}$$

□

This tells us that if z is a solution to a polynomial $P(z)$, then the reciprocal of the polynomial $1/P(z)$ is bounded above by $R = |z|$. (i.e. It is bounded by a circle of radius $|z|$.)

10.3 Polar and Exponential Form

Definition 10.3.1: Argument of z

Consider any $z \in \mathbb{C}$ where $z \neq 0$. Let θ be the angle in radians between z and the real axis. Then $\forall n \in \mathbb{N}$, $0 \leq \theta < 2\pi$, the argument of z :

$$\arg(z) = \theta + 2n\pi$$

We know $\forall n \in \mathbb{N}, \theta + 2\pi n = \theta$. This leads us to the definition of the principal argument of z .

Definition 10.3.2: Principal Argument of z

Consider any $z \in \mathbb{C}$ where $z \neq 0$. Let θ be the angle in radians between z and the real axis. Then for $0 \leq \theta < 2\pi$, the principal argument of z :

$$\text{Arg}(z) = \theta$$

It is clear that $\arg(z) = \text{Arg}(z) + 2n\pi$.

Definition 10.3.3: Polar Form of z

Consider $z \in \mathbb{C}$. Let $r = |z|$, and $\theta = \arg(z)$. Then $\forall z \in \mathbb{C}, z \neq 0$:

$$z = x + iy = r(\cos(\theta) + i \sin(\theta))$$

Notice that all three definitions require that $z \neq 0$ as θ is undefined at $z = 0$.

Theorem 10.3.1: Euler's Formula

$$e^{i\theta} = \cos(\theta) + i \sin(\theta)$$

Combining definition 10.3.3 with theorem 10.3.1, we obtain the Exponential Form of z :

Definition 10.3.4: Exponential Form of z

Consider any $z \in \mathbb{C}$, and let $r = |z|$ and $\theta = \arg(z)$. Then the exponential form of z :

$$z = re^{i\theta}$$

10.3.1 Properties of Polar Form

10.3.2 Properties of Exponential Form

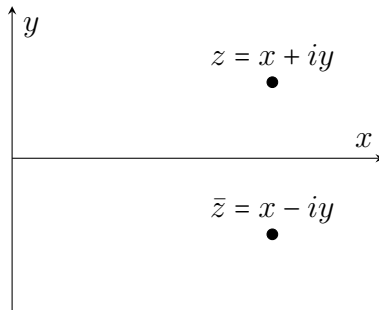
10.4 Complex Conjugates

Definition 10.4.1: Complex Conjugate

The complex conjugate of $z \in \mathbb{C}$ is denoted \bar{z} .

$$\bar{z} = x - iy$$

Graphically, it is the reflection of z across the real axis.



It is then easy to see

$$\operatorname{Re}(z) = \frac{z + \bar{z}}{2}$$

$$\operatorname{Im}(z) = \frac{z - \bar{z}}{2i}$$

$$|z|^2 = z\bar{z}$$

Chapter 11

Conformal Mapping

Part V

Ordinary Differential Equations

Part VI

Nonlinear Dynamics

Part VII

Partial Differential Equations

Calculus of Variations

Part VIII

Integral Equations

Part IX

Linear Algebra

Chapter 12

Markov Chains

Part X

Tensors

Part XI

Riemann Geometry

Part XII

Abstract Algebra

Chapter 13

Groups

Chapter 14

Rings

14.1 Ideals

Chapter 15

Integral Domains

Chapter 16

GCD Domains

Chapter 17

Unique Factorization Domains

Chapter 18

Principal Ideal Domains

Chapter 19

Fields

Part XIII

Galois Theory

Lie Algebra

Part XIV

C-Star Algebra

Part XV

Set Theory

Part XVI

Model Theory

Part XVII

Statistics

Part XVIII

Tips and Tricks

Chapter 20

Integration Techniques

20.1 DI Method (Integration Table)

20.2 Feynman Integration

Part XIX

Index

Part XX

Bibliography

Bibliography

- [1] Kenneth A. Ross. *Elementary Analysis*. Springer, 2 edition, 2013.
- [2] James Ward Brown and Ruel V. Churchill. *Complex Variables and Applications*. McGraw-Hill Education, 9 edition, 2014.