

# Algebra

Notes and Practice

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July 23, 2025

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## 1 Introduction

This document contains concise notes and worked examples.

## 2 Algebra Basics

### 2.1 Constants

A **constant** is a fixed value that does not change. Unlike a **variable**, which can represent different numbers, a **constant** always has the same value.

Examples of **constant** include:

- Specific numbers like 2,  $-7$ , or  $\frac{1}{2}$
- Mathematical constants like  $\pi \approx 3.1416$  or  $e \approx 2.718$

In the equation:

$$x + 3 = 7$$

the number 3 and 7 are constants — they stay the same, while  $x$  is the variable we solve for.

### 2.2 Variables

A **variable** is a symbol, usually a letter like  $x$ ,  $y$ , or  $z$ , that represents an unknown or changeable value.

For example, in the equation:

$$x + 3 = 7$$

the variable  $x$  represents a number. Solving the equation means finding the value of  $x$  that makes the equation true in this case,  $x = 4$ .

**Variables** are fundamental in algebra because they allow us to generalize problems and create formulas.

### 2.3 Coefficients

A **coefficient** is the numerical factor multiplied by a variable in an algebraic expression.

For example, in the term:

$$5x$$

the number 5 is the coefficient of the variable  $x$ . It tells us how many times  $x$  is being counted or scaled.

More examples:

- In  $-3y$ , the coefficient is  $-3$
- In  $\frac{1}{2}a$ , the coefficient is  $\frac{1}{2}$
- In  $z$ , the coefficient is implicitly 1, since  $z = 1 \cdot z$

Coefficients help determine the slope of a line in linear equations and play a major role in simplifying and solving expressions.

### 3 Equations vs. Expressions

Understanding the difference between expressions and equations is essential in algebra.

#### 3.1 Expressions

An **expression** is a combination of numbers, variables, and operations (like addition or multiplication), but it does **not** contain an equals sign.

Examples:

$$2x + 5, \quad 3a^2 - 4, \quad \frac{1}{2}y$$

Expressions represent a value, but not a complete statement to solve. You can simplify or evaluate expressions, but you cannot "solve" them unless they're part of an equation.

#### 3.2 Equations

An **equation** is a mathematical statement that two expressions are equal. It always contains an equals sign (=) and usually involves finding the value of a variable that makes the equation true.

Examples:

$$2x + 5 = 11, \quad a^2 = 16, \quad \frac{1}{2}y = 3$$

Solving an **equation** means determining the value(s) of the variable(s) that make both sides equal.

#### Summary Table

Expression	Equation
No equals sign	Has an equals sign
Represents a value	Represents a relationship
Can be simplified or evaluated	Can be solved
Example: $3x + 2$	Example: $3x + 2 = 11$

### 4 The Associative Property

The **associative property** refers to the grouping of terms using parentheses in addition or multiplication. It tells us that the way numbers are grouped does not change the result — only the order of operations inside parentheses changes, not the outcome.

#### 4.1 Associative Property of Addition

The associative property of addition states:

$$(a + b) + c = a + (b + c)$$

You can add numbers in any grouping, and the sum will stay the same.

**Example:**

$$(2 + 3) + 4 = 5 + 4 = 9$$

$$2 + (3 + 4) = 2 + 7 = 9$$

So,  $(2 + 3) + 4 = 2 + (3 + 4)$ .

## 4.2 Associative Property of Multiplication

The associative property of multiplication states:

$$(a \times b) \times c = a \times (b \times c)$$

You can multiply in any grouping, and the product remains unchanged.

**Example:**

$$(2 \times 3) \times 4 = 6 \times 4 = 24$$

$$2 \times (3 \times 4) = 2 \times 12 = 24$$

So,  $(2 \times 3) \times 4 = 2 \times (3 \times 4)$ .

## 5 The Commutative Property

The **commutative property** describes how the order of numbers does not affect the result when adding or multiplying. It applies only to **addition and multiplication** — not subtraction or division.

### 5.1 Commutative Property of Addition

The commutative property of addition states:

$$a + b = b + a$$

You can change the order of the numbers being added without changing the sum.

**Example:**

$$4 + 7 = 11 \quad \text{and} \quad 7 + 4 = 11$$

So,  $4 + 7 = 7 + 4$

### 5.2 Commutative Property of Multiplication

The commutative property of multiplication states:

$$a \times b = b \times a$$

You can change the order of the numbers being multiplied without changing the product.

**Example:**

$$6 \times 5 = 30 \quad \text{and} \quad 5 \times 6 = 30$$

So,  $6 \times 5 = 5 \times 6$

## 6 Like Terms

**Like terms** are terms that have the same variable(s) raised to the same power(s). Only the numerical coefficients can be different. Like terms can be combined using addition or subtraction.

### 6.1 Addition and Subtraction of Like Terms

To combine like terms, simply add or subtract their coefficients.

**Example 1:**

$$3x + 5x = (3 + 5)x = 8x$$

**Example 2:**

$$7a^2 - 2a^2 = 5a^2$$

**Note:** You *cannot* combine terms that are not like terms.

$$4x + 2x^2 \neq 6x^2 \quad (\text{not like terms})$$

### 6.2 Multiplication and Division of Like Terms

When multiplying or dividing like terms, you combine coefficients and apply exponent rules to the variables.

**Multiplication Example:**

$$(3x)(2x) = 6x^2$$

$$(4a^2)(-2a^3) = -8a^5$$

**Division Example:**

$$\frac{10x^3}{2x} = 5x^2$$

$$\frac{-6y^4}{3y^2} = -2y^2$$

**Key Idea**

- **Addition/Subtraction:** Combine only like terms (same variables and exponents)
- **Multiplication/Division:** Use exponent rules, even for unlike terms

## 7 The Distributive Property

The **distributive property** connects multiplication and addition or subtraction. It allows you to multiply a number or variable by each term inside parentheses.

$$a(b + c) = ab + ac \quad \text{and} \quad a(b - c) = ab - ac$$

This property is used frequently in algebra to expand expressions and solve equations.

**Examples****Example 1 (with numbers):**

$$3(4 + 5) = 3 \cdot 9 = 27$$

$$3 \cdot 4 + 3 \cdot 5 = 12 + 15 = 27$$

**Example 2 (with variables):**

$$x(2 + y) = 2x + xy$$

**Example 3 (with subtraction):**

$$5(a - 3) = 5a - 15$$

**Why It Matters**

The distributive property helps you:

- Expand expressions like  $2(x + 3)$
- Simplify algebraic expressions
- Solve equations more efficiently
- Factor expressions in reverse

**More on the Distributive Property**

The distributive property is also essential when working with variables, negative numbers, and factoring expressions.

**Example with Variables and Negatives**

$$-2(x - 4) = -2 \cdot x + (-2) \cdot (-4) = -2x + 8$$

Notice:

- The negative sign distributes to both terms
- Be careful with signs:  $-2 \cdot -4 = +8$

**Common Mistake to Avoid**

Incorrect:

$$3(x + 2) = 3x + 2 \quad (\text{Only distributed to } x)$$

Correct:

$$3(x + 2) = 3x + 6$$

Always distribute to *every* term inside the parentheses.

## Using the Distributive Property to Factor

The distributive property also works *in reverse*, which is how we factor expressions.

$$6x + 12 = 6(x + 2)$$

Here, we pulled out the common factor of 6 — essentially undoing the distribution.

Factoring is the process of writing an expression as a product using the distributive property in reverse.

**Tip:** Look for a greatest common factor (GCF) before factoring!

## 8 Polynomials

A **polynomial** is an expression made up of variables, constants, and exponents, combined using addition, subtraction, and multiplication — but no variables in the denominator or under radicals.

### Examples of Polynomials

$$3x^2 + 2x - 5, \quad x^3 - 4x + 7, \quad 2a^2b + 3ab^2$$

### 8.1 Addition and Subtraction of Polynomials

To add or subtract polynomials:

- Combine like terms (same variables raised to the same powers)
- Add/subtract the coefficients of like terms

#### Example 1 — Addition:

$$\begin{aligned} & (2x^2 + 3x + 1) + (x^2 + 4x - 5) \\ &= (2x^2 + x^2) + (3x + 4x) + (1 - 5) = 3x^2 + 7x - 4 \end{aligned}$$

#### Example 2 — Subtraction:

$$\begin{aligned} & (5x^2 - 2x + 6) - (3x^2 + x - 4) \\ &= (5x^2 - 3x^2) + (-2x - x) + (6 + 4) = 2x^2 - 3x + 10 \end{aligned}$$

### 8.2 Multiplication of Polynomials

To multiply polynomials:

- Use the distributive property (FOIL for binomials)
- Multiply each term in the first polynomial by each term in the second
- Combine like terms



**Example:**

$$(x + 2)(x + 5) = x(x + 5) + 2(x + 5) = x^2 + 5x + 2x + 10 = x^2 + 7x + 10$$

**Another Example:**

$$\begin{aligned}(2x - 3)(x^2 + x - 4) &= 2x(x^2 + x - 4) - 3(x^2 + x - 4) \\ &= 2x^3 + 2x^2 - 8x - 3x^2 - 3x + 12 = 2x^3 - x^2 - 11x + 12\end{aligned}$$

### 8.3 Division of Polynomials (Intro)

Dividing polynomials can be done using:

- Long division
- Synthetic division (when dividing by linear terms like  $x - a$ )

**Basic Example:**

$$\frac{6x^2 + 9x}{3x} = \frac{6x^2}{3x} + \frac{9x}{3x} = 2x + 3$$

**Note:** More complex division techniques will be covered in a later section.

#### Polynomial Operations Summary

**Polynomials** are expressions with variables and constants using only addition, subtraction, and multiplication (no variables in denominators or exponents).

##### Addition/Subtraction:

- Combine like terms (same variable and exponent)
- Only coefficients are added or subtracted

##### Multiplication:

- Use the distributive property or FOIL
- Multiply each term in one polynomial by each term in the other
- Combine like terms

##### Division:

- Simplify each term if possible
- For complex division, use long division or synthetic division (covered later)

### 8.4 Long Division

Long division is a step-by-step method for dividing numbers or algebraic expressions.

- **Dividend:** the number or expression being divided
- **Divisor:** the number or expression you are dividing by
- **Quotient:** the result of the division (goes on top)

**Example 1: Long Division with Whole Numbers**

Divide:

$$125 \div 5$$

Here:

- Dividend = 125
- Divisor = 5
- Quotient = 25

$$\begin{array}{r|l} 5 & 125 \\ & 25 \end{array}$$

Steps:

1. Divide 12 by 5  $\rightarrow 2$  (since  $5 \times 2 = 10$ )
2. Subtract:  $12 - 10 = 2$ , bring down the 5  $\rightarrow 25$
3. Divide 25 by 5  $\rightarrow 5$  (since  $5 \times 5 = 25$ )
4. Final result: 25

**Example 2: Polynomial Long Division**

Divide:

$$\frac{x^2 + 3x + 2}{x + 1}$$

Here:

- Dividend =  $x^2 + 3x + 2$
- Divisor =  $x + 1$
- Quotient = the expression that results from division

**Step 1:** Divide leading terms:

$$x^2 \div x = x$$

**Step 2:** Multiply and subtract:

$$(x^2 + 3x + 2) - (x)(x + 1) = x^2 + 3x + 2 - (x^2 + x) = 2x + 2$$

**Step 3:** Divide leading terms again:

$$2x \div x = 2$$

**Step 4:** Multiply and subtract:

$$(2x + 2) - 2(x + 1) = 2x + 2 - (2x + 2) = 0$$

So the division is exact.

**Final Answer:**

$$\frac{x^2 + 3x + 2}{x + 1} = x + 2$$

### Terminology Review

- **Dividend:** what you're dividing (e.g.,  $x^2 + 3x + 2$ )
- **Divisor:** what you're dividing by (e.g.,  $x + 1$ )
- **Quotient:** result of the division (e.g.,  $x + 2$ )

## 8.5 Multivariable Polynomial Long Division

Polynomial long division can also be performed with expressions that include more than one variable. The process is similar, but care must be taken to match like terms correctly and order terms consistently by degree.

**Example: Divide  $6x^2y + 9xy^2$  by  $3xy$**

Here:

- Dividend:  $6x^2y + 9xy^2$
- Divisor:  $3xy$

**Step 1: Divide the first term of the dividend by the first term of the divisor**

$$\frac{6x^2y}{3xy} = 2x$$

**Step 2: Multiply the entire divisor by  $2x$**

$$2x \cdot (3xy) = 6x^2y$$

**Step 3: Subtract**

$$(6x^2y + 9xy^2) - 6x^2y = 9xy^2$$

**Step 4: Divide next term**

$$\frac{9xy^2}{3xy} = 3y$$

**Step 5: Multiply and subtract**

$$\begin{aligned} 3y \cdot (3xy) &= 9xy^2 \\ 9xy^2 - 9xy^2 &= 0 \end{aligned}$$

**Final Answer:**

$$\frac{6x^2y + 9xy^2}{3xy} = 2x + 3y$$

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### Tips for Multivariable Long Division

- Organize terms in descending order of one variable (typically  $x$ )
- Divide one term at a time, matching both variable parts and coefficients
- Use standard subtraction to cancel each step before proceeding

## 9 Quadratic Polynomials

A **quadratic polynomial** is a polynomial of degree 2, meaning the highest power of the variable is 2.

### General Form

$$ax^2 + bx + c$$

where:

- $a, b, c$  are real numbers and  $a \neq 0$
- $a$  is the **leading coefficient**
- $b$  is the **linear coefficient**
- $c$  is the **constant term**

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### Examples

- $x^2 + 5x + 6$
- $3x^2 - 2x + 1$
- $-x^2 + 4$

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### Graphing Quadratics

Quadratic functions graph as a **parabola**. The shape of the parabola depends on the sign of  $a$ :

- If  $a > 0$ : the parabola opens **upward** (like a smile)
- If  $a < 0$ : the parabola opens **downward** (like a frown)

The highest or lowest point on the parabola is called the **vertex**.

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### Solving Quadratic Equations

Quadratics can be solved using several methods:

- **Factoring**

- Completing the square
- Quadratic formula:

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

#### Quick Facts About Quadratics

- Degree = 2 (because of  $x^2$ )
- Graph = parabola
- May have 0, 1, or 2 real roots depending on the discriminant  $b^2 - 4ac$
- Coefficients tell you the shape and position of the graph

### 9.1 Factoring a Quadratic Polynomial

Factoring is one of the most common ways to solve a quadratic equation when it can be written as a product of two binomials.

**Example: Factor**  $x^2 + 5x + 6$

**Step 1:** Look for two numbers that multiply to 6 (the constant term) and add to 5 (the linear coefficient).

$$\begin{aligned} \text{Factors of 6: } & (1, 6), (2, 3) \\ 2 + 3 = 5 & \Rightarrow \text{Use 2 and 3} \end{aligned}$$

**Step 2:** Write the factored form:

$$x^2 + 5x + 6 = (x + 2)(x + 3)$$

**Step 3:** Check by expanding:

$$(x + 2)(x + 3) = x^2 + 3x + 2x + 6 = x^2 + 5x + 6$$

✓Confirmed!

#### Factoring Tips

- Always look for a greatest common factor (GCF) first
- Use a factoring method like:
  - Simple guess-and-check
  - Box or area method
  - AC method (for trinomials where  $a \neq 1$ )
- Always double-check by expanding!

## 9.2 Difference of Squares

The **difference of squares** is a special factoring pattern that applies when a binomial consists of two perfect squares being subtracted.

$$a^2 - b^2 = (a - b)(a + b)$$

This works because when expanded:

$$(a - b)(a + b) = a^2 + ab - ab - b^2 = a^2 - b^2$$

### Examples

- $x^2 - 9 = (x - 3)(x + 3)$
- $4x^2 - 25 = (2x - 5)(2x + 5)$
- $49y^2 - 1 = (7y - 1)(7y + 1)$
- $x^4 - 16 = (x^2)^2 - 4^2 = (x^2 - 4)(x^2 + 4) = (x - 2)(x + 2)(x^2 + 4)$

### Important Notes:

- Works only with **subtraction**, not addition
- Both terms must be perfect squares
- Often used to simplify expressions or solve equations

#### Difference of Squares Summary

$$a^2 - b^2 = (a - b)(a + b)$$

#### Examples:

- $x^2 - 16 = (x - 4)(x + 4)$
- $9a^2 - 1 = (3a - 1)(3a + 1)$

## 9.3 Completing the Square

To solve a quadratic equation of the form:

$$ax^2 + bx + c = 0$$

we can complete the square — a method that rewrites the expression as a perfect square trinomial.

### What is a Trinomial?

A **trinomial** is a polynomial with three terms.

In quadratic form:

$$ax^2 + bx + c$$

is a trinomial.

When completing the square, we turn:

$$x^2 + bx \quad (2 \text{ terms})$$

into:

$$x^2 + bx + \left(\frac{b}{2}\right)^2 \quad (3 \text{ terms} \text{ — a perfect square trinomial})$$

### Steps to Complete the Square (when $a = 1$ )

1. Move the constant to the other side:

$$x^2 + bx = -c$$

2. Take half of the coefficient of  $x$ , square it, and add to both sides:

$$\left(\frac{b}{2}\right)^2$$

3. Now the left-hand side is a perfect square:

$$\left(x + \frac{b}{2}\right)^2$$

4. Solve by taking the square root of both sides
5. Solve for  $x$

**Example:** Solve  $x^2 + 6x + 4 = 0$

$$x^2 + 6x + 4 = 0$$

$$x^2 + 6x = -4$$

$$\left(\frac{6}{2}\right)^2 = 9$$

$$x^2 + 6x + 9 = -4 + 9$$

$$(x + 3)^2 = 5$$

$$x + 3 = \pm\sqrt{5}$$

$$x = -3 \pm \sqrt{5}$$

So the solution is:

$$x = -3 \pm \sqrt{5}$$

—

#### Tip for Completing the Square

**When**  $a \neq 1$ , divide the whole equation by  $a$  first. Completing the square is also how we derive the quadratic formula!

### Nature of Solutions: Real vs Complex

After completing the square (when  $a = 1$ ), we get:

$$x^2 + bx + c = 0 \quad \Rightarrow \quad \left(x + \frac{b}{2}\right)^2 = \left(\frac{b}{2}\right)^2 - c$$

The number and type of solutions depend on the value of:

$$\left(\frac{b}{2}\right)^2 - c$$

- If  $\left(\frac{b}{2}\right)^2 - c > 0$ , then  $x$  has **two real** solutions
- If  $\left(\frac{b}{2}\right)^2 - c = 0$ , then  $x$  has **one real** solution (a repeated root)
- If  $\left(\frac{b}{2}\right)^2 - c < 0$ , then  $x$  has **two complex** (nonreal) solutions

—

#### Real vs Complex Solutions from Completing the Square

Given:

$$x^2 + bx + c = 0 \Rightarrow \left(x + \frac{b}{2}\right)^2 = \left(\frac{b}{2}\right)^2 - c$$

Then:

- $\left(\frac{b}{2}\right)^2 - c > 0 \Rightarrow 2$  distinct real solutions
- $\left(\frac{b}{2}\right)^2 - c = 0 \Rightarrow 1$  real solution
- $\left(\frac{b}{2}\right)^2 - c < 0 \Rightarrow 2$  complex solutions

### Example: Completing the Square with Imaginary Solutions

Solve the equation:

$$x^2 + 4x + 8 = 0$$

**Step 1: Move the constant to the other side.**

$$x^2 + 4x = -8$$



**Step 2: Complete the square.** Take half of 4 and square it:

$$\left(\frac{4}{2}\right)^2 = 4$$

Add 4 to both sides:

$$\begin{aligned}x^2 + 4x + 4 &= -8 + 4 \\(x + 2)^2 &= -4\end{aligned}$$

**Step 3: Take the square root of both sides.**

$$\begin{aligned}x + 2 &= \pm\sqrt{-4} \\x + 2 &= \pm 2i\end{aligned}$$

**Step 4: Solve for  $x$ .**

$$x = -2 \pm 2i$$

**Final Answer:**

$$\boxed{x = -2 \pm 2i}$$

### Imaginary Solutions

When completing the square leads to a negative number under the square root, the equation has **two complex conjugate solutions**, involving the imaginary unit  $i = \sqrt{-1}$ .

### Complex Conjugate Solutions and the Discriminant (When $a = 1$ )

Consider the quadratic equation:

$$x^2 + 2x + 5 = 0$$

Completing the square:

$$x^2 + 2x = -5$$

Take half of 2 and square it:

$$\left(\frac{2}{2}\right)^2 = 1$$

Add 1 to both sides:

$$\begin{aligned}x^2 + 2x + 1 &= -5 + 1 \\(x + 1)^2 &= -4\end{aligned}$$

Taking the square root:

$$x + 1 = \pm\sqrt{-4} = \pm 2i$$

Therefore,

$$x = -1 \pm 2i$$

**Complex Conjugates:** These solutions come in pairs called complex conjugates:

$$a + bi \quad \text{and} \quad a - bi$$

Here,  $a = -1$  and  $b = 2$ .

**Discriminant:** The discriminant is:

$$\Delta = b^2 - 4ac$$

For the equation:

$$a = 1, \quad b = 2, \quad c = 5$$

$$\Delta = 2^2 - 4 \cdot 1 \cdot 5 = 4 - 20 = -16 < 0$$

Since  $\Delta < 0$ , the solutions are complex conjugates.

#### Summary

- $\Delta > 0$ : Two distinct real solutions
- $\Delta = 0$ : One repeated real solution
- $\Delta < 0$ : Two complex conjugate solutions

### The Quadratic Formula and the Discriminant

Any quadratic equation of the form:

$$ax^2 + bx + c = 0$$

can be solved using the **quadratic formula**:

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

**Discriminant:** The expression under the square root, denoted by:

$$\Delta = b^2 - 4ac$$

is called the **discriminant**. It determines the type of solutions:

#### Discriminant Summary

- If  $\Delta > 0$ : two distinct real solutions
- If  $\Delta = 0$ : one real solution (a repeated root)
- If  $\Delta < 0$ : two complex conjugate solutions

**Example:** Solve  $x^2 - 2x - 3 = 0$  using the quadratic formula.

Here,  $a = 1$ ,  $b = -2$ , and  $c = -3$ . Compute the discriminant:

$$\Delta = (-2)^2 - 4(1)(-3) = 4 + 12 = 16$$

Now apply the formula:

$$x = \frac{-(-2) \pm \sqrt{16}}{2(1)} = \frac{2 \pm 4}{2}$$

So the two solutions are:

$$x = \frac{2+4}{2} = 3 \quad \text{and} \quad x = \frac{2-4}{2} = -1$$

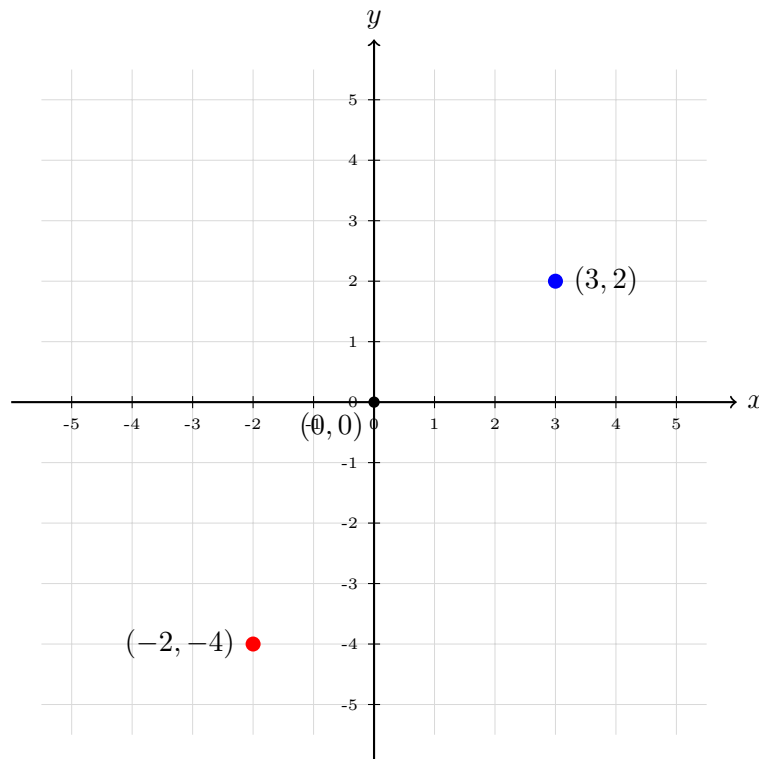
**Conclusion:** The quadratic formula is a universal method for solving any quadratic equation, and the discriminant tells you what kind of solutions to expect.

## 10 The Cartesian Plane

The Cartesian Plane is a two-dimensional coordinate system defined by a horizontal number line called the **x-axis**, and a vertical number line called the **y-axis**. These axes intersect at the **origin**, denoted as  $(0,0)$ .

Each point on the plane is represented by an ordered pair  $(x,y)$ , where:

- $x$  is the horizontal value (left/right),
- $y$  is the vertical value (up/down).



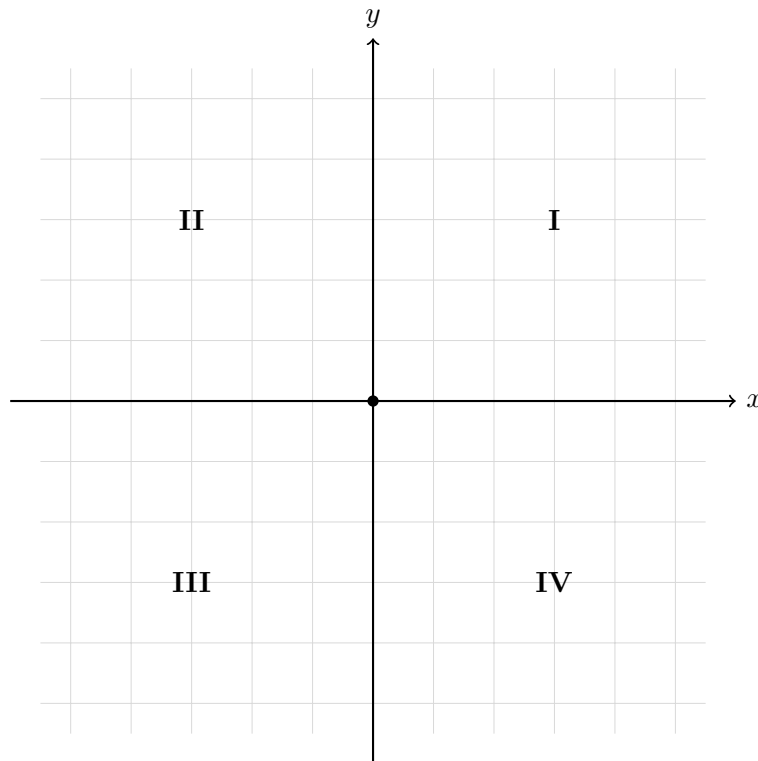
**Summary**

- The Cartesian Plane has two axes:  $x$ -axis (horizontal),  $y$ -axis (vertical).
- The point where they meet is the origin  $(0,0)$ .
- Each point is identified by an ordered pair (Called a coordinate)  $(x,y)$ .

**10.1 The Four Quadrants**

The Cartesian Plane is divided into four regions called **quadrants**. These are numbered in a counterclockwise direction starting from the upper-right:

- **Quadrant I:**  $(+x, +y)$
- **Quadrant II:**  $(-x, +y)$
- **Quadrant III:**  $(-x, -y)$
- **Quadrant IV:**  $(+x, -y)$

**Summary of Quadrants**

- Points in each quadrant have characteristic signs for  $x$  and  $y$ .
- The quadrants are labeled I through IV, moving counterclockwise.

**10.2 Slope of a Line**

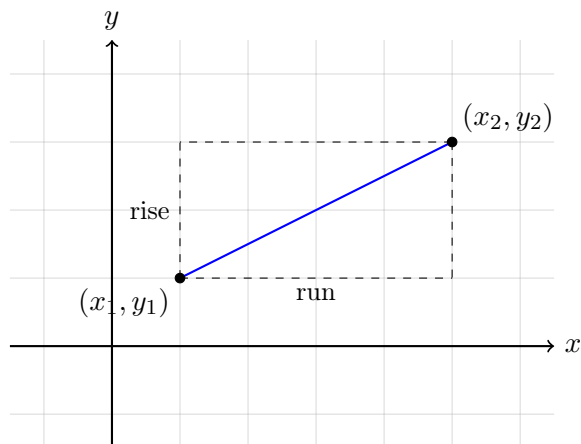
The **slope** of a line is a measure of its steepness. It tells us how much the  $y$ -value changes for a given change in the  $x$ -value.

Given two points on a line,  $(x_1, y_1)$  and  $(x_2, y_2)$ , the slope  $m$  is calculated using the formula:

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

This is also known as “rise over run”:

- **Rise:** the vertical change  $(y_2 - y_1)$
- **Run:** the horizontal change  $(x_2 - x_1)$



#### Summary: Slope of a Line

- Slope measures how steep a line is.
- Use  $m = \frac{y_2 - y_1}{x_2 - x_1}$  to calculate it.
- A positive slope rises left to right; negative slope falls.

### 10.3 Point-Slope Form of a Line

If you know the slope  $m$  of a line and a point  $(x_1, y_1)$  it passes through, you can write the line's equation using the **point-slope form**:

$$y - y_1 = m(x - x_1)$$

#### Requirements:

- A single point  $(x_1, y_1)$
- The slope  $m$

**Example:** Given the point  $(2, 3)$  and slope  $m = 4$ , the equation becomes:

$$y - 3 = 4(x - 2)$$

This can be left in point-slope form or simplified to slope-intercept form.

## Point-Slope Summary

- Use when you know one point and the slope.
- Formula:  $y - y_1 = m(x - x_1)$

## 10.4 Slope-Intercept Form of a Line

The **slope-intercept form** expresses a linear equation as:

$$y = mx + b$$

Where:

- $m$  is the slope of the line.
- $b$  is the **y-intercept** — the value of  $y$  when  $x = 0$ .

**Requirements:**

- Slope  $m$
- Y-intercept  $b$

**Example:** If a line has slope  $m = -2$  and y-intercept  $b = 5$ , the equation is:

$$y = -2x + 5$$

This form is especially useful for graphing.

## Slope-Intercept Summary

- Use when slope and y-intercept are known.
- Formula:  $y = mx + b$
- $b$  tells you where the line crosses the  $y$ -axis.

## 10.5 Converting Between Forms of a Linear Equation

Linear equations can be written in multiple forms. It's often helpful to convert between them depending on the context (e.g., graphing, solving, or analyzing).

## 1. Point-Slope to Slope-Intercept

Start with the point-slope form:

$$y - y_1 = m(x - x_1)$$

Distribute the slope and solve for  $y$  to convert to slope-intercept form:

$$\begin{aligned} y - y_1 &= m(x - x_1) \\ y &= m(x - x_1) + y_1 \quad (\text{Slope-Intercept Form: } y = mx + b) \end{aligned}$$

**Example:** Convert  $y - 2 = 3(x + 1)$  to slope-intercept form:

$$y - 2 = 3(x + 1)$$

$$y - 2 = 3x + 3$$

$$y = 3x + 5$$

## 2. Two Points to Any Form

Given two points  $(x_1, y_1)$  and  $(x_2, y_2)$ :

1. Find the slope  $m = \frac{y_2 - y_1}{x_2 - x_1}$
2. Use point-slope form with one point
3. Convert to slope-intercept form if needed

### Summary: Converting Forms

- Point-slope to slope-intercept: distribute and solve for  $y$
- Two points  $\rightarrow$  slope  $\rightarrow$  point-slope  $\rightarrow$  slope-intercept
- Use the form that best suits the problem (graphing, solving, etc.)

## 10.6 Undefined Slope and Vertical Lines

A **vertical line** goes straight up and down and has an **undefined slope**. This is because its run (change in  $x$ ) is zero:

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

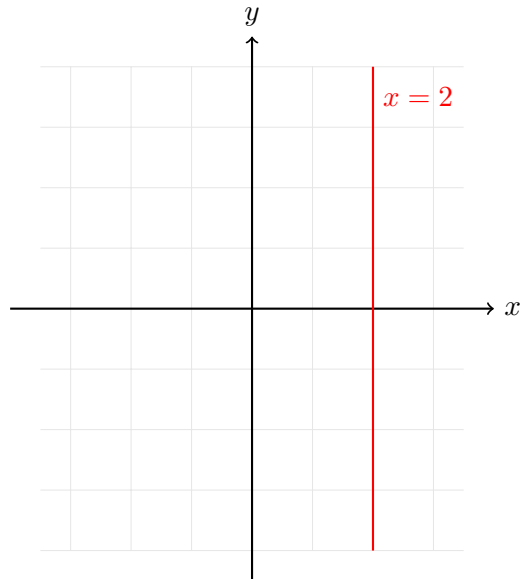
If  $x_2 = x_1$ , then the denominator becomes 0, and division by zero is undefined.

### Equation of a Vertical Line:

A vertical line through  $x = a$  is written as:

$$x = a$$

- It has an **undefined slope**.
- It has an **x-intercept only** — it does not cross the  $y$ -axis.



#### Important Notes on Vertical Lines

- Vertical lines have the form  $x = a$
- Their slope is undefined.
- They do not cross the  $y$ -axis — no  $y$ -intercept exists.

## 11 Graphing Linear Equations

To graph a linear equation, such as:

$$y = mx + b$$

you can create a **table of values** by plugging in values for  $x$  and solving for  $y$ . This gives you a set of points you can plot on the Cartesian plane.

### Steps to Graph a Line

1. Choose three  $x$ -values (commonly:  $-1, 0, 1$ )
2. Plug them into the equation to find corresponding  $y$ -values
3. Plot the points  $(x, y)$  on the graph
4. Draw a straight line through the points

**Example:** Graph  $y = 2x + 1$

**Step 1:** Create a table

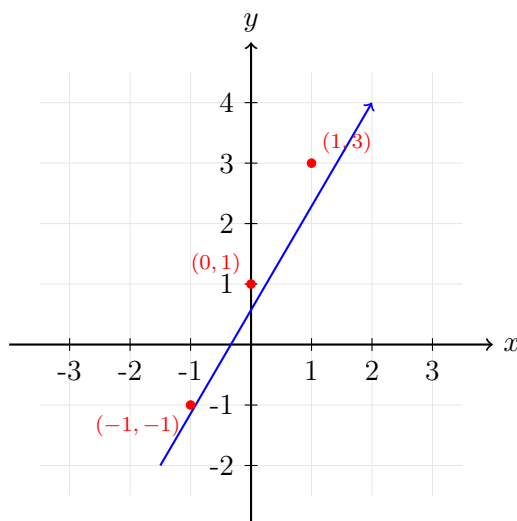


$x$	$y = 2x + 1$
-1	$2(-1) + 1 = -2 + 1 = -1$
0	$2(0) + 1 = 0 + 1 = 1$
1	$2(1) + 1 = 2 + 1 = 3$

**Step 2: Plot points**

$$(-1, -1), \quad (0, 1), \quad (1, 3)$$

**Step 3: Draw a straight line through the points**



#### Graphing Summary

- Pick easy  $x$ -values:  $-1, 0, 1$
- Solve for  $y$ , make a table
- Plot at least 3 points and draw the line

## 12 Functions

A **function** is a relation where each input has exactly one output. The input is called the **independent variable** (usually  $x$ ), and the output is the **dependent variable** (usually  $y$ ).

Formally, a function  $f$  from a set  $A$  (domain) to a set  $B$  (codomain) assigns each element  $x \in A$  to exactly one element  $y \in B$ , written as:

$$y = f(x)$$

**Key points about functions:**

- For every  $x$ , there is *only one* corresponding  $y$ .
- The value of  $y$  depends on the choice of  $x$ .
- Functions can be represented by equations, tables, graphs, or mappings.

**Example:** Consider the function

$$f(x) = 2x + 3.$$

To find the output when  $x = 4$ , substitute 4 into the function:

$$f(4) = 2(4) + 3 = 8 + 3 = 11.$$

So, the function value at  $x = 4$  is 11.

**Function notation:**

$$f(x) = y$$

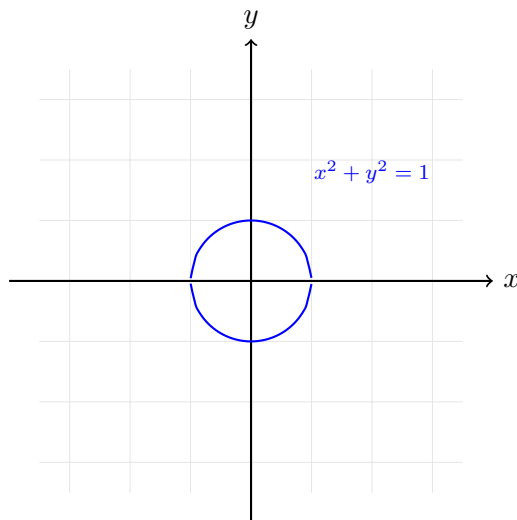
means "the value of the function  $f$  at input  $x$  is  $y$ ."

### 12.1 Not a Function

An equation is **not a function** if one input has *multiple outputs*. You can test this with the **vertical line test** — if a vertical line touches the graph in more than one place, it is *not* a function.

**Examples of equations that are not functions:**

- $x = 3$  — a vertical line (undefined slope)
- $x^2 + y^2 = 1$  — a circle (one  $x$  leads to two  $y$  values)



#### Function Summary

- A function gives exactly one output for each input.
- It passes the **vertical line test**.
- Not all equations are functions!

### 12.2 Domain and Range

**Domain:** The set of all possible input values ( $x$ ) for which the function is defined.

**Range:** The set of all possible output values ( $y$ ) that the function can produce.

**How to find Domain and Range:**

- **Given a function  $f(x)$ :** Analyze the equation to determine which  $x$ -values are allowed. For example, avoid division by zero or square roots of negative numbers.
- **Given a set of points:** The domain is the set of all  $x$ -coordinates, and the range is the set of all  $y$ -coordinates.
- **Given a graph:** - The domain corresponds to all  $x$ -values covered by the graph (horizontally).  
- The range corresponds to all  $y$ -values covered by the graph (vertically).

**Example:**

Consider the function

$$f(x) = \sqrt{x - 2}.$$

- **Domain:** Since the expression inside the square root must be non-negative,

$$x - 2 \geq 0 \implies x \geq 2,$$

so the domain is  $[2, \infty)$ .

- **Range:** The square root outputs non-negative values, so

$$y \geq 0,$$

and the range is  $[0, \infty)$ .

**12.3 Is It a Function? (Testing Sets of Values)**

To determine if a relation (a set of ordered pairs or an equation) is a function, use the following rule:

**Function Test**

A relation is a **function** if *every input* ( $x$ -value) corresponds to *exactly one output* ( $y$ -value).

**Example 1 (Function — Set of Points):**

$$\{(1, 2), (2, 3), (3, 4)\}$$

Each input is unique — this **is** a function.

**Example 2 (Not a Function — Set of Points):**

$$\{(1, 2), (1, 3), (2, 4)\}$$

The input 1 maps to two different outputs (2 and 3) — this is **not** a function.

**Example 3 (Algebraic Test):**

Consider the equation:

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

Solve for  $y$ :

$$y^2 = 1 - x^2 \Rightarrow y = \pm\sqrt{1 - x^2}$$

This gives two  $y$ -values for a single  $x$ -value. **Conclusion:** This is **not** a function.

**Steps to check:**

1. List all  $x$ -values or solve for  $y$ .
2. If any  $x$ -value gives more than one  $y$ , it's **not** a function.

## 13 Operations with Functions

### 13.1 Sum of Functions

The **sum of two functions** means adding their outputs for the same input value.

#### Sum of Functions

If  $f(x)$  and  $g(x)$  are two functions, then:

$$(f + g)(x) = f(x) + g(x)$$

This means you add the two expressions for each value of  $x$ .

#### Example

Let:

$$f(x) = 2x + 3 \quad \text{and} \quad g(x) = x^2 - 1$$

Then:

$$(f + g)(x) = f(x) + g(x) = (2x + 3) + (x^2 - 1)$$

Simplify:

$$(f + g)(x) = x^2 + 2x + 2$$

#### Evaluation Example

Find  $(f + g)(2)$ :

$$f(2) = 2(2) + 3 = 7$$

$$g(2) = (2)^2 - 1 = 3$$

$$(f + g)(2) = f(2) + g(2) = 7 + 3 = 10$$

### 13.2 Adding Functions from Sets of Points

You can also add two functions given as sets of ordered pairs. Just add the  $y$ -values for matching  $x$ -values.

#### Adding Point-Based Functions

If:

$$f = \{(1, 2), (2, 4), (3, 6)\}, \quad g = \{(1, 5), (2, 1), (3, -2)\}$$

Then:

$$(f + g)(x) = \{(1, 2 + 5), (2, 4 + 1), (3, 6 + (-2))\} = \{(1, 7), (2, 5), (3, 4)\}$$

**Note:** This only works when both functions share the same  $x$ -values.

### 13.3 Product of Functions

The **product of two functions** means multiplying their outputs for each input value.

#### Product of Functions

If  $f(x)$  and  $g(x)$  are functions, then:

$$(f \cdot g)(x) = f(x) \cdot g(x)$$

This means you multiply their expressions together.

#### Example (Algebraic Expressions)

Let:

$$f(x) = 2x + 1, \quad g(x) = x - 3$$

Then:

$$(f \cdot g)(x) = f(x) \cdot g(x) = (2x + 1)(x - 3)$$

Use distribution (FOIL):

$$(f \cdot g)(x) = 2x^2 - 6x + x - 3 = 2x^2 - 5x - 3$$

#### Evaluation Example

Find  $(f \cdot g)(2)$ :

$$f(2) = 2(2) + 1 = 5$$

$$g(2) = 2 - 3 = -1$$

$$(f \cdot g)(2) = 5 \cdot (-1) = -5$$

### 13.3.1 Product from Sets of Points

If:

$$f = \{(1, 2), (2, 4), (3, 6)\}, \quad g = \{(1, 5), (2, 1), (3, -2)\}$$

Then:

$$(f \cdot g)(x) = \{(1, 2 \cdot 5), (2, 4 \cdot 1), (3, 6 \cdot (-2))\} = \{(1, 10), (2, 4), (3, -12)\}$$

**Note:** Only valid if the  $x$ -values match in both functions.

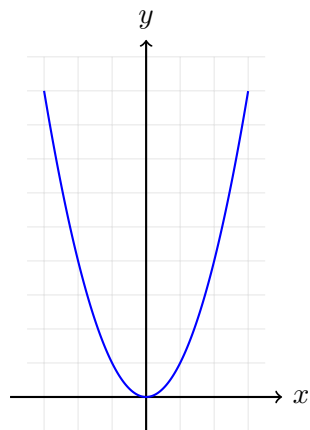
### 13.4 Even, Odd, or Neither

To classify a function as **even**, **odd**, or **neither**, evaluate  $f(-x)$  and compare it to  $f(x)$  and  $-f(x)$ :

#### Function Symmetry Rules

- **Even:**  $f(-x) = f(x)$  — symmetric about the **y-axis**
- **Odd:**  $f(-x) = -f(x)$  — symmetric about the **origin**
- **Neither:**  $f(-x) \neq f(x)$  and  $f(-x) \neq -f(x)$

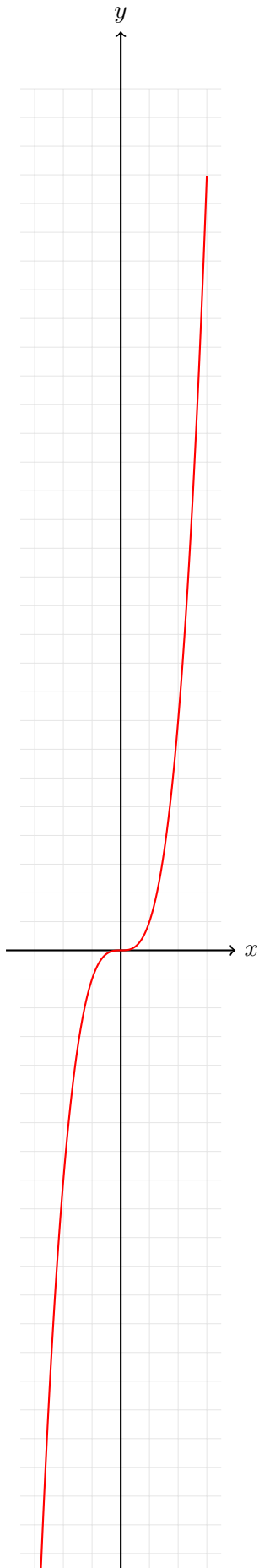
**Even Function** —  $f(x) = x^2$



**Table of values:**

$x$	$f(x)$
-2	4
-1	1
0	0
1	1
2	4

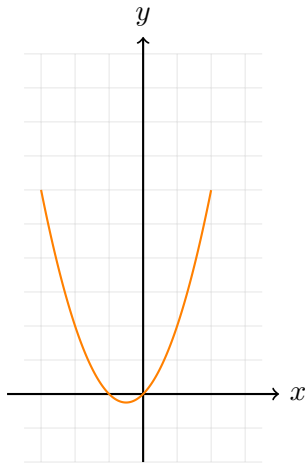
**Odd Function** —  $f(x) = x^3$



**Table of values:**

$x$	$f(x)$
-2	-8
-1	-1
0	0
1	1
2	8

**Neither** —  $f(x) = x^2 + x$



**Why is it neither?**

$$f(-x) = x^2 - x \neq f(x) \text{ and } \neq -f(x)$$

No symmetry about the y-axis or origin.

### Quick Summary

- **Even:** Symmetric about the  $y$ -axis (e.g.,  $x^2$ )
- **Odd:** Symmetric about the origin (e.g.,  $x^3$ )
- **Neither:** Fails both tests (e.g.,  $x^2 + x$ )

## 14 Trichotomy

### The Trichotomy Property

The **Trichotomy Property** states that for any real number  $a$ , exactly one of the following is true:

- $a > 0$  (positive)
- $a = 0$  (zero)
- $a < 0$  (negative)

This property applies to all real numbers and ensures that any number must fall into one — and only one — of these categories.

#### Trichotomy Summary

For any real number  $a$ , exactly one of the following holds:

$$a > 0 \quad \text{or} \quad a = 0 \quad \text{or} \quad a < 0$$

Only one condition can be true at a time.



## Examples

- $7 > 0$ : Positive
- $0 = 0$ : Zero
- $-5 < 0$ : Negative

## Why It Matters

Trichotomy is fundamental in:

- Solving inequalities
- Proving properties in algebra and calculus
- Understanding number line positioning

## Inequalities and Negative Numbers

### 14.1 Working with Inequalities

Inequalities show relationships between two values using symbols:

- $<$ : less than
- $>$ : greater than
- $\leq$ : less than or equal to
- $\geq$ : greater than or equal to

### 14.2 Multiplying or Dividing by Negatives

When you **multiply or divide** both sides of an inequality by a **negative number**, you must **reverse the direction** of the inequality.

#### Important Rule

If you multiply or divide both sides of an inequality by a negative number, the inequality sign flips:

$$\text{If } a < b, \text{ then } -a > -b$$

## Examples

- Original:  $3 < 5$  Multiply both sides by  $-1$ :  $-3 > -5$
- Solve:  $-2x > 6$  Divide both sides by  $-2$ :  $x < -3$  (Notice the sign flip!)

## Why This Happens

Negative numbers reverse order on the number line. For example:

$$-3 > -5 \quad \text{because } -3 \text{ is to the right of } -5$$

## Summary

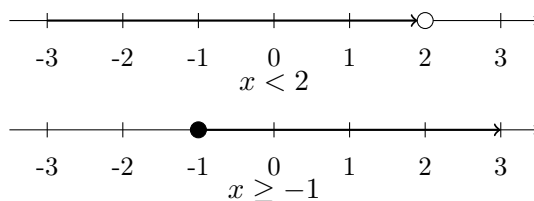
- Inequalities describe relative size.
- Operations like addition and subtraction don't flip the sign.
- Multiplying or dividing by a **negative** *does*.

## 14.3 Graphing Inequalities on a Number Line

To graph inequalities, we use a number line with:

- An **open circle** for  $<$  or  $>$  (value is *not* included)
- A **closed (filled) circle** for  $\leq$  or  $\geq$  (value *is* included)
- An arrow to indicate all values greater than or less than the point

## Examples



## Summary

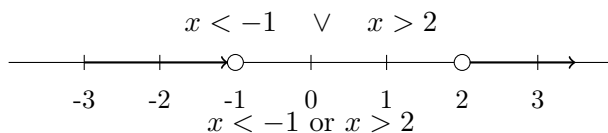
- Use **open circles** for strict inequalities ( $<$ ,  $>$ )
- Use **closed circles** for inclusive inequalities ( $\leq$ ,  $\geq$ )
- Shade to the left for "less than", and to the right for "greater than"

## 14.4 Graphing Disjunctions (OR)

A **disjunction** connects two inequalities with "or" (symbol:  $\vee$ ). The solution includes values that satisfy *either* inequality.

- Graph both inequalities separately.
- Shade all values that satisfy *either* one.
- The graph is the **union** of both solution sets.

## Example:



### 14.5 Graphing Conjunctions (AND)

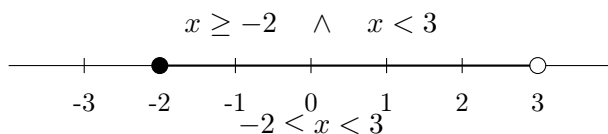
A **conjunction** connects two inequalities with "and" (symbol:  $\wedge$ ). The solution includes values that satisfy *both* inequalities simultaneously.

- Graph both inequalities separately.
- The solution is the **intersection** of the two graphs.
- Shade only where both overlap.

**Example:**

$$-2 \leq x < 3$$

This can be written as the conjunction:



#### Summary

- **Disjunction (OR)** solutions combine all values satisfying either inequality.
- **Conjunction (AND)** solutions are values satisfying both inequalities simultaneously.
- On number lines, OR means shading the union, AND means shading the intersection.

### 14.6 Graphing Inequalities in the Plane

To graph a linear inequality in two variables (like  $y < 2x + 1$ ), follow these steps:

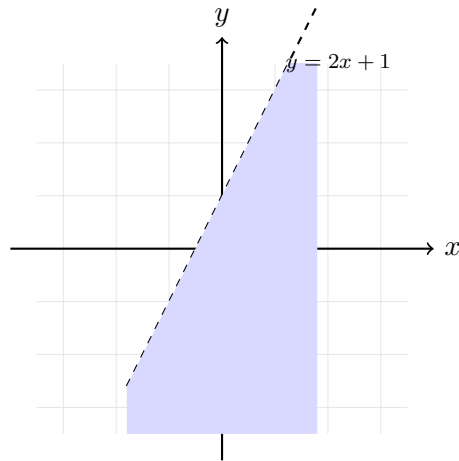
1. **Graph the boundary line:** Replace the inequality symbol with an equals sign and graph the resulting line:

$$y = 2x + 1$$

Use a **dashed line** for  $<$  or  $>$ , and a **solid line** for  $\leq$  or  $\geq$ .

2. **Choose a test point:** Often the point  $(0, 0)$  is easiest. Plug it into the inequality to check if it makes the inequality true.
3. **Shade the correct region:** If the test point satisfies the inequality, shade the side of the line that includes it. Otherwise, shade the opposite side.

**Example:**  $y < 2x + 1$



#### Tips

- Dashed line: inequality does **not include** the boundary (e.g.,  $<$ ,  $>$ )
- Solid line: inequality **includes** the boundary (e.g.,  $\leq$ ,  $\geq$ )
- Shade the region where the inequality holds true.