More problems:

$$x^a x^b = x^{a+b} \qquad x^2x^4 = x^6 \qquad 2^2 2^3 = 4.8 = 32 = 2^5$$
$$(x^a)^b = x^{ab} \qquad (x^2)^3 = x^6 \qquad (2^2)^3 = 4^3 = 64 = 2^6$$
$$x^{-a} = \frac{1}{x^a} \qquad x^{-2} = \frac{1}{x^2} \qquad 2^{-2} = \frac{1}{2^2} = \frac{1}{4}$$
$$x^{1/2} = \sqrt{x} \qquad 9^{1/2} = \sqrt{9} = 3$$

Problem: Simplify:

$$(a) \qquad (x^6y^4)^{1/2}x^{-3}y^{-1}$$
$$(b) \qquad (ab)^{-1} + \frac{a^3b^4}{a^2b^3}$$

Solution:

$$(a) \qquad (x^6y^4)^{1/2}x^{-3}y^{-1} = \frac{(x^6)^{1/2}(y^4)^{1/2}}{x^3y^1} = \frac{x^3y^2}{x^3y} = y, \quad x, y \neq 0$$
$$(b) \qquad (ab)^{-1} + \frac{a^2b^3}{a^3b^4} = \frac{1}{ab} + \frac{1}{ab} = \frac{2}{ab}, \quad a, b \neq 0$$

4 Linear Equations

4.1 Numerical Solution

Equation: mathematical statement that relates two algebraic expressions involving at least one variable.

- $5x + 3 = 2 - x$
- $x^3 + 3x^2 - 1 = 7 + x - x^2$
- $\frac{3}{x^2 - x + 1} = x + 2$

Properties of equality:

1. if $a = b$ then $a + c = b + c$ addition
2. if $a = b$ then $a - c = b - c$ subtraction
3. if $a = b$ then $ca = cb$, $c \neq 0$ multiplication

4. if $a = b$ then $\frac{a}{c} = \frac{b}{c}$, $c \neq 0$ division
5. if $a = b$ then they can be used interchangeably substitution

Linear equation has the following form: $ax + b = 0$

To solve linear equations in one variable we use the properties of equality. Remember, that whatever you do with one side of the equation has to be done with the other side as well.

$7x - 4 = 3$ add 4 to both sides of equation

$7x - 4 + 4 = 3 + 4$

$7x = 7$ dived both sides of equation by 7

$$\frac{7x}{7} = \frac{7}{7}$$

$x = 1$

Exercise 1: Solve the following equation and check if your result is correct: $6x + 2 = 2x + 14$.

Problem: Find 5 consecutive natural numbers such that their sum is 50.

Solution: Let's denote the first number x. Then the four remaining numbers are $x+1, x+2, x+3$ and $x + 4$. Their sum is supposed to be equal to 50. So we have the following equation:

$$x + (x + 1) + (x + 2) + (x + 3) + (x + 4) = 50$$
$$5x + 10 = 50$$
$$5x = 40$$
$$x = 8$$

Hence the numbers are 8, 9, 10, 11 and 12.

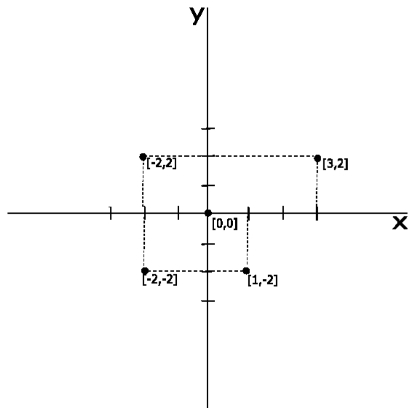
Exercise 2: Find 4 consecutive odd integers such that the sum of the last two is equal to 2 times the sum of the first two numbers.

4.2 Graphical Representation

Cartesian coordinate system, point, line

Cartesian coordinate system is formed by two real lines, one horizontal and one vertical, which cross through their origins. These two lines are called the horizontal axis and vertical axis.

Point: Every point is represented by two numbers - coordinates. The first number represents the value on axis x and the second number represents the value on axis y.



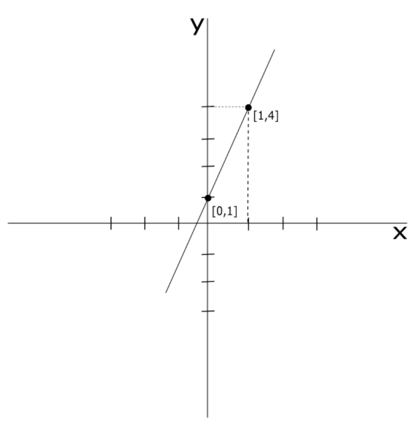
Linear function - Straight line:

Generally, linear function has the following form: $y = ax + b$. This can be graphically represented by a straight line. Any straight line can be represented by two points. If we find two points lying on the line, we can draw the whole line. Coefficient a is called *slope*. The bigger (smaller) a the steeper (flatter) the line.

Example: $y = 3x + 1$.

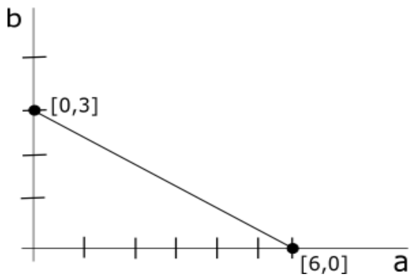
To find two points lying on this line we use 0 and 1 for x and find corresponding values of y from the equation:

x	0	1
y	$3 \times 0 + 1 = 1$	$3 \times 1 + 1 = 4$



In economics, we often deal with the budget constraint. We can draw the budget line or alternatively budget set in the following way:

Example: Assume that there are only two goods: apples and bananas. The price of apples is \$2 and the price of bananas is \$4. You have \$12. If you spend all the money on apples, you can afford to buy 6 of them. If you spend all the money on bananas, you can buy 3. So the budget line goes through points [6,0] and [0,3]. The budget line can be represented by the following equation $2a + 4b = 12$ and graphically:



Budget line represents all combinations of apples and bananas that we can buy spending *exactly* \$12.

The budget set represents all combinations of apples and bananas that we can afford, i.e. that we can buy spending *at most* \$12. This can be represented by inequality $2a + 4b \leq 12$ or graphically it is the triangle below the budget line.

In general, linear equation can be written in the following slope-intercept form: $y = mx + c$, where m is the slope of the line and c is the y-intercept, which is the y-coordinate of the point where the line crosses the y axis. This can be seen by letting $x = 0$, which immediately gives that $y = c$.

Special cases:

1. **y=const:** This is a special case of the general form where $A = 0$ and $B = 1$, or of the slope-intercept form where the slope $m = 0$. The graph is a horizontal line with y-intercept equal to *const*. There is no x-intercept, unless $const = 0$, in which case the graph of the line is the x-axis, and so every real number is an x-intercept.

2. **x=const:** This is a special case of the standard form where $A = 1$ and $B = 0$. The graph is a vertical line with x-intercept equal to *const*. The slope is undefined. There is no y-intercept, unless $const = 0$, in which case the graph of the line is the y-axis, and so every real number is a y-intercept.

4.3 Changes in Linear Equation

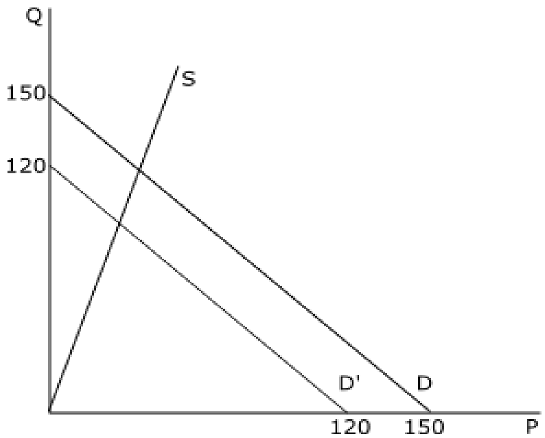
In this section we will look at what happens when parameters of the linear equation change. In particular, what happens with graphical representation of linear equation defined by slope-intercept form if parameters m and/or c change.

Example: Consider the following supply and demand function for beef.

Supply: $P = 4Q$

Demand: $P = 150 - Q$

Now suppose that people learn about the mad cow disease and decrease the demand to $P = 120 - Q$. The situation is illustrated on the picture below. Notice that the two lines representing demand function are parallel. This is because the slope of the demand function remains the same only the intercept changed. In general, changes in intercept cause shifts in the line, changes in the slope "rotate" the line.



4.4 Answers

Exercise 1: $x = 3$.

Exercise 2: Let's denote the first number x. Then we need to solve equation $2[x + (x + 2)] = (x + 4) + (x + 6)$. Solution is $x = 3$ and hence the numbers are 3, 5, 7 and 9.

5 Systems of Linear Equations

5.1 Solving by Substitution

Eliminate one of the variables by replacement when solving a system of equations. Think of it as "grabbing" what one variable equals from one equation and "plugging" it into the other equation.

Problem: Solve the following system of equations:

$$3x + 2y = 12$$
$$4x - y = 5$$

Solution:

$$3x + 2y = 12$$
$$4x - y = 5 \qquad \Rightarrow y = 4x - 5$$

Now, plug $4x - 5$ for y in the first equation:

$$3x + 2(4x - 5) = 12$$
$$3x + 8x - 10 = 12$$
$$11x = 22$$
$$x = 2$$

Now we get back to $y = 4x - 5$ and therefore $y = 4 \times 2 - 5 = 3$.

Problem: Solve the system of linear equations given below using substitution.

Suppose there is a piggybank that contains 57 coins, which are only quarters and dimes. The total number of coins in the bank is 57, and the total value of these coins is $9.45. This information can be represented by the following system of equations:

$$D + Q = 57$$
$$00.10D + 0.25Q = 9.45$$

Determine how many of the coins are quarters and how many are dimes.

Solution:

$$D + Q = 57 \qquad \Rightarrow D = 57 - Q$$
$$00.10D + 0.25Q = 9.45$$

Plug $57 - Q$ for D in the second equation

$$\begin{aligned} 00.10(57 - Q) + 0.25Q &= 9.45 \\ 5.7 - 0.1Q + 0.25Q &= 9.45 \\ 0.15Q &= 3.75 \\ Q &= 25 \qquad D = 57 - Q = 57 - 25 = 32 \end{aligned}$$

5.2 Solving by Addition (Elimination) Method

The addition method says we can just add everything on the left hand side and add everything on the right hand side and keep the equal sign in between.

Problem: Solve the following system of equations:

$$3x + y = 14$$
$$4x - y = 14$$

Solution: Add the two equations; i.e sum left hand sides, sum right hand sides and keep equal sign in between. This way, we eliminate variable y and get only one equation in one variable x:

$$3x + 4x + y - y = 14 + 14$$
$$7x = 28$$
$$x = 4$$

Now we plug 4 for x and use any of two equations to determine y:

$$3x + y = 14$$
$$3 \times 4 + y = 14$$
$$y = 2$$

Check:

$$3x + y = 14 \ldots 3 \times 4 + 2 \stackrel{?}{=} 14 \ldots 14 \stackrel{\checkmark}{=} 14$$
$$4x - y = 14 \ldots 4 \times 4 - 2 \stackrel{?}{=} 14 \ldots 14 \stackrel{\checkmark}{=} 14$$

Exercise 1: Solve the following system of equations:

$$2x + 2y = 12$$
$$3x - y = 14$$

Exercise 2: Solve the following system of equations:

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

Problem: Find the equilibrium price of apple and equilibrium quantity consumed if demand and supply equations are as follows:

$$p = -q + 20 \quad \text{Demand equation (consumer)}$$
$$p = 4q - 55 \quad \text{Supply equation (supplier)}$$

Solution:

$$p = -q + 20$$
$$p = 4q - 55 \quad \Rightarrow \quad -q + 20 = 4q - 55 \quad \Rightarrow \quad 5q = 75 \quad \Rightarrow \quad q = 15$$
$$p = -q + 20 = -15 + 20 = 5$$