# Introduction to differentiation

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## Introduction

This leaflet provides a rough and ready introduction to **differentiation**. This is a technique used to calculate the gradient, or slope, of a graph at different points.

## The gradient function

Given a function, for example, $y = x^2$, it is possible to derive a formula for the gradient of its graph. We can think of this formula as the **gradient function**, precisely because it tells us the gradient of the graph. For example,

$$\text{when } y = x^2 \qquad \text{the gradient function is} \qquad 2x$$

So, the gradient of the graph of $y = x^2$ at any point is twice the $x$ value there. To understand how this formula is actually found you would need to refer to a textbook on calculus. The important point is that using this formula we can calculate the gradient of $y = x^2$ at different points on the graph. For example,

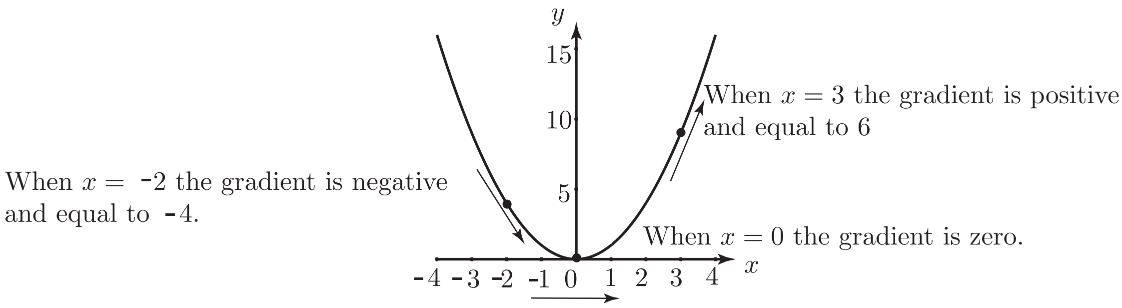
$$\text{when } x = 3, \text{ the gradient is } 2 \times 3 = 6.$$

$$\text{when } x = -2, \text{ the gradient is } 2 \times (-2) = -4.$$

How do we interpret these numbers ? A gradient of 6 means that values of $y$ are increasing at the rate of 6 units for every 1 unit increase in $x$. A gradient of $-4$ means that values of $y$ are decreasing at a rate of 4 units for every 1 unit increase in $x$.

Note that when $x = 0$, the gradient is $2 \times 0 = 0$.

Below is a graph of the function $y = x^2$. Study the graph and you will note that when $x = 3$ the graph has a positive gradient. When $x = -2$ the graph has a negative gradient. When $x = 0$ the gradient of the graph is zero. Note how these properties of the graph can be predicted from knowledge of the gradient function, $2x$.




**Example** When $y = x^3$, its gradient function is $3x^2$. Calculate the gradient of the graph of $y = x^3$ when a) $x = 2$, b) $x = -1$, c) $x = 0$.

**Solution**

a) when $x = 2$ the gradient function is $3(2)^2 = 12$.

b) when $x = -1$ the gradient function is $3(-1)^2 = 3$.

c) when $x = 0$ the gradient function is $3(0)^2 = 0$.

**Notation for the gradient function**

You will need to use a notation for the gradient function which is in widespread use.

> If $y$ is a function of $x$, that is $y = f(x)$, we write its gradient function as $\dfrac{\mathrm{d}y}{\mathrm{d}x}$.

$\dfrac{\mathrm{d}y}{\mathrm{d}x}$, pronounced 'dee $y$ by dee $x$', is not a fraction even though it might look like one! This notation can be confusing. Think of $\dfrac{\mathrm{d}y}{\mathrm{d}x}$ as the 'symbol' for the gradient function of $y = f(x)$. The process of finding $\dfrac{\mathrm{d}y}{\mathrm{d}x}$ is called **differentiation with respect to** $x$.

**Example**

For any value of $n$, the gradient function of $x^n$ is $nx^{n-1}$. We write:

$$\text{if} \qquad y = x^n, \qquad \text{then} \qquad \frac{\mathrm{d}y}{\mathrm{d}x} = nx^{n-1}$$

You have seen specific cases of this result earlier on. For example, if $y = x^3$, $\dfrac{\mathrm{d}y}{\mathrm{d}x} = 3x^2$.

**More notation and terminology**

When $y = f(x)$ alternative ways of writing the gradient function, $\dfrac{\mathrm{d}y}{\mathrm{d}x}$, are $y'$, pronounced '$y$ dash', or $\dfrac{\mathrm{d}f}{\mathrm{d}x}$, or $f'$, pronounced '$f$ dash'. In practice you do not need to remember the formulas for the gradient functions of all the common functions. Engineers usually refer to a table known as a *Table of Derivatives*. A **derivative** is another name for a gradient function. The derivative is also known as the **rate of change** of a function.

**Exercises**

1. Given that when $y = x^2$, $\frac{\mathrm{d}y}{\mathrm{d}x} = 2x$, find the gradient of $y = x^2$ when $x = 7$.
2. Given that when $y = x^n$, $\frac{\mathrm{d}y}{\mathrm{d}x} = nx^{n-1}$, find the gradient of $y = x^4$ when a) $x = 2$, b) $x = -1$.
3. Find the rate of change of $y = x^3$ when a) $x = -2$, b) $x = 6$.
4. Given that when $y = 7x^2 + 5x$, $\frac{\mathrm{d}y}{\mathrm{d}x} = 14x + 5$, find the gradient of $y = 7x^2 + 5x$ when $x = 2$.

**Answers**

1. 14. 2. a) 32, b) $-4$. 3. a) 12, b) 108. 4. 33.