

## 1 Approximation

### 1.1 Newton-Raphson process

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

### 1.2 Linear interpolation

Draw triangles, use similar triangles.

### 1.3 Interval bisection

$a$	$f(a)$	$b$	$f(b)$	$\frac{a+b}{2}$	$f\left(\frac{a+b}{2}\right)$
2	-1	3	2	2.5	0.1569
2	-1	2.5	0.1569	2.25	-0.493

## 2 Summation of Series

### 2.1 Summation of Series

$$\begin{aligned}\sum_{x=1}^n x &= \frac{n(n+1)}{2} \\ \sum_{x=1}^n x^2 &= \frac{n(n+1)(2n+1)}{6} \\ \sum_{x=1}^n x^3 &= \frac{n^2(n+1)^2}{4}\end{aligned}$$

### 2.2 Summation of Arithmetic Progression

$$S_n = a_1 n + \frac{(n)(n-1)d}{2}$$

$$S_n = a_0 n + \frac{(n)(n+1)d}{2}$$

$$S_n = \frac{n \times (a_1 + a_n)}{2}$$

$$S_n = n \times a_{\frac{n+1}{2}}$$

### 2.3 Summation of Geometric Progression

$$S_n = \frac{a_1 \times (1 - q^n)}{1 - q}$$

$$S_\infty = \frac{a_1}{1 - q}$$

## 3 Matrices

### 3.1 Transformations

#### 3.1.1 Enlargement

- Stretch in x-direction by a scale factor  $k$ :  $\begin{pmatrix} k & 0 \\ 0 & 1 \end{pmatrix}$
- Stretch in y-direction by a scale factor  $k$ :  $\begin{pmatrix} 1 & 0 \\ 0 & k \end{pmatrix}$
- Enlargement with centre of the origin by a scale factor  $k$ :  $\begin{pmatrix} k & 0 \\ 0 & k \end{pmatrix}$

### 3.1.2 Reflection

- Reflection in x-axis:  $\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$
- Reflection in y-axis:  $\begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix}$
- Reflection in  $y = x$ :  $\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$
- Reflection in  $y = -x$ :  $\begin{pmatrix} 0 & -1 \\ -1 & 0 \end{pmatrix}$

### 3.1.3 Rotation

- Rotation about the origin by  $\theta$  anti-clockwise:  $\begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix}$

## 3.2 Inverse matrix 2\*2

$$A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$$
$$\det A = ad - bc$$

$$I = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

If  $\det A = 0$ ,  $A$  is singular, so  $A$  has no inverse.

$$A^{-1} = \frac{1}{\det A} \begin{pmatrix} d & -b \\ -c & a \end{pmatrix}$$

## 3.3 Inverse matrix 3\*3

$$\begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix}^{-1} = \frac{1}{\Delta} \begin{pmatrix} A & -B & C \\ -D & E & -F \\ G & -H & I \end{pmatrix}^T$$

where

$$A = ei - hf$$

$$\Delta = aA - bB + cC$$

### 3.3.1 Transpose

$$\begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix}^T = \begin{pmatrix} a & d & g \\ b & e & h \\ c & f & i \end{pmatrix}$$

## 3.4 Calculating area of an triangle

$$\begin{pmatrix} x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \end{pmatrix}$$

$$A = \frac{1}{2} (x_2y_1 + x_3y_2 + x_1y_3 - x_1y_2 - x_2y_3 - x_3y_1)$$

## 4 Complex Numbers

1) Translation

$$w = z + a + bi : \text{translation by } \begin{pmatrix} a \\ b \end{pmatrix}$$

2) Enlargement

$$w = kz : \text{enlargement by a scale factor } k$$

3) Enlargement followed by translation

$$w = kz + a + bi : \text{enlargement by a scale factor } k \text{ followed by a translation by } \begin{pmatrix} a \\ b \end{pmatrix}$$

### 4.1 Transformations

#### 4.1.1 Example 1

Find the transformation  $w = \frac{1}{z}, z \neq 0$ , find the locus of  $w$  when  $z$  lies on the line with equation  $y = 2x + 1$

$$x + yi = \frac{1}{u + vi} = \frac{u - vi}{u^2 + v^2} = \frac{u}{u^2 + v^2} + \frac{-v}{u^2 + v^2}i$$

## 5 Differentiation

### 5.1 First order differentiation

$$f(x) \frac{dy}{dx} + f'(x)y = \frac{d(f(x)y)}{dx}$$

Integration factor:  $\boxed{e^{\int p dx}}$

$$\frac{dy}{dx} + py = Q \Rightarrow \frac{d(\boxed{e^{\int p dx}} y)}{dx} = \boxed{e^{\int p dx}} Q$$

### 5.2 Second order differentiation

$$a \frac{d^2 y}{dx^2} + b \frac{dy}{dx} + cy = 0$$

#### 5.2.1 Auxiliary equation

$$am^2 + bm + c = 0$$

If  $\Delta > 0$ , it has two distinct roots  $\alpha, \beta$ . General solution:

$$y = Ae^{\alpha x} + Be^{\beta x}$$

If  $\Delta = 0$ , it has two repeated roots. General solution:

$$y = (A + Bx)e^{\alpha x}$$

If  $\Delta < 0$ , it has two complex roots,  $p + qi$  and  $p - qi$ . General solution:

$$y = e^{px}(A \cos qx + B \sin qx)$$

#### 5.2.2 Example for finding a general solution for Second order differentiation

$$\frac{d^2 y}{dx^2} + 5 \frac{dy}{dx} + 6y = 0$$

$$a = 1, b = 5, c = 6$$

$$m^2 + 5m + 6 = 0$$

$$m = -2 \text{ or } m = -3$$

$$y = Ae^{-2x} + Be^{-3x}$$

### 5.2.3 Complementary functions

$$a \frac{d^2 y}{dx^2} + b \frac{dy}{dx} + cy = f(x)$$

Solution:  $y = \text{complementary function} + \text{particular integral}$

Particular integral is the general form of  $f(x)$ .

### 5.2.4 Complementary functions example

$$\frac{d^2 y}{dx^2} - 8 \frac{dy}{dx} + 12y = 36x$$

Step 1. State CF and PI

$$\text{CF: } y = Ae^{2x} + Be^{6x}$$

$$\text{PI: } y = \lambda x + \mu$$

Step 2. Differentiate PI

Obtain:

$$\frac{dy}{dx} = \lambda$$

$$\frac{d^2 y}{dx^2} = 0$$

Step 3. Substitute  $\frac{d^2 y}{dx^2}$ ,  $\frac{dy}{dx}$ ,  $y$  into the differentiation equation.

Then find  $\lambda$  and  $\mu$ .

### 5.3 Appendix: Particular Integrals

$f(x)$	Particular integral
$k$	$\lambda$
$ax + b$	$\lambda x + \mu$
$ax^2 + bx + c$	$\lambda x^2 + \mu x + \gamma$
$ae^{kx}$	$\lambda e^{kx}$
$a \sin kx$ $a \sin kx$ $a \sin kx + b \cos kx$	$\lambda \sin kx + \mu \cos kx$

## 6 Maclaurin and Taylor series

### 6.1 Maclaurin expansion

$$f(x) = f(0) + f'(0)x + \frac{f''(0)}{2!}x^2 + \frac{f^{(r)}(0)}{r!}x^r + \dots$$

#### 6.1.1 Provided expansions

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

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \dots$$

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \dots$$

$$\ln(1+x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \frac{x^4}{4} + \dots, -1 < x < 1$$

$$(1+x)^n = 1 + nx + \frac{n(n-1)}{2!}x^2 + \dots, -1 < x < 1$$

## 6.2 Taylor expansion

$$f(x) = f(a) + f'(a)(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \frac{f^{(r)}(a)}{r!}(x-a)^r + \dots$$

$$f(x-a) = f(a) + f'(a)x + \frac{f''(a)}{2!}x^2 + \frac{f^{(r)}(a)}{r!}x^r + \dots$$

## 7 Polar Coordinates

### 7.1 Sketching Graphs in Polar Coordinates

### 7.2 Integration in Polar Coordinates

$$A = \frac{1}{2} \int_{\alpha}^{\beta} r^2 d\theta$$

### 7.3 Differentiation in Polar Coordinates

Polar function  $r = f(\theta)$  can be transformed to

$$y = r \sin \theta$$

$$x = r \cos \theta$$

Then differentiation:

$$\frac{dy}{dx} = \frac{\frac{dy}{d\theta}}{\frac{dx}{d\theta}}$$

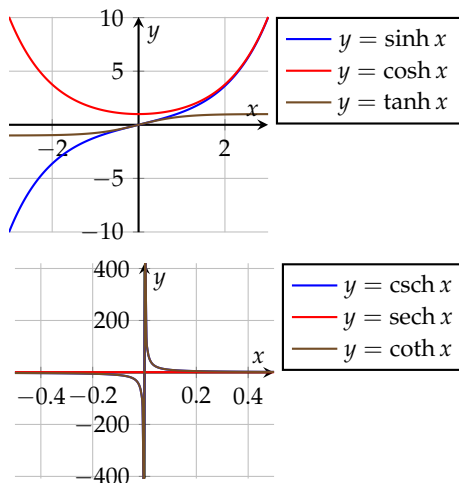
- For tangent parallel to initial line,  $\frac{dy}{dx} = 0$ , hence  $\frac{dy}{d\theta} = 0$ .
- For tangent perpendicular to initial line,  $\frac{dy}{dx}$  is undefined, hence  $\frac{dx}{d\theta} = 0$

## 8 Hyperbolic Functions

$$\sinh x = \frac{e^x - e^{-x}}{2}$$

$$\cosh x = \frac{e^x + e^{-x}}{2}$$

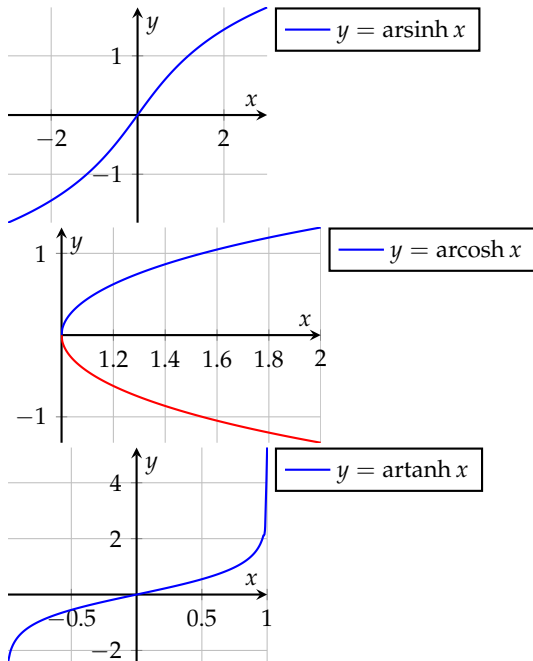
$$\tanh x = \frac{e^x - e^{-x}}{e^x + e^{-x}}$$



$$\operatorname{arsinh} x = \ln(x + \sqrt{x^2 + 1})$$

$$\operatorname{arcosh} x = \ln(x \pm \sqrt{x^2 - 1})$$

$$\operatorname{artanh} x = \frac{1}{2} \ln\left(\frac{1+x}{1-x}\right)$$



## 8.1 Osborn's rule

Replace  $\sin$  with  $\sinh$ ,  $\cos$  with  $\cosh$ ,  $\sin^2$  with  $-\sinh^2$

## 9 Further coordinates

### 9.1 Ellipses

#### 9.1.1 Standard equation

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

#### 9.1.2 Parametric equation

$$\begin{cases} x = a \cos \theta \\ y = b \sin \theta \end{cases}$$

#### 9.1.3 Gradient of tangent for ellipse

$$\frac{dy}{dx} = \frac{\frac{dy}{d\theta}}{\frac{dx}{d\theta}} = \frac{b \cos \theta}{-a \sin \theta}$$

### 9.2 Hyperbola

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$$

#### 9.2.1 Asymptotes

$$y = \pm \frac{b}{a} x$$

### 9.2.2 Intersections

$$x = \pm a$$

### 9.2.3 Parametric equations

$$\begin{cases} x = a \sec \theta \\ y = b \tan \theta \end{cases}$$

$$\begin{cases} x = a \cosh \theta \\ y = b \sinh \theta \end{cases}$$

### 9.2.4 Differentiation

$$\frac{dy}{dx} = \frac{b}{a} \csc \theta$$

$$\frac{dy}{dx} = \frac{b}{a} \coth \theta$$

### 9.3 Eccentricity

$$e = \frac{\text{distance to focus}}{\text{distance to directrix}}$$

- If  $0 < e < 1$ , it's an ellipse. *foci*  $(\pm ae, 0)$ . *directrix*:  $x = \pm \frac{a}{e}$
- If  $e = 1$ , it's a parabola.

### Conics

	Ellipse	Parabola	Hyperbola	Rectangular Hyperbola
Standard Form	$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$	$y^2 = 4ax$	$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$	$xy = c^2$
Parametric Form	$(a \cos \theta, b \sin \theta)$	$(at^2, 2at)$	$(a \sec \theta, b \tan \theta)$ $(\pm a \cosh \theta, b \sinh \theta)$	$\left(ct, \frac{c}{t}\right)$
Eccentricity	$e < 1$ $b^2 = a^2(1 - e^2)$	$e = 1$	$e > 1$ $b^2 = a^2(e^2 - 1)$	$e = \sqrt{2}$
Foci	$(\pm ae, 0)$	$(a, 0)$	$(\pm ae, 0)$	$(\pm \sqrt{2}c, \pm \sqrt{2}c)$
Directrices	$x = \pm \frac{a}{e}$	$x = -a$	$x = \pm \frac{a}{e}$	$x + y = \pm \sqrt{2}c$
Asymptotes	none	none	$\frac{x}{a} = \pm \frac{y}{b}$	$x = 0, y = 0$

Eccentricity for ellipse:

$$b^2 = a^2(1 - e^2)$$

$$e^2 = 1 - \frac{b^2}{a^2}$$

Eccentricity for hyperbola:

$$a^2 = b^2(1 - e^2)$$

$$e^2 = 1 + \frac{b^2}{a^2}$$

## 10 Appendix: Formulas of Integration and Differentiation

$$\int \frac{f'(x)}{f(x)} dx = \ln(f(x))$$

$$\sin^2(x) = \frac{1 - \cos(2x)}{2}$$

$$\cos^2(x) = \frac{1 + \cos(2x)}{2}$$

$$\int \sec x dx = \ln(\sec x + \tan x) + C$$

$$\int \csc x dx = -\ln(\csc x + \cot x) + C$$

$$\frac{d}{dx}(\sec x) = \sec x \tan x$$

$$\frac{d}{dx}(\tan x) = \sec^2 x$$

$$\frac{d}{dx}(\cot x) = -\csc^2 x$$

$$\frac{d}{dx}(\csc x) = -\csc x \cot x$$