

3.5 Differentiation rules and implicit work

Name: _____ Class: _____ Date: _____

Total: 22 marks

KEY WORDS product rule

• quotient rule

• chain rule

• implicit differentiation

Objective

Differentiate $\sin kx$, $\cos kx$, $\tan kx$, e^{kx} and $\ln x$; apply the product, quotient and chain rules (including to $\sec$, cosec and $\cot$); use $\frac{dy}{dx} = 1 \div \frac{dx}{dy}$; and set up exponential models. Original teaching questions for specification items P3.4.1 to P3.4.4; the exam-style part adapts reviewed WMA13 June 2025 demand.

1 Key knowledge and worked examples

$$\frac{d}{dx} \sin kx = k \cos kx \quad \frac{d}{dx} \cos kx = -k \sin kx \quad \frac{d}{dx} \tan kx = k \sec^2 kx$$

$$\frac{d}{dx} e^{kx} = k e^{kx} \quad \frac{d}{dx} \ln x = \frac{1}{x}$$

$$\text{product } (uv)' = u'v + uv' \quad \text{quotient } \left(\frac{u}{v}\right)' = \frac{u'v - uv'}{v^2} \quad \text{chain } \frac{dy}{dx} = \frac{dy}{du} \frac{du}{dx}$$

If x is given in terms of y , flip: $\frac{dy}{dx} = 1 \bigg/ \frac{dx}{dy}$.

Worked example – product and chain together (adapted from Edexcel IAL WMA13 June 2025 Q7). Differentiate $y = e^{-x^2} \sin 3x$.

- $u = e^{-x^2}$: chain with inner $-x^2 \Rightarrow u' = -2x e^{-x^2}$.
- $v = \sin 3x \Rightarrow v' = 3 \cos 3x$. Product rule:

$$\frac{dy}{dx} = -2x e^{-x^2} \sin 3x + 3 e^{-x^2} \cos 3x = e^{-x^2} (3 \cos 3x - 2x \sin 3x)$$

- Check at $x = 0$: $\frac{dy}{dx} = 3$; the curve leaves the origin like $\sin 3x$ (gradient 3) ✓.

Worked example – implicit flip. Find $\frac{dy}{dx}$ for $x = \sin 3y$.

- Differentiate the given form with respect to y :

$$\frac{dx}{dy} = 3 \cos 3y \quad \Rightarrow \quad \frac{dy}{dx} = \frac{1}{3 \cos 3y}$$

- Check at $y = 0$: $\frac{dy}{dx} = \frac{1}{3}$, and near the origin $x \approx 3y$, so $y \approx x/3$ (gradient $\frac{1}{3}$) ✓.

2 Practice

2.1 Differentiate $y = \sin 5x$. [1]

2.2 Differentiate $y = e^{-3x}$. [1]

2.3 Differentiate $y = x^2 \cos x$ using the product rule. [3]

2.4 Differentiate $y = \frac{e^x}{x}$ using the quotient rule. [3]

2.5 Differentiate $y = \ln(4x^3 + 1)$ using the chain rule. [2]

2.6 Find $\frac{dy}{dx}$ for $x = e^{2y}$. [3]

3 Exam-style questions

3.1 (*Adapted from Edexcel IAL WMA13 June 2025 Q7.*) The curve C has equation $y = e^{-x^2} \sin 3x$ for $0 \leq x \leq 3$. Show, using calculus, that the x -coordinates of the stationary points of C satisfy

$$x = \frac{1}{3} \arctan \frac{3}{2x}$$

[4]

3.2 A cylindrical tank drains so that the volume of water is $V = 500e^{-0.1t}$ litres after t minutes. Find the rate at which water leaves at $t = 10$, and the time at which the rate is 5 litres per minute.

[5]
