



Let  $f(x) = \cos x$  and  $g(x) = 2x^2$ . Find expressions for  $(g \circ f)(x)$  and  $(f \circ g)'(x)$ .

(a)  $(g \circ f)(x) = g(\cos x) = 2(\cos x)^2 = 2\cos^2 x$

(b)  $(f \circ g)(x) = f(2x^2) = \cos(2x^2)$

$$u = 2x^2 \quad \frac{du}{dx} = 4x$$

$$y = \cos u \quad \frac{dy}{du} = -\sin u$$

$$\frac{dy}{dx} = \frac{dy}{du} \times \frac{du}{dx} = -4x \sin u = -4x \sin(2x^2)$$

Calculus questions often involve maths from any of the other areas of the syllabus – in this case we have to find a composite function and then differentiate it.

We can identify it as a chain rule differentiation because one function is contained within a second function.

Remember that  $\ln a$  is a constant.

**Differentiating  $a^x$ :**  $a^x = e^{\ln a^x} = e^{x \ln a}$ . This can be differentiated using the chain rule:

$$\frac{d}{dx}(a^x) = \ln a \times e^{x \ln a} = a^x \ln a.$$

## 5.5 Product and Quotient Rules

When you have to differentiate two functions multiplied together you must use the *product rule*; and when two functions are divided, you must use the *quotient rule*. If the two functions are  $u(x)$  and  $v(x)$  – normally shortened to  $u$  and  $v$  – then the rules are:

• Product Rule:  $\frac{d}{dx}(uv) = u \frac{dv}{dx} + v \frac{du}{dx}$

• Quotient Rule:  $\frac{d}{dx}\left(\frac{u}{v}\right) = \frac{v \frac{du}{dx} - u \frac{dv}{dx}}{v^2}$

It may be helpful to think of the rules more informally as:

*Product Rule:*

(1st fn  $\times$  2nd fn differentiated) + (2nd fn  $\times$  1st fn differentiated)

*Quotient Rule:*

(bottom  $\times$  top differentiated) – (top  $\times$  bottom differentiated)  
(bottom line squared)

Note the plus sign in the product rule and the minus sign in the quotient rule. Also remember that, because of the minus sign, the order is important in the quotient rule.

When you are asked to do these more complicated differentiations, you can either write down every step in the formulae (safe but time-consuming) or you can do some of it in your head (faster, but you can go wrong). Here is an example of full working:

**Example:** Differentiate  $y = x^2 \sin x$

**Solution:**  $u = x^2 \quad \frac{du}{dx} = 2x$

$$v = \sin x \quad \frac{dv}{dx} = \cos x$$

$$\frac{dy}{dx} = u \frac{dv}{dx} + v \frac{du}{dx} = x^2 \cos x + 2x \sin x$$

It is possible that either (or both, if you are unlucky) of  $u$  and  $v$  are composite functions, in which case you will have to use the chain rule as well.

Another quick way to remember them:

Product Rule is  $uv' + vu'$

Quotient Rule is  $\frac{vu' - uv'}{v^2}$

# Ib Math HL Study Guide

**Liyong Dong**



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