



## UNIT 5 - Multiple Integrals

Problems based on Area as a double Integral in Cartesian coordinates:

1. Find the area enclosed by the curves  $y^2 = 4x$  and  $x^2 = 4y$

Given that  
 $y^2 = 4x \rightarrow \textcircled{1}$   
 $x^2 = 4y$   
 $y = \frac{x^2}{4} \rightarrow \textcircled{2}$

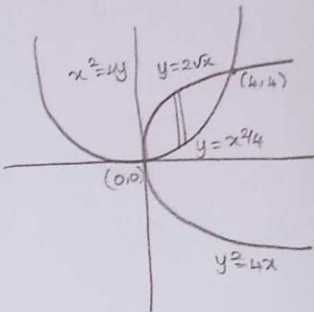
Sub  $y$  in  $\textcircled{1}$   
 $\left(\frac{x^2}{4}\right)^2 = 4x$   
 $\frac{x^4}{16} = 4x$   
 $x^3 = 64$   
 $x = 4$

Subs  $x = 4$  in  $\textcircled{2}$   
 $y = \frac{x^2}{4}$   
 $= \frac{16}{4}$   
 $y = 4$

Intersection point is  $(4, 4)$

Limits:  
 $x: 0$  to  $4$   
 $y: \frac{x^2}{4}$  to  $2\sqrt{x}$

We know that  
 $A = \iint_R dy dx = \int_0^4 \int_{\frac{x^2}{4}}^{2\sqrt{x}} dy dx$



$dy dx \rightarrow$  Vertical strip  
 $y$  limit  $\rightarrow$  intervals of  $x$   
 $x$  limit  $\rightarrow$  Constant limits



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$$\begin{aligned}
 &= \int_0^4 [y]_{y=x^2/4}^{2\sqrt{x}} dx = \int_0^4 \left[ 2\sqrt{x} - \frac{x^2}{4} \right] dx \\
 &= \int_0^4 \left[ 2x^{1/2} - \frac{x^2}{4} \right] dx = \left[ \frac{2 \cdot 2 x^{3/2}}{3/2} - \frac{x^3}{4 \times 3} \right]_0^4 \\
 &= \left[ \frac{4}{3} x^{3/2} - \frac{x^3}{12} \right]_0^4 = \left[ \frac{4}{3} (4)^{3/2} - \frac{(4)^3}{12} - 0 \right] \\
 &= \left[ \frac{4}{3} \cdot (8) - \frac{64}{12} \right] = \frac{32}{3} - \frac{16}{3} = \frac{16}{3}.
 \end{aligned}$$


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2. Find the smallest area bounded by  
 $y = 2 - x$ ,  $x^2 + y^2 = 4$

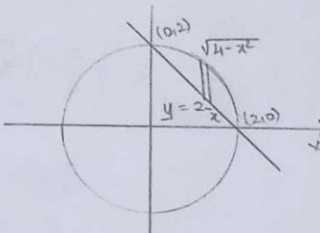
**Solution:-**  
 Given that  $y = 2 - x \rightarrow \textcircled{1}$   
 $x^2 + y^2 = 4 \rightarrow \textcircled{2}$

Sub ① in ②  
 $x^2 + (2-x)^2 = 4$   
 $x^2 + 4 + x^2 - 4x = 4$   
 $2x^2 - 4x = 0$   
 $2x(x-2) = 0$   
 $x = 0, x = 2$

When  $x = 0$ ,  $y = 2 - 0 = 2$   
 $x = 2$ ,  $y = 2 - 2 = 0$

$\therefore$  The intersection points are  $(0, 2)$  &  $(2, 0)$

Limits :  $x$  : 0 to 2  
 $y$  :  $2 - x$  to  $\sqrt{4 - x^2}$

$$\text{Area} = \iint_R dy dx = \int_0^2 \int_{2-x}^{\sqrt{4-x^2}} dy dx$$


$dy dx \rightarrow$  Vertical strip  
 $y$  limit  $\rightarrow$  integrals of  $x$   
 $x$  limit  $\rightarrow$  Constant limits  
 $x^2 + y^2 = 4$   
 $y^2 = 4 - x^2$   
 $y = \pm \sqrt{4 - x^2}$



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$$\begin{aligned}
 &= \int_0^2 \left[ y \right]_{2-x}^{\sqrt{4-x^2}} dx \\
 &= \int_0^2 [\sqrt{4-x^2} - (2-x)] dx \\
 &= \int_0^2 \sqrt{4-x^2} dx - \int_0^2 (2-x) dx \\
 &= \left[ \frac{x}{2} \sqrt{4-x^2} + \frac{2^2}{2} \sin^{-1} \left( \frac{x}{2} \right) \right]_0^2 - \left[ 2x - \frac{x^2}{2} \right]_0^2 \\
 &= \left[ \frac{2}{2} \sqrt{4-2^2} + 2 \sin^{-1} \left( \frac{2}{2} \right) \right] - 0 - \left[ 4 - \frac{4}{2} \right] \\
 &= 2 \sin^{-1}(1) - [4-2] \\
 &= 2 \left( \frac{\pi}{2} \right) - 2 \quad \boxed{A = \pi - 2}
 \end{aligned}$$

Q. Find the area bounded by the ellipse  $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$

using double integration

Given that:

$$\begin{aligned}
 \frac{x^2}{a^2} + \frac{y^2}{b^2} &= 1 \\
 \frac{y^2}{b^2} &= 1 - \frac{x^2}{a^2} \\
 &= \frac{a^2 - x^2}{a^2} \\
 y^2 &= \frac{b^2}{a^2} (a^2 - x^2) \\
 y &= \pm \frac{b}{a} \sqrt{a^2 - x^2}
 \end{aligned}$$

$dy dx \rightarrow$  Vertical strip  
 $y$  limit  $\rightarrow$  in terms of  $x$   
 $x$  limit  $\rightarrow$  constant limit

Limits

$$\begin{aligned}
 x &: 0 \text{ to } a \\
 y &: 0 \text{ to } \frac{b}{a} \sqrt{a^2 - x^2}
 \end{aligned}$$



## UNIT 5 - Multiple Integrals

The area of the ellipse is

$A = 4 \times$  Area in the first quadrant

$$= 4 \int_0^a \int_0^{\frac{b}{a}\sqrt{a^2-x^2}} dy dx$$

$$= 4 \int_0^a \left[ y \right]_0^{\frac{b}{a}\sqrt{a^2-x^2}} dx$$

$$= 4 \int_0^a \left[ \frac{b}{a}\sqrt{a^2-x^2} - 0 \right] dx$$

$$= \frac{4b}{a} \int_0^a \sqrt{a^2-x^2} dx$$

$$= \frac{4b}{a} \left[ \frac{x}{2}\sqrt{a^2-x^2} + \frac{a^2}{2}\sin^{-1}\frac{x}{a} \right]_0^a$$

$$= \frac{4b}{a} \left[ \frac{a}{2}\sqrt{a^2-a^2} + \frac{a^2}{2}\sin^{-1}\frac{a}{a} \right]$$

$$= \frac{4b}{a} \left[ \frac{a^2}{2} \left( \frac{\pi}{2} \right) \right] = \pi ab$$

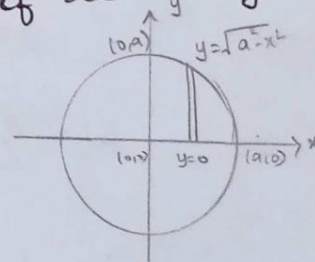
4. Find the area of a circle of radius  $a$  by double integration

Equation of the circle is

$$x^2 + y^2 = a^2$$

$$y^2 = a^2 - x^2$$

$$y = \pm \sqrt{a^2 - x^2}$$



$dy dx \rightarrow$  vertical strip  
 $y$  limit  $\rightarrow$  in terms of  $x$   
 $x$  limit  $\rightarrow$  Constant limits



## UNIT 5 - Multiple Integrals

Limits:

$$x : 0 \text{ to } a$$

$$y : 0 \text{ to } \sqrt{a^2 - x^2}$$

The area of the circle is

$A = 4 \times$  Area in the 1st quadrant

$$= 4 \int_0^a \int_0^{\sqrt{a^2 - x^2}} dy dx$$

$$= 4 \int_0^a [y]_0^{\sqrt{a^2 - x^2}} dx$$

$$= 4 \int_0^a [\sqrt{a^2 - x^2} - 0] dx$$

$$= 4 \left[ \frac{x}{2} \sqrt{a^2 - x^2} + \frac{a^2}{2} \sin^{-1} \frac{x}{a} \right]_0^a$$

$$= 4 \left[ \left[ 0 + \frac{a^2}{2} \sin^{-1} 1 \right] - 0 \right]$$

$$= 2a^2 \left[ \frac{\pi}{2} \right]$$

$$A = \pi a^2.$$