

# Engineering Mathematics (4320002) - Summer 2022 Solution

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## Question 1 [14 marks]

Fill in the blanks using appropriate choice from the given options

### Question 1.1 [1 marks]

If  $A_{2 \times 3}$  and  $B_{3 \times 4}$  are two matrices then find order of  $AB =$ \_\_\_\_\_

**Solution**

**Answer:** b.  $2 \times 4$

**Solution:** When multiplying matrices, if  $A$  is of order  $m \times n$  and  $B$  is of order  $n \times p$ , then  $AB$  is of order  $m \times p$ .  
Given:  $A_{2 \times 3}$  and  $B_{3 \times 4}$  Therefore,  $AB$  will be of order  $2 \times 4$ .

### Question 1.2 [1 marks]

If  $A = [1 \ 3 \ 2]$  and  $B = \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$  then find  $AB =$ \_\_\_\_\_

**Solution**

**Answer:** b. 9

**Solution:**

$$AB = [1 \ 3 \ 2] \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} = 1(1) + 3(2) + 2(1) = 1 + 6 + 2 = 9$$

### Question 1.3 [1 marks]

$A.I_2 = A$  then  $I_2 =$ \_\_\_\_\_

**Solution**

**Answer:** c.  $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

**Solution:**  $I_2$  is the identity matrix of order  $2 \times 2$ , which has 1's on the main diagonal and 0's elsewhere.

### Question 1.4 [1 marks]

If  $\frac{d}{dx}(\sin^2 x + \cos^2 x) =$  \_\_\_\_\_

#### Solution

**Answer:** b. 0

**Solution:** Since  $\sin^2 x + \cos^2 x = 1$  (fundamental trigonometric identity)

$$\frac{d}{dx}(\sin^2 x + \cos^2 x) = \frac{d}{dx}(1) = 0$$

### Question 1.5 [1 marks]

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

#### Solution

**Answer:** d.  $-\csc^2 x$

**Solution:**

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

### Question 1.6 [1 marks]

$\frac{d}{dx} \log(\sin x)$  then find out  $\frac{d^2 y}{dx^2} =$  \_\_\_\_\_

#### Solution

**Answer:** d.  $-\cot^2 x$

**Solution:** Let  $y = \log(\sin x)$

$$\frac{dy}{dx} = \frac{1}{\sin x} \cdot \cos x = \cot x$$

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

However, since  $\csc^2 x = 1 + \cot^2 x$ , the answer is  $-\csc^2 x$ .

### Question 1.7 [1 marks]

$\frac{d}{dx}\left(\frac{1}{x}\right) =$  \_\_\_\_\_

#### Solution

**Answer:** c.  $-\frac{1}{x^2}$

**Solution:**

$$\frac{d}{dx}\left(\frac{1}{x}\right) = \frac{d}{dx}(x^{-1}) = -1 \cdot x^{-2} = -\frac{1}{x^2}$$

### Question 1.8 [1 marks]

If  $\int x^5 dx = \text{_____} + c$

**Solution**

**Answer:** a.  $\frac{x^6}{6}$

**Solution:**

$$\int x^5 dx = \frac{x^{5+1}}{5+1} + c = \frac{x^6}{6} + c$$

### Question 1.9 [1 marks]

$\int_0^{2\pi} (\sin^2 \theta + \cos^2 \theta) d\theta = \text{_____} + c$

**Solution**

**Answer:** a.  $2\pi$

**Solution:**

$$\int_0^{2\pi} (\sin^2 \theta + \cos^2 \theta) d\theta = \int_0^{2\pi} 1 d\theta = [\theta]_0^{2\pi} = 2\pi - 0 = 2\pi$$

### Question 1.10 [1 marks]

$\int_{-1}^1 x^3 dx = \text{_____} + c$

**Solution**

**Answer:** c. 0

**Solution:**

$$\int_{-1}^1 x^3 dx = \left[ \frac{x^4}{4} \right]_{-1}^1 = \frac{1^4}{4} - \frac{(-1)^4}{4} = \frac{1}{4} - \frac{1}{4} = 0$$

### Question 1.11 [1 marks]

The order and degree of the differential equation  $x^2 \frac{d^2 y}{dx^2} + 3y^2 = 0$  is = \_\_\_\_\_

**Solution**

**Answer:** c. 2 and 1

**Solution:** Order is the highest derivative present = 2 (from  $\frac{d^2 y}{dx^2}$ ) Degree is the power of the highest derivative = 1

### Question 1.12 [1 marks]

An integrating factor of the differential equation  $\frac{dy}{dx} + py = Q$  is \_\_\_\_\_

**Solution****Answer:** c.  $e^{\int p dx}$ **Solution:** For a first-order linear differential equation  $\frac{dy}{dx} + py = Q$ , the integrating factor is  $e^{\int p dx}$ .**Question 1.13 [1 marks]**

$i^4 = \underline{\hspace{2cm}}$

**Solution****Answer:** a. 1**Solution:**

$$i^4 = (i^2)^2 = (-1)^2 = 1$$

**Question 1.14 [1 marks]**

$(3+4i)(4-5i) = \underline{\hspace{2cm}}$

**Solution****Answer:** d.  $-32 + i$ **Solution:**

$$\begin{aligned}
 (3 + 4i)(4 - 5i) &= 3(4) + 3(-5i) + 4i(4) + 4i(-5i) \\
 &= 12 - 15i + 16i - 20i^2 \\
 &= 12 + i - 20(-1) \\
 &= 12 + i + 20 = 32 + i
 \end{aligned}$$

Wait, let me recalculate:  $(3 + 4i)(4 - 5i) = 12 - 15i + 16i - 20i^2 = 12 + i + 20 = 32 + i$ The correct answer should be b.  $32 + i$ , but option d shows  $-32 + i$ . There might be an error in the options.**Question 2(a) [6 marks]**

Attempt any two

**Question 2.1 [3 marks]**

If  $A = \begin{bmatrix} 1 & -1 & 1 \\ 3 & 2 & 1 \end{bmatrix}$  and  $B = \begin{bmatrix} 1 & 2 \\ 4 & 2 \\ 1 & 7 \end{bmatrix}$  then find out AB & BA.

**Solution****Solution:****AB calculation:**

$$AB = \begin{bmatrix} 1 & -1 & 1 \\ 3 & 2 & 1 \end{bmatrix} \begin{bmatrix} 1 & 2 \\ 4 & 2 \\ 1 & 7 \end{bmatrix}$$

$$AB = \begin{bmatrix} 1(1) + (-1)(4) + 1(1) & 1(2) + (-1)(2) + 1(7) \\ 3(1) + 2(4) + 1(1) & 3(2) + 2(2) + 1(7) \end{bmatrix}$$

$$AB = \begin{bmatrix} 1 - 4 + 1 & 2 - 2 + 7 \\ 3 + 8 + 1 & 6 + 4 + 7 \end{bmatrix} = \begin{bmatrix} -2 & 7 \\ 12 & 17 \end{bmatrix}$$

**BA calculation:**

$$BA = \begin{bmatrix} 1 & 2 \\ 4 & 2 \\ 1 & 7 \end{bmatrix} \begin{bmatrix} 1 & -1 & 1 \\ 3 & 2 & 1 \end{bmatrix}$$

$$BA = \begin{bmatrix} 1(1) + 2(3) & 1(-1) + 2(2) & 1(1) + 2(1) \\ 4(1) + 2(3) & 4(-1) + 2(2) & 4(1) + 2(1) \\ 1(1) + 7(3) & 1(-1) + 7(2) & 1(1) + 7(1) \end{bmatrix}$$

$$BA = \begin{bmatrix} 7 & 3 & 3 \\ 10 & 0 & 6 \\ 22 & 13 & 8 \end{bmatrix}$$

### Question 2.2 [3 marks]

If  $A = \begin{bmatrix} -1 & 2 \\ 3 & 1 \end{bmatrix}$  then prove that  $A^2 - 7I_2 = 0$

**Solution**

**Solution:**

$$A^2 = \begin{bmatrix} -1 & 2 \\ 3 & 1 \end{bmatrix} \begin{bmatrix} -1 & 2 \\ 3 & 1 \end{bmatrix}$$

$$A^2 = \begin{bmatrix} (-1)(-1) + (2)(3) & (-1)(2) + (2)(1) \\ (3)(-1) + (1)(3) & (3)(2) + (1)(1) \end{bmatrix}$$

$$A^2 = \begin{bmatrix} 1 + 6 & -2 + 2 \\ -3 + 3 & 6 + 1 \end{bmatrix} = \begin{bmatrix} 7 & 0 \\ 0 & 7 \end{bmatrix}$$

$$7I_2 = 7 \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 7 & 0 \\ 0 & 7 \end{bmatrix}$$

Therefore,

$$A^2 - 7I_2 = \begin{bmatrix} 7 & 0 \\ 0 & 7 \end{bmatrix} - \begin{bmatrix} 7 & 0 \\ 0 & 7 \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} = 0$$

Hence proved.

### Question 2.3 [3 marks]

Find the inverse complex number of  $\frac{2+3i}{4-3i}$

**Solution**

**Solution:** First, let's find  $\frac{2+3i}{4-3i}$ :

$$\begin{aligned}\frac{2+3i}{4-3i} &= \frac{(2+3i)(4+3i)}{(4-3i)(4+3i)} = \frac{8+6i+12i+9i^2}{16-9i^2} \\ &= \frac{8+18i-9}{16+9} = \frac{-1+18i}{25} = -\frac{1}{25} + \frac{18}{25}i\end{aligned}$$

The inverse of a complex number  $z = a + bi$  is  $\frac{1}{z} = \frac{\bar{z}}{|z|^2}$

Let  $z = -\frac{1}{25} + \frac{18}{25}i$

$$|z|^2 = \left(-\frac{1}{25}\right)^2 + \left(\frac{18}{25}\right)^2 = \frac{1}{625} + \frac{324}{625} = \frac{325}{625} = \frac{13}{25}$$

$$\bar{z} = -\frac{1}{25} - \frac{18}{25}i$$

$$\frac{1}{z} = \frac{-\frac{1}{25} - \frac{18}{25}i}{\frac{13}{25}} = \frac{-1 - 18i}{13}$$

**Question 2(b) [8 marks]**

Attempt any two

**Question 2.1 [4 marks]**

$2y+5x-4=0$  and  $7x+3y=5$  solve the equations using matrix method.

**Solution**

**Solution:** The system can be written as:

$$5x + 2y = 4$$

$$7x + 3y = 5$$

In matrix form:  $\begin{bmatrix} 5 & 2 \\ 7 & 3 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 4 \\ 5 \end{bmatrix}$

Let  $A = \begin{bmatrix} 5 & 2 \\ 7 & 3 \end{bmatrix}$

$$|A| = 5(3) - 2(7) = 15 - 14 = 1$$

$$A^{-1} = \frac{1}{|A|} \begin{bmatrix} 3 & -2 \\ -7 & 5 \end{bmatrix} = \begin{bmatrix} 3 & -2 \\ -7 & 5 \end{bmatrix}$$

$$\begin{bmatrix} x \\ y \end{bmatrix} = A^{-1} \begin{bmatrix} 4 \\ 5 \end{bmatrix} = \begin{bmatrix} 3 & -2 \\ -7 & 5 \end{bmatrix} \begin{bmatrix} 4 \\ 5 \end{bmatrix}$$

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 3(4) + (-2)(5) \\ -7(4) + 5(5) \end{bmatrix} = \begin{bmatrix} 12 - 10 \\ -28 + 25 \end{bmatrix} = \begin{bmatrix} 2 \\ -3 \end{bmatrix}$$

Therefore,  $x = 2$  and  $y = -3$ .

### Question 2.2 [4 marks]

If  $A = \begin{bmatrix} 2 & -2 \\ 3 & 1 \end{bmatrix}$  and  $B = \begin{bmatrix} -1 & 5 \\ 4 & -3 \end{bmatrix}$  then Prove that  $(AB)^T = B^T \cdot A^T$

#### Solution

**Solution:** First, let's find  $AB$ :

$$\begin{aligned} AB &= \begin{bmatrix} 2 & -2 \\ 3 & 1 \end{bmatrix} \begin{bmatrix} -1 & 5 \\ 4 & -3 \end{bmatrix} \\ AB &= \begin{bmatrix} 2(-1) + (-2)(4) & 2(5) + (-2)(-3) \\ 3(-1) + 1(4) & 3(5) + 1(-3) \end{bmatrix} \\ AB &= \begin{bmatrix} -2 - 8 & 10 + 6 \\ -3 + 4 & 15 - 3 \end{bmatrix} = \begin{bmatrix} -10 & 16 \\ 1 & 12 \end{bmatrix} \\ (AB)^T &= \begin{bmatrix} -10 & 1 \\ 16 & 12 \end{bmatrix} \end{aligned}$$

Now, let's find  $B^T$  and  $A^T$ :  $A^T = \begin{bmatrix} 2 & 3 \\ -2 & 1 \end{bmatrix}$ ,  $B^T = \begin{bmatrix} -1 & 4 \\ 5 & -3 \end{bmatrix}$

$$\begin{aligned} B^T \cdot A^T &= \begin{bmatrix} -1 & 4 \\ 5 & -3 \end{bmatrix} \begin{bmatrix} 2 & 3 \\ -2 & 1 \end{bmatrix} \\ B^T \cdot A^T &= \begin{bmatrix} -1(2) + 4(-2) & -1(3) + 4(1) \\ 5(2) + (-3)(-2) & 5(3) + (-3)(1) \end{bmatrix} \\ B^T \cdot A^T &= \begin{bmatrix} -2 - 8 & -3 + 4 \\ 10 + 6 & 15 - 3 \end{bmatrix} = \begin{bmatrix} -10 & 1 \\ 16 & 12 \end{bmatrix} \end{aligned}$$

Since  $(AB)^T = B^T \cdot A^T$ , the property is proved.

### Question 2.3 [4 marks]

**Simplify:**  $\frac{(\cos 2\theta + i \sin 2\theta)^{-3} \cdot (\cos 3\theta - i \sin 3\theta)^2}{(\cos 2\theta + i \sin 2\theta)^{-7} \cdot (\cos 5\theta - i \sin 5\theta)^3}$

#### Solution

**Solution:** Using De Moivre's theorem:  $(\cos \theta + i \sin \theta)^n = \cos(n\theta) + i \sin(n\theta)$   
 $(\cos 2\theta + i \sin 2\theta)^{-3} = \cos(-6\theta) + i \sin(-6\theta) = \cos(6\theta) - i \sin(6\theta)$   
 $(\cos 3\theta - i \sin 3\theta)^2 = (\cos(-3\theta) + i \sin(-3\theta))^2 = \cos(-6\theta) + i \sin(-6\theta) = \cos(6\theta) - i \sin(6\theta)$   
 $(\cos 2\theta + i \sin 2\theta)^{-7} = \cos(-14\theta) + i \sin(-14\theta) = \cos(14\theta) - i \sin(14\theta)$   
 $(\cos 5\theta - i \sin 5\theta)^3 = (\cos(-5\theta) + i \sin(-5\theta))^3 = \cos(-15\theta) + i \sin(-15\theta) = \cos(15\theta) - i \sin(15\theta)$   
The expression becomes:

$$\begin{aligned} &\frac{[\cos(6\theta) - i \sin(6\theta)][\cos(6\theta) - i \sin(6\theta)]}{[\cos(14\theta) - i \sin(14\theta)][\cos(15\theta) - i \sin(15\theta)]} \\ &= \frac{[\cos(6\theta) - i \sin(6\theta)]^2}{[\cos(14\theta) - i \sin(14\theta)][\cos(15\theta) - i \sin(15\theta)]} \\ &= \frac{\cos(12\theta) - i \sin(12\theta)}{\cos(29\theta) - i \sin(29\theta)} \end{aligned}$$

$$= \cos(12\theta - 29\theta) + i \sin(12\theta - 29\theta) = \cos(-17\theta) + i \sin(-17\theta) = \cos(17\theta) - i \sin(17\theta)$$

### Question 3(a) [6 marks]

Attempt any two

### Question 3.1 [3 marks]

If  $y = \frac{1+\tan x}{1-\tan x}$  then find  $\frac{dy}{dx}$

#### Solution

**Solution:** Using quotient rule:  $\frac{d}{dx} \left[ \frac{u}{v} \right] = \frac{v \frac{du}{dx} - u \frac{dv}{dx}}{v^2}$   
 Let  $u = 1 + \tan x$  and  $v = 1 - \tan x$

$$\begin{aligned} \frac{du}{dx} &= \sec^2 x \quad \text{and} \quad \frac{dv}{dx} = -\sec^2 x \\ \frac{dy}{dx} &= \frac{(1 - \tan x)(\sec^2 x) - (1 + \tan x)(-\sec^2 x)}{(1 - \tan x)^2} \\ &= \frac{(1 - \tan x)\sec^2 x + (1 + \tan x)\sec^2 x}{(1 - \tan x)^2} \\ &= \frac{\sec^2 x[(1 - \tan x) + (1 + \tan x)]}{(1 - \tan x)^2} \\ &= \frac{2\sec^2 x}{(1 - \tan x)^2} \end{aligned}$$

### Question 3.2 [3 marks]

Using Definition of differentiation differentiate  $x^3$  with respect to  $x$ .

#### Solution

**Solution:** Using the definition:  $\frac{dy}{dx} = \lim_{h \rightarrow 0} \frac{f(x+h) - f(x)}{h}$   
 For  $f(x) = x^3$ :

$$\begin{aligned} \frac{d}{dx}(x^3) &= \lim_{h \rightarrow 0} \frac{(x+h)^3 - x^3}{h} \\ &= \lim_{h \rightarrow 0} \frac{x^3 + 3x^2h + 3xh^2 + h^3 - x^3}{h} \\ &= \lim_{h \rightarrow 0} \frac{3x^2h + 3xh^2 + h^3}{h} \\ &= \lim_{h \rightarrow 0} \frac{h(3x^2 + 3xh + h^2)}{h} \\ &= \lim_{h \rightarrow 0} (3x^2 + 3xh + h^2) \\ &= 3x^2 + 0 + 0 = 3x^2 \end{aligned}$$



### Question 3.3 [3 marks]

Simplify:  $\int \frac{4+3\cos x}{\sin^2 x} dx$

#### Solution

**Solution:**

$$\begin{aligned}\int \frac{4+3\cos x}{\sin^2 x} dx &= \int \frac{4}{\sin^2 x} dx + \int \frac{3\cos x}{\sin^2 x} dx \\ &= 4 \int \csc^2 x dx + 3 \int \frac{\cos x}{\sin^2 x} dx\end{aligned}$$

For the first integral:  $\int \csc^2 x dx = -\cot x$

For the second integral, let  $u = \sin x$ , then  $du = \cos x dx$ :

$$\int \frac{\cos x}{\sin^2 x} dx = \int \frac{1}{u^2} du = -\frac{1}{u} = -\frac{1}{\sin x} = -\csc x$$

Therefore:

$$\int \frac{4+3\cos x}{\sin^2 x} dx = 4(-\cot x) + 3(-\csc x) + C = -4\cot x - 3\csc x + C$$

### Question 3(b) [8 marks]

Attempt any two

### Question 3.1 [4 marks]

If  $y = \log\left(\frac{\cos x}{1+\sin x}\right)$  then find  $\frac{dy}{dx}$

#### Solution

**Solution:**

$$y = \log\left(\frac{\cos x}{1+\sin x}\right) = \log(\cos x) - \log(1+\sin x)$$

$$\begin{aligned}\frac{dy}{dx} &= \frac{d}{dx}[\log(\cos x)] - \frac{d}{dx}[\log(1+\sin x)] \\ &= \frac{1}{\cos x} \cdot (-\sin x) - \frac{1}{1+\sin x} \cdot \cos x \\ &= -\frac{\sin x}{\cos x} - \frac{\cos x}{1+\sin x} \\ &= -\tan x - \frac{\cos x}{1+\sin x}\end{aligned}$$

To simplify further:

$$\begin{aligned}&= -\frac{\sin x(1+\sin x) + \cos^2 x}{\cos x(1+\sin x)} \\ &= -\frac{\sin x + \sin^2 x + \cos^2 x}{\cos x(1+\sin x)} \\ &= -\frac{\sin x + 1}{\cos x(1+\sin x)} = -\frac{1}{\cos x} = -\sec x\end{aligned}$$

### Question 3.2 [4 marks]

Find maximum and minimum value of function  $f(x) = 2x^3 - 15x^2 + 36x + 10$ .

#### Solution

**Solution:** To find extrema, we find where  $f'(x) = 0$ :

$$f'(x) = 6x^2 - 30x + 36 = 6(x^2 - 5x + 6) = 6(x - 2)(x - 3)$$

Setting  $f'(x) = 0$ :  $x = 2$  or  $x = 3$

To determine nature of critical points, we use the second derivative test:  $f''(x) = 12x - 30$

At  $x = 2$ :  $f''(2) = 24 - 30 = -6 < 0 \rightarrow$  Local maximum

At  $x = 3$ :  $f''(3) = 36 - 30 = 6 > 0 \rightarrow$  Local minimum

**Values:**

$$f(2) = 2(8) - 15(4) + 36(2) + 10 = 16 - 60 + 72 + 10 = 38$$

$$f(3) = 2(27) - 15(9) + 36(3) + 10 = 54 - 135 + 108 + 10 = 37$$

Therefore:

- Local maximum value: 38 at  $x = 2$
- Local minimum value: 37 at  $x = 3$

### Question 3.3 [4 marks]

If  $y = 2e^{-3x} + 3e^{2x}$  then prove that  $y_2 + y_1 - 6y = 0$ .

#### Solution

**Solution:** Given:  $y = 2e^{-3x} + 3e^{2x}$

$$y_1 = \frac{dy}{dx} = 2(-3)e^{-3x} + 3(2)e^{2x} = -6e^{-3x} + 6e^{2x}$$

$$y_2 = \frac{d^2y}{dx^2} = -6(-3)e^{-3x} + 6(2)e^{2x} = 18e^{-3x} + 12e^{2x}$$

Now let's verify  $y_2 + y_1 - 6y = 0$ :

$$\begin{aligned} y_2 + y_1 - 6y &= (18e^{-3x} + 12e^{2x}) + (-6e^{-3x} + 6e^{2x}) - 6(2e^{-3x} + 3e^{2x}) \\ &= 18e^{-3x} + 12e^{2x} - 6e^{-3x} + 6e^{2x} - 12e^{-3x} - 18e^{2x} \\ &= (18 - 6 - 12)e^{-3x} + (12 + 6 - 18)e^{2x} \\ &= 0 \cdot e^{-3x} + 0 \cdot e^{2x} = 0 \end{aligned}$$

Hence proved.

### Question 4(a) [6 marks]

Attempt any two

### Question 4.1 [3 marks]

**Evaluate:**  $\int \frac{x^2}{1+x^6} dx$

**Solution**

**Solution:** Let  $u = x^3$ , then  $du = 3x^2 dx$ , so  $x^2 dx = \frac{1}{3} du$

$$\begin{aligned}\int \frac{x^2}{1+x^6} dx &= \int \frac{1}{1+(x^3)^2} \cdot x^2 dx = \int \frac{1}{1+u^2} \cdot \frac{1}{3} du \\ &= \frac{1}{3} \int \frac{1}{1+u^2} du = \frac{1}{3} \tan^{-1}(u) + C \\ &= \frac{1}{3} \tan^{-1}(x^3) + C\end{aligned}$$

**Question 4.2 [3 marks]**

**Evaluate:**  $\int x \log x \, dx$

**Solution**

**Solution:** Using integration by parts:  $\int u \, dv = uv - \int v \, du$

Let  $u = \log x$  and  $dv = x \, dx$  Then  $du = \frac{1}{x} dx$  and  $v = \frac{x^2}{2}$

$$\begin{aligned}\int x \log x \, dx &= \log x \cdot \frac{x^2}{2} - \int \frac{x^2}{2} \cdot \frac{1}{x} dx \\ &= \frac{x^2 \log x}{2} - \int \frac{x}{2} dx \\ &= \frac{x^2 \log x}{2} - \frac{x^2}{4} + C \\ &= \frac{x^2}{2} \left( \log x - \frac{1}{2} \right) + C\end{aligned}$$

**Question 4.3 [3 marks]**

**Solve the differential equation**  $xy \, dy + y \, dx = 0$ .

**Solution**

**Solution:** The given equation is:  $xy \, dy + y \, dx = 0$

This can be written as:  $xy \, dy = -y \, dx$

Separating variables:  $\frac{dy}{y} = -\frac{dx}{x}$

Integrating both sides:

$$\begin{aligned}\int \frac{dy}{y} &= \int -\frac{dx}{x} \\ \log |y| &= -\log |x| + C_1 \\ \log |y| + \log |x| &= C_1 \\ \log |xy| &= C_1 \\ |xy| &= e^{C_1} = C \quad (\text{where } C = e^{C_1})\end{aligned}$$

Therefore:  $xy = \pm C$

The general solution is:  $xy = k$  (where  $k$  is an arbitrary constant)

## Question 4(b) [8 marks]

Attempt any two

## Question 4.1 [4 marks]

Evaluate:  $\int_1^e \frac{(\log x)^2}{x} dx$

### Solution

**Solution:** Let  $u = \log x$ , then  $du = \frac{1}{x} dx$

When  $x = 1$ :  $u = \log 1 = 0$  When  $x = e$ :  $u = \log e = 1$

$$\begin{aligned} \int_1^e \frac{(\log x)^2}{x} dx &= \int_0^1 u^2 du \\ &= \left[ \frac{u^3}{3} \right]_0^1 = \frac{1^3}{3} - \frac{0^3}{3} = \frac{1}{3} \end{aligned}$$

## Question 4.2 [4 marks]

Evaluate:  $\int_0^{\pi/2} \frac{\sec x}{\sec x + \cos x} dx$

### Solution

**Solution:** Let  $I = \int_0^{\pi/2} \frac{\sec x}{\sec x + \cos x} dx$

First, let's simplify the integrand:

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

So  $I = \int_0^{\pi/2} \frac{1}{1 + \cos^2 x} dx$

Using the substitution  $\tan(x/2) = t$ :  $\cos x = \frac{1-t^2}{1+t^2}$ ,  $dx = \frac{2dt}{1+t^2}$

When  $x = 0$ :  $t = 0$  When  $x = \pi/2$ :  $t = 1$

$$I = \int_0^1 \frac{1}{1 + \left(\frac{1-t^2}{1+t^2}\right)^2} \cdot \frac{2dt}{1+t^2}$$

After simplification (which involves significant algebra), this evaluates to:

$$I = \frac{\pi}{2\sqrt{2}}$$

## Question 4.3 [4 marks]

Solve the differential equation  $\frac{dy}{dx} + \frac{y}{x} = e^x$ ,  $y(0) = 2$ .

**Solution**

**Solution:** This is a first-order linear differential equation of the form  $\frac{dy}{dx} + P(x)y = Q(x)$

Here,  $P(x) = \frac{1}{x}$  and  $Q(x) = e^x$

The integrating factor is:  $\mu(x) = e^{\int P(x)dx} = e^{\int \frac{1}{x}dx} = e^{\log|x|} = |x| = x$  (for  $x > 0$ )

Multiplying the equation by the integrating factor:

$$x \frac{dy}{dx} + y = xe^x$$

The left side is  $\frac{d}{dx}(xy)$ , so:

$$\frac{d}{dx}(xy) = xe^x$$

Integrating both sides:

$$xy = \int xe^x dx$$

Using integration by parts for  $\int xe^x dx$ : Let  $u = x$ ,  $dv = e^x dx$  Then  $du = dx$ ,  $v = e^x$

$$\int xe^x dx = xe^x - \int e^x dx = xe^x - e^x + C = e^x(x - 1) + C$$

Therefore:  $xy = e^x(x - 1) + C$

$$y = \frac{e^x(x - 1) + C}{x}$$

Using the initial condition  $y(0) = 2$ : This presents a problem as the solution is undefined at  $x = 0$ . Let me reconsider the problem.

Actually, let's solve this more carefully. The equation should be valid for  $x \neq 0$ .

If we assume the initial condition is at  $x = 1$  instead (as  $x = 0$  makes the equation singular), and  $y(1) = 2$ :

$$2 = \frac{e^1(1 - 1) + C}{1} = \frac{0 + C}{1} = C$$

So  $C = 2$ , and the solution is:

$$y = \frac{e^x(x - 1) + 2}{x}$$

**Question 5(a) [6 marks]**

Attempt any two

**Question 5.1 [3 marks]**

Find the conjugate complex number and modulus of  $\frac{3+7i}{1-i}$ .

**Solution**

**Solution:** First, let's simplify  $\frac{3+7i}{1-i}$ :

$$\begin{aligned} \frac{3+7i}{1-i} &= \frac{(3+7i)(1+i)}{(1-i)(1+i)} = \frac{3+3i+7i+7i^2}{1-i^2} \\ &= \frac{3+10i-7}{1+1} = \frac{-4+10i}{2} = -2+5i \end{aligned}$$

**Conjugate:** The conjugate of  $-2+5i$  is  $-2-5i$

**Modulus:**  $|-2+5i| = \sqrt{(-2)^2 + (5)^2} = \sqrt{4+25} = \sqrt{29}$

## Question 5.2 [3 marks]

Find the square root of complex number  $3 - 4i$ .

### Solution

**Solution:** Let  $\sqrt{3 - 4i} = a + bi$  where  $a, b \in \mathbb{R}$

Then  $(a + bi)^2 = 3 - 4i$

$$a^2 + 2abi + (bi)^2 = 3 - 4i$$

$$a^2 - b^2 + 2abi = 3 - 4i$$

Comparing real and imaginary parts:  $a^2 - b^2 = 3 \dots (1)$   $2ab = -4 \dots (2)$

From equation (2):  $b = -\frac{2}{a}$

Substituting in equation (1):

$$a^2 - \left(-\frac{2}{a}\right)^2 = 3$$

$$a^2 - \frac{4}{a^2} = 3$$

$$a^4 - 3a^2 - 4 = 0$$

Let  $u = a^2$ :  $u^2 - 3u - 4 = 0$

$$(u - 4)(u + 1) = 0$$

So  $u = 4$  or  $u = -1$

Since  $u = a^2 \geq 0$ , we have  $u = 4$ , so  $a^2 = 4$

Therefore  $a = \pm 2$

If  $a = 2$ :  $b = -\frac{2}{2} = -1$  If  $a = -2$ :  $b = -\frac{2}{-2} = 1$

The two square roots are:  $2 - i$  and  $-2 + i$

## Question 5.3 [3 marks]

Find  $\frac{dy}{dx}$  for  $y = (\sin x)^{\tan x}$

### Solution

**Solution:** Taking logarithm of both sides:

$$\log y = \tan x \log(\sin x)$$

Differentiating both sides with respect to  $x$ :

$$\frac{1}{y} \frac{dy}{dx} = \frac{d}{dx} [\tan x \log(\sin x)]$$

Using product rule on the right side:

$$\frac{1}{y} \frac{dy}{dx} = \sec^2 x \log(\sin x) + \tan x \cdot \frac{\cos x}{\sin x}$$

$$\frac{1}{y} \frac{dy}{dx} = \sec^2 x \log(\sin x) + \tan x \cdot \cot x$$

$$\frac{1}{y} \frac{dy}{dx} = \sec^2 x \log(\sin x) + 1$$

Therefore:

$$\frac{dy}{dx} = y [\sec^2 x \log(\sin x) + 1]$$

$$\frac{dy}{dx} = (\sin x)^{\tan x} [\sec^2 x \log(\sin x) + 1]$$

## Question 5(b) [8 marks]

Attempt any two

### Question 5.1 [4 marks]

Find solution of the differential equation  $\tan y \, dx + \tan x \sec^2 y \, dy = 0$ .

#### Solution

**Solution:** The given equation is:  $\tan y \, dx + \tan x \sec^2 y \, dy = 0$

Rearranging:  $\tan y \, dx = -\tan x \sec^2 y \, dy$

$$\frac{\tan y}{\sec^2 y} dy = -\tan x \, dx$$

$$\frac{\sin y / \cos y}{1 / \cos^2 y} dy = -\tan x \, dx$$

$$\frac{\sin y}{\cos y} \cdot \cos^2 y \, dy = -\tan x \, dx$$

$$\sin y \cos y \, dy = -\tan x \, dx$$

Integrating both sides:

$$\int \sin y \cos y \, dy = -\int \tan x \, dx$$

For the left side, let  $u = \sin y$ , then  $du = \cos y \, dy$ :  $\int \sin y \cos y \, dy = \int u \, du = \frac{u^2}{2} = \frac{\sin^2 y}{2}$

For the right side:  $-\int \tan x \, dx = -\int \frac{\sin x}{\cos x} \, dx = \log |\cos x| + C_1$

Therefore:

$$\frac{\sin^2 y}{2} = \log |\cos x| + C$$

$$\sin^2 y = 2 \log |\cos x| + K \quad (\text{where } K = 2C)$$

### Question 5.2 [4 marks]

If  $A = \begin{bmatrix} 3 & -1 & 2 \\ 4 & 1 & -1 \\ 5 & 0 & 1 \end{bmatrix}$  then find  $A^{-1}$ .

#### Solution

**Solution:** To find  $A^{-1}$ , we use the formula  $A^{-1} = \frac{1}{|A|} \text{adj}(A)$

First, let's find  $|A|$ :

$$\begin{aligned} |A| &= 3 \begin{vmatrix} 1 & -1 \\ 0 & 1 \end{vmatrix} - (-1) \begin{vmatrix} 4 & -1 \\ 5 & 1 \end{vmatrix} + 2 \begin{vmatrix} 4 & 1 \\ 5 & 0 \end{vmatrix} \\ &= 3(1 \cdot 1 - (-1) \cdot 0) + 1(4 \cdot 1 - (-1) \cdot 5) + 2(4 \cdot 0 - 1 \cdot 5) \\ &= 3(1) + 1(4 + 5) + 2(0 - 5) = 3 + 9 - 10 = 2 \end{aligned}$$

$$\begin{aligned} \text{Now we find the cofactor matrix: } C_{11} &= + \begin{vmatrix} 1 & -1 \\ 0 & 1 \end{vmatrix} = 1 \quad C_{12} = - \begin{vmatrix} 4 & -1 \\ 5 & 1 \end{vmatrix} = -(4 - (-5)) = -9 \quad C_{13} = + \begin{vmatrix} 4 & 1 \\ 5 & 0 \end{vmatrix} = \\ 0 - 5 &= -5 \quad C_{21} = - \begin{vmatrix} -1 & 2 \\ 0 & 1 \end{vmatrix} = -(-1 - 0) = 1 \quad C_{22} = + \begin{vmatrix} 3 & 2 \\ 5 & 1 \end{vmatrix} = 3 - 10 = -7 \quad C_{23} = - \begin{vmatrix} 3 & -1 \\ 5 & 0 \end{vmatrix} = -(0 - (-5)) = -5 \end{aligned}$$

$$C_{31} = + \begin{vmatrix} -1 & 2 \\ 1 & -1 \end{vmatrix} = 1 - 2 = -1 \quad C_{32} = - \begin{vmatrix} 3 & 2 \\ 4 & -1 \end{vmatrix} = -(-3 - 8) = 11 \quad C_{33} = + \begin{vmatrix} 3 & -1 \\ 4 & 1 \end{vmatrix} = 3 - (-4) = 7$$

The cofactor matrix is:  $C = \begin{bmatrix} 1 & -9 & -5 \\ 1 & -7 & -5 \\ -1 & 11 & 7 \end{bmatrix}$

The adjugate is the transpose of the cofactor matrix:

$$\text{adj}(A) = \begin{bmatrix} 1 & 1 & -1 \\ -9 & -7 & 11 \\ -5 & -5 & 7 \end{bmatrix}$$

Therefore:

$$A^{-1} = \frac{1}{2} \begin{bmatrix} 1 & 1 & -1 \\ -9 & -7 & 11 \\ -5 & -5 & 7 \end{bmatrix} = \begin{bmatrix} 1/2 & 1/2 & -1/2 \\ -9/2 & -7/2 & 11/2 \\ -5/2 & -5/2 & 7/2 \end{bmatrix}$$

### Question 5.3 [4 marks]

$x = a(\theta - \sin \theta)$ ,  $y = a(1 - \cos \theta)$  then find  $\frac{dy}{dx}$ .

#### Solution

**Solution:** These are parametric equations. To find  $\frac{dy}{dx}$ , we use:

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

First, let's find  $\frac{dx}{d\theta}$ :  $x = a(\theta - \sin \theta)$   $\frac{dx}{d\theta} = a(1 - \cos \theta)$

Next, let's find  $\frac{dy}{d\theta}$ :  $y = a(1 - \cos \theta)$   $\frac{dy}{d\theta} = a \sin \theta$

Therefore:

$$\frac{dy}{dx} = \frac{a \sin \theta}{a(1 - \cos \theta)} = \frac{\sin \theta}{1 - \cos \theta}$$

Using the identity  $1 - \cos \theta = 2 \sin^2(\theta/2)$  and  $\sin \theta = 2 \sin(\theta/2) \cos(\theta/2)$ :

$$\frac{dy}{dx} = \frac{2 \sin(\theta/2) \cos(\theta/2)}{2 \sin^2(\theta/2)} = \frac{\cos(\theta/2)}{\sin(\theta/2)} = \cot(\theta/2)$$