

## Module 4 :

→ Principles of counting - II

- Principle of Inclusion and Exclusion .
- Derangements .
- Rook polynomials .

→ Recurrence Relations

- first order linear Recurrence Relation .
- Second order linear Homogeneous Recurrence rel<sup>n</sup> with constant coefficient

## Principles of Counting - II

①

- Recall :-
- 1)  $|A \cup B| = |A| + |B| - |A \cap B|$
  - 2)  $|\bar{A}| = |S| - |A|$ , S is the universal set.
  - 2)  $\bar{A} \cap \bar{B} = \overline{A \cup B}$ , and  $|\bar{A \cup B}| = |S| - |A \cup B|$
  - 3)  $|\bar{A} \cap \bar{B}| = |\bar{A \cup B}| = |S| - |A \cup B|$
  - $|\bar{A \cup B}| = |S| - |A| - |B| + |A \cap B| \rightarrow ①$

Eqn ① is called the addition principle (or) Principle of inclusion - exclusion for 2 sets.

Principle of Inclusion - Exclusion for 'n' sets :-

Let S be a finite set &  $A_1, A_2, \dots, A_n$  be subsets of S,

then

$$|\bar{A_1 \cup A_2 \cup \dots \cup A_n}| = |S| - \sum_{i=1}^n |A_i| + \sum_{i < j} |A_i \cap A_j| - \sum_{i < j < k} |A_i \cap A_j \cap A_k| \\ + \dots + (-1)^{n-1} |A_1 \cap A_2 \cap \dots \cap A_n| \rightarrow ②$$

Note :-

2) The no. of elements in S that satisfy exactly 'm' of the given 'n' condns ( $0 \leq m \leq n$ ) is given by

$$E_m = s_m - \binom{m+1}{1} s_{m+1} + \binom{m+2}{2} s_{m+2} - \dots + (-1)^{n-m} \binom{n}{n-m} s_n$$

3) The no. of elements in S that satisfy atleast 'm' of

the 'n' condns ( $1 \leq m \leq n$ ) is given by

$$I_m = s_m - \binom{m}{m-1} s_{m+1} + \binom{m+1}{m-1} s_{m+2} - \dots + (-1)^{n-m} \binom{n-1}{m-1} s_n$$

1) Let  $s_0 = |S|$ ,  $s_1 = \sum |A_i|$ ,

$$s_2 = \sum |A_i \cap A_j|, \quad s_3 = \sum |A_i \cap A_j \cap A_k|$$

$\dots \quad s_n = |A_1 \cap A_2 \cap \dots \cap A_n|$ , then ② becomes.

$$|\bar{A_1 \cup A_2 \cup \dots \cup A_n}| = s_0 - s_1 + s_2 - \dots + (-1)^n s_n$$

### Problems :-

1) Among the students in a hostel, 12 students study mathematics & (A), 20 study physics (B), 20 study chemistry (C) & 8 study biology (D). There are 5 students for A & B, 16 for B & C, 4 for A & D, 4 for B & D, 3 for C & D, ~~3 for A, B & C~~. There are 3 students for A, B & C, 2 for A, B & D, 2 for B, C & D, 3 for A, C & D. Finally there are 2 who study all three subjects. Further, there are 71 students who do not study any of these subjects. Find the total no. of students in the hostel.

Soln:- by data,  $|A| = 12$ ,  $|B| = 20$ ,  $|C| = 20$ ,  $|D| = 8$ .

$$|A \cap B| = 5, |A \cap C| = 7, |A \cap D| = 4, |B \cap C| = 16, |B \cap D| = 4$$

$$|C \cap D| = 3, |A \cap B \cap C| = 3, |A \cap B \cap D| = 2, |B \cap C \cap D| = 2$$

$$|A \cap C \cap D| = 3, |A \cap B \cap C \cap D| = 2,$$

$$|\bar{A} \cap \bar{B} \cap \bar{C} \cap \bar{D}| = 71.$$

To find  $|S|$ , where  $S$  is the set of all students in the hostel.

we have

$$\begin{aligned} |\bar{A} \cap \bar{B} \cap \bar{C} \cap \bar{D}| &= |\overline{A \cup B \cup C \cup D}| \\ &= |S| - |A \cup B \cup C \cup D| \\ &= |S| - [(|A| + |B| + |C| + |D|) + \end{aligned}$$

$$[(A \cap B) + (A \cap C) + (A \cap D) + (B \cap C) + (B \cap D) + (C \cap D)]]$$

$$\begin{aligned} &- [(A \cap B \cap C) + (A \cap B \cap D) + (B \cap C \cap D) + (A \cap C \cap D)] \\ &+ |A \cap B \cap C \cap D| \end{aligned}$$

$$\Rightarrow 71 = |S| - [12 + 20 + 20 + 8] + [5 + 7 + 4 + 16 + 4 + 3] - [3 + 2 + 2 + 3] + 2$$

$$\Rightarrow |S| = 100 \Rightarrow \text{total no. of students in the hostel is } 100.$$

2) In the above example, among all the subjects find how many study (i) exactly one subject (ii) exactly 2 subjects (iii) exactly 3 subjects (iv) atleast 1 subject (v) atleast 2 subjects (vi) atleast 3 subjects.

Soln:- WKT

$$E_m = s_m - \binom{m+1}{1} s_{m+1} + \binom{m+2}{2} s_{m+2} - \dots + (-1)^{n-m} \binom{n}{n-m} s_n \rightarrow (1)$$

$s_m$  is the no. of students studying exactly 'm' subjects out of 'n'.

$$L_m = s_m - \binom{m}{m-1} s_{m+1} + \binom{m+1}{m-1} s_{m+2} - \dots + (-1)^{n-m} \binom{n-1}{m-1} s_n \rightarrow (2)$$

$s_m$  is the no. of students studying atleast 'm' subjects out of 'n'.

$$\text{we have } s_0 = |S| = 100. \quad s_1 = |A| + |B| + |C| + |D| = 60.$$

$$s_2 = |A \cap B| + |B \cap C| + |C \cap D| + |A \cap D| + |B \cap D| + |A \cap C| = 39$$

$$s_3 = |A \cap B \cap C| + |A \cap B \cap D| + |A \cap C \cap D| + |B \cap C \cap D| = 10.$$

$$s_4 = |A \cap B \cap C \cap D| = 2.$$

$$(i) E_1 = s_1 - \binom{2}{1} s_2 + \binom{3}{2} s_3 - \binom{4}{3} s_4 = 60 - 2 \times 39 + 3 \times 10 - 4 \times 2$$

$$E_1 = 4$$

$$(ii) E_2 = s_2 - \binom{3}{1} s_3 + \binom{4}{2} s_4 = 39 - 3 \times 10 + 6 \times 2 = 21$$

$$(iii) E_3 = s_3 - \binom{4}{1} s_4 = 10 - 4 \times 2 = 2.$$

$$(iv) L_1 = s_1 - \binom{1}{0} s_2 + \binom{2}{0} s_3 - \binom{3}{0} s_4 = 60 - 39 + 10 - 2 = 29$$

$$(v) L_2 = s_2 - \binom{2}{1} s_3 + \binom{3}{1} s_4 = 39 - 2 \times 10 + 3 \times 2 = 25$$

$$(vi) L_3 = s_3 - \binom{3}{2} s_4 = 10 - 3 \times 2 = 4.$$

3) Out of 30 students in a hostel, 15 study History, 8 study Economics, 6 study Geography. It is known that 3 students study all these subjects. Show that there are 7 or more students who study none of the subjects.

Soln :-  $1st = \frac{\text{no}}{\text{of students in the hostel}} = 30$

Let A, B, C represent students studying history, economics

Geography resp. Then

$$|A| = 15, |B| = 8, |C| = 6, |A \cap B \cap C| = 3$$

$$\text{we have } |\bar{A} \cap \bar{B} \cap \bar{C}| = |S| - [|A| + |B| + |C|] + [|A \cap B| + |B \cap C| + |A \cap C|] - |A \cap B \cap C|$$

$$\Rightarrow |\overline{A \cap B} \cap \overline{C}| = 30 - (15+8+6) + (|A \cap B| + |B \cap C| + |A \cap C|) - 3 \\ = |A \cap B| + |B \cap C| + |A \cap C| - 2.$$

$$\text{wkt } |AnB| \geq |AnBnC|, |BnC| \geq |AnBnC|,$$

$|\text{ANCl}| > |\text{ANBnCl}|$

$$\therefore |\overline{A} \cap \overline{B} \cap \overline{C}| \geq 3 |A \cap B \cap C| - 2 = 3 \times 3 - 2 = 7$$

4) Determine the no. of positive integers ' $n$ ',  $1 \leq n \leq 100$ , such that  
    (i)  $n$  is not divisible by 2, 3 or 5.  
    (ii)  $n$  is divisible by at least two of 2, 3 or 5.  
    (iii)  $\nwarrow$   $n$  is divisible by exactly two of 2, 3 or 5.

Solo :-

$$S = \{1, 2, 3, \dots, 100\} \quad \therefore |S| = 100 \quad \therefore S_0 = 100$$

Let A = set of no's divisible by 2

Let A - set of no's 3

$$c = " \underline{\hspace{2cm}} " \quad \underline{\hspace{2cm}} "$$

(i) To find  $|A \cap B \cap C|$  i.e.  $|\overline{A \cup B \cup C}|$

$\therefore |A| = \text{no of elements in } S \text{ that are divisible by 2}$

$$\text{i.e. } |A| = \left\lfloor \frac{100}{2} \right\rfloor = 50$$

$$\text{iii) } |B| = \left\lfloor \frac{100}{3} \right\rfloor = \left\lfloor 33.33 \right\rfloor = 33$$

$$|c| = \left\lfloor \frac{100}{5} \right\rfloor = 20$$

$$\therefore S_1 = |A| + |B| + |C| = 50 + 33 + 20 = 103$$

$|A \cap B| = \frac{\text{no. of elements in } S \text{ divisible by both 2 & 3}}{(\text{i.e. LCM} = 6)}$  ③

$$|A \cap B| = \left\lfloor \frac{100}{6} \right\rfloor = \lfloor 16.66 \rfloor = 16.$$

$$|A \cap C| = \left\lfloor \frac{100}{10} \right\rfloor = 10.$$

$$|B \cap C| = \left\lfloor \frac{100}{15} \right\rfloor = 6. \quad \therefore s_2 = 16 + 10 + 6 = 32.$$

$$|A \cap B \cap C| = \frac{\text{no. of elements in } S \text{ divisible by all 2, 3, 5}}{(\text{i.e. LCM} = 30)} = \left\lfloor \frac{100}{30} \right\rfloor = 3. \quad \therefore s_3 = 3$$

∴  $|\bar{A} \cap \bar{B} \cap \bar{C}| = 100 - (|A| + |B| + |C|) + (|A \cap B| + |B \cap C| + |A \cap C|)$

$\downarrow$   
write alternate

$$= 100 - (50 + 33 + 20) + (16 + 10 + 6) - 3$$

$$= 26.$$

∴ No. of integers  $1 \leq n \leq 100$ , not divisible by ~~any~~ 2, 3 or 5  
is 26.

$$(ii) L_m = s_m - \binom{m}{m-1} s_{m+1} + \binom{m+1}{m-1} s_{m+2} - \dots + (-1)^{n-m} \binom{n-1}{m-1} s_n$$

$$\begin{aligned} \therefore L_2 &= s_2 - \binom{2}{1} s_3 \\ &= |A \cap B| + |B \cap C| + |A \cap C| - 2 \times |A \cap B \cap C| \\ &= 16 + 10 + 6 - 2 \times 3 \\ &= 26. \end{aligned}$$

$$(iii) E_m = s_m - \binom{m+1}{1} s_{m+1} + \binom{m+2}{2} s_{m+2} - \dots + (-1)^{n-m} \binom{n}{n-m} s_n$$

$$\begin{aligned} \therefore E_2 &= s_2 - \binom{3}{1} s_3 + \binom{4}{2} \\ &= |A \cap B| + |B \cap C| + |A \cap C| - 3 \times 3 \\ &= 16 + 10 + 6 - 9 \\ &= 23 \end{aligned}$$

- 5) How many integers b/w 1 & 300 (inclusive) are divisible by atleast one of 5, 6, 8?
- divisible by none of 5, 6, 8?
  - divisible by exactly two of 5, 6, 8
  - divisible by atleast two of 5, 6, 8
- Soln:-  $|S| = 300$ .
- let A, B, C be the no. of integers divisible by 5, 6, 8 resp.
- then  $|A| = \left\lfloor \frac{300}{5} \right\rfloor = 60$ ,  $|B| = \left\lfloor \frac{300}{6} \right\rfloor = 50$ ,  $|C| = \left\lfloor \frac{300}{8} \right\rfloor = 37$
- $|A \cap B| = \left\lfloor \frac{300}{30} \right\rfloor = 10$
- ,
- $|B \cap C| = \left\lfloor \frac{300}{24} \right\rfloor = 12$
- .
- $|A \cap C| = \left\lfloor \frac{300}{40} \right\rfloor = 7$
- ,
- $|A \cap B \cap C| = \left\lfloor \frac{300}{120} \right\rfloor = 2$
- .

$$\therefore S_1 = |A| + |B| + |C| = 145$$

$$S_2 = |A \cap B| + |B \cap C| + |A \cap C| = 29.$$

$$S_3 = |A \cap B \cap C| = 2.$$

(i) No. of integers b/w 1 & 300 divisible by atleast one of 5, 6, 8 is  $L_1 = S_1 - \binom{1}{0} S_2 + \binom{2}{0} S_3 = 145 - 29 + 2 = 128$  ①

(ii) No. of integers divisible by none of 5, 6, 8 is

$$|\overline{A} \cap \overline{B} \cap \overline{C}| = |S| - S_1 + S_2 - S_3 = 300 - 145 + 29 - 2 = 180$$

(iii) No. of integers divisible by exactly two of 5, 6, 8 is

$$E_2 = S_2 - \binom{3}{1} S_3 = 29 - 3 \times 2 = 23$$

(iv) No. of integers divisible by atleast two of 5, 6, 8 is

$$L_2 = S_2 - \binom{2}{1} S_3 = 29 - 2 \times 2 = 25.$$

6) In how many ways 5 no. of a's, 4 no. of b's & 3 no. of c's can be arranged so that all identical letters are not in a single block?

Soln:- Altogether there are 12 letters, in which 5 are a's, 4 are b's, 3 are c's.

Let  $S$  be the set of all arrangements of the 12 letters.

(4)

$$\therefore |S| = \frac{12!}{5!4!3!} = 27,720.$$

Let  $A_1$  be the set of all arrangements in which all 5 a's are in a single block.

aaaaaa bbbb ccc  
1x

$$\text{i.e. } |A_1| = \frac{8!}{4!3!1!} = 280.$$

iii)  $|A_2| = \underline{\text{no.}}$  of ways of arranging in which all 4 b's are together.

$$\text{i.e. } |A_2| = \frac{9!}{5!1!3!} = 504$$

$|A_3| = \underline{\text{no.}}$  of ways of arranging in which all 3 c's are together.

$$\text{i.e. } |A_3| = \frac{10!}{5!4!1!} = 1260.$$

Also  $|A_1 \cap A_2| = \underline{\text{no.}}$  of ways of arranging in which all 5 a's & all 4 b's are together.

aaaaaa bbbb ccc  
1x 1y 1z

$$\text{i.e. } |A_1 \cap A_2| = \frac{5!}{1!1!3!} = 20$$

aaaaaa bbbb ccc  
1x 1y 1z

$$\text{iii) } |A_2 \cap A_3| = \frac{7!}{5!1!1!} = 42$$

aaaaaa bbbb ccc  
1x 1y 1z

$$|A_1 \cap A_3| = \frac{6!}{1!4!1!} = 30$$

aaaaaa bbbb ccc  
1x 1y 1z

$$\text{and } |A_1 \cap A_2 \cap A_3| = 3! = 6.$$

$$\begin{aligned}\therefore |\overline{A_1} \cap \overline{A_2} \cap \overline{A_3}| &= |S| - [|A_1| + |A_2| + |A_3|] + [|A_1 \cap A_2| + |A_2 \cap A_3| \\ &\quad + |A_1 \cap A_3|] - |A_1 \cap A_2 \cap A_3| \\ &= 27,720 - [280 + 504 + 1260] + [20 + 42 + 30] - 6 \\ &= 25,762\end{aligned}$$

=====

Do 6<sup>th</sup>, then 7<sup>th</sup>.

7) Find the no. of permutations of letters a, b, c...  $\in \{1, 2\}$  in which none of the patterns spin, game, path or net occurs.

$$\text{Soln: } |S| = 26!$$

$|A_1| = \text{no. of permutations containing the pattern 'spin'}$

$$= (26-4+1)! = 23!$$

pattern 'spin'  
 SPIN ~~22~~ ~~26~~ 4 letters in  
 TX ~~spin - 22~~  
~~22+1X - 23~~

$|A_2| = \text{no. of permutations containing the pattern 'game'}$

$$= (26-4+1)! = 23!$$

$$\text{iii) } |A_3| = 23!$$

$$|A_4| = (26-3+1)! = 24!$$

$$\therefore |A_1 \cap A_2| = ((26-8)+2)! = 20!$$

$|A_1 \cap A_3| = 0$  ( $\because$  no pattern can contain spin & path) — P repeated & cannot be made a pattern since in word spin, P is not at end.

$$|A_1 \cap A_4| = ((26-6)+1)! = 21!$$

$$|A_2 \cap A_3| = 0, |A_2 \cap A_4| = 0, |A_3 \cap A_4| = 0$$

$$|A_1 \cap A_2 \cap A_3| = 0, |A_2 \cap A_3 \cap A_4| = 0, |A_1 \cap A_3 \cap A_4| = 0$$

$$|A_1 \cap A_2 \cap A_4| = 0$$

$$|A_1 \cap A_2 \cap A_3 \cap A_4| = 0.$$

$$\therefore \text{Req. no.} = |\overline{A_1 \cup A_2 \cup A_3 \cup A_4}| = |\overline{A_1} \cap \overline{A_2} \cap \overline{A_3} \cap \overline{A_4}|$$

$$= |S| - [\sum |A_i|] + [\sum |A_{ij}|] - [\sum |A_{ijk}|]$$

$$+ [\sum |A_1 \cap A_2 \cap A_3 \cap A_4|]$$

$$= 26! - (24! + 3 \times 23!) + (20! + 21!)$$

$$= 4.026 \times 10^{26}$$

- 8) Find the no. of permutations of the digits 1 through 9 in which the blocks a) 23, 57, 468 do not appear.  
 b) 36, 78, 672 do not appear.

Sol. a)  $|S| = \text{no. of permutations of the digits 1 to 9}$

$$|S| = 9!$$

$|A_1| = \text{no. of permutations of 1 to 9 such that 23 is (present) contained in it}$

$$\frac{23}{1x} - \frac{7}{7} \quad 1+7=8$$

$$= (\cancel{2} \cancel{3} \cancel{1} \cancel{4} \cancel{5} \cancel{6} \cancel{7} \cancel{8})! = 8!$$

$$|A_2| = (\cancel{1} \cancel{2} \cancel{3} \cancel{4} \cancel{5} \cancel{6} \cancel{7} \cancel{8})! = 8!$$

$$|A_3| = (\cancel{2} \cancel{3} \cancel{4} \cancel{5} \cancel{6} \cancel{7})! = 7!$$

$$\frac{23}{1x}, \frac{57}{1y}$$

$$|A_1 \cap A_2| = (\cancel{2} \cancel{3} \cancel{4} \cancel{5})! = 5!$$

$$|A_1 \cap A_3| = (\cancel{2} \cancel{3} \cancel{5})! = 6!$$

$$|A_2 \cap A_3| = (\cancel{2} \cancel{3} \cancel{5})! = 6!$$

$$\frac{23}{1x}, \frac{57}{1y}, \frac{468}{1z}$$

$$|A_1 \cap A_2 \cap A_3| = (\cancel{2} \cancel{3} \cancel{5})! = 5!$$

$$\therefore \text{Req. No.} = |\bar{A}_1 \cap \bar{A}_2 \cap \bar{A}_3|$$

$$= |S| - [\sum |A_i|] + [\sum |A_i \cap A_j|] - [\sum |A_i \cap A_j \cap A_k|]$$

$$= 9! - (8! + 8! + 7!) + (7! + 6! + 6!) - 5!$$

$$= \underline{\underline{2,82,560}}$$

b)  $|S| = 9!$

$|A_1| = \text{no. of permutations such that 36 is present in that}$

$$\frac{36}{1x} - \frac{7}{7}$$

$$= (\cancel{1} \cancel{2} \cancel{3} \cancel{4} \cancel{5} \cancel{6})! = 8!$$

$$|A_2| = (\cancel{1} \cancel{2} \cancel{3} \cancel{4})! = 8!$$

$$|A_3| = (\cancel{1} \cancel{2} \cancel{3} \cancel{5})! = 7!$$

$$\frac{36}{1x}, \frac{78}{1y} - \frac{5}{5}$$

$$|A_1 \cap A_2| = (\cancel{1} \cancel{2} \cancel{3} \cancel{4} \cancel{5})! = 7!$$

$$\frac{36}{1x}, \frac{672}{1x} -$$

$$|A_1 \cap A_3| = (\cancel{1} \cancel{2} \cancel{3} \cancel{4} \cancel{6})! = 6!$$

$$\frac{3672}{1x}, \frac{78}{5} -$$

$$|A_2 \cap A_3| = 0.$$

and  $|A_1 \cap A_2 \cap A_3| = 0.$

$$\text{Thus Req. No.} = |\bar{A}_1 \cap \bar{A}_2 \cap \bar{A}_3|$$

$$= 9! - (2 \times 8! + 7!) + (\cancel{8!} + 6!)$$

$$= \underline{\underline{2,82,960}}$$

Q) In how many ways can 26 letters of English alphabet be permuted so that (i) none of the patterns CAR, DOG, PUN or BYTE occurs (ii) a) exactly 2 b) exactly 3 c) atleast 3 of patterns CAR, DOG, PUN & BYTE occurs.

$$\text{Soln: } |S| = 26!$$

Let  $A_1, A_2, A_3, A_4$  be sets of permutations containing the patterns CAR, DOG, PUN, BYTE alone resp.

$$|A_1| = \cancel{(26-3+2)!} = 24!$$

$$\begin{array}{rcl} \cancel{\text{CAR}} \\ \cancel{\text{IX}} \end{array} \quad \frac{23!}{23+1=24}$$

$$|A_2| = 24!$$

$$|A_3| = 24!$$

$$|A_4| = \cancel{(26-4+1)!} = 23!$$

$$\begin{array}{rcl} \cancel{\text{CAR}}, \cancel{\text{DOG}} \\ \cancel{\text{IX}} \quad \cancel{\text{IY}} \end{array} \quad \frac{20!}{20}$$

$$|A_1 \cap A_2| = \cancel{(26-6+2)!} = 22!$$

$$|A_1 \cap A_3| = \cancel{(26-6+2)!} = 22!$$

$$|A_1 \cap A_4| = \cancel{(26-7+2)!} = 21!$$

$$|A_2 \cap A_3| = \cancel{(26-6+2)!} = 22!$$

$$|A_2 \cap A_4| = \cancel{(26-7+2)!} = 21!$$

$$|A_3 \cap A_4| = \cancel{(26-7+2)!} = 21!$$

$$|A_1 \cap A_2 \cap A_3| = \cancel{(26-9+3)!} = 20!$$

$$\begin{array}{rcl} \cancel{\text{CAR}}, \cancel{\text{DOG}}, \cancel{\text{PUN}} \\ \cancel{\text{IX}} \quad \cancel{\text{IY}} \quad \cancel{\text{IZ}} \end{array} \quad \frac{17!}{17}$$

$$|A_1 \cap A_2 \cap A_4| = \cancel{(26-10+3)!} = 19!$$

$$|A_1 \cap A_3 \cap A_4| = \cancel{(26-10+3)!} = 19!$$

$$|A_2 \cap A_3 \cap A_4| = \cancel{(26-10+3)!} = 19!$$

$$\& |A_1 \cap A_2 \cap A_3 \cap A_4| = \cancel{(26-13+4)!} = 17!$$

$$(i) \text{ Reg. no.} = |A_1 \cup A_2 \cup A_3 \cup A_4| = |A_1 \cap A_2 \cap A_3 \cap A_4|$$

$$= 26! - (3 \times 24! + 23!) + (3 \times 22! + 3 \times 21!) - (20! + 3 \times 19!) + 17!$$

$$= 4.014 \times 10^{26}$$

$$(ii) E_m = s_m - \binom{m+1}{1} s_{m+1} + \binom{m+2}{2} s_{m+2} - \dots$$

$$E_2 = s_2 - \binom{3}{1} s_3 + \binom{4}{2} s_4$$

$$= (3 \times 22!) + 3 \times 21! - 3 \times (20! + 3 \times 19!) + 6 \times 17!$$

$$= 3.517 \times 10^{21}$$

$$(iv) E_3 = S_3 - \binom{4}{1} S_4 = (20! + 3 \times 19!) - 4 \times 19! \\ = \underline{\underline{2.796 \times 10^{18}}}$$

$$(iv) L_m = S_m - \binom{m}{m-1} S_{m+1} + \binom{m+1}{m-1} S_{m+2} + \dots$$

$$L_3 = S_3 - \binom{3}{2} S_4 = 3 \times 19! + 20! = 8 \times 19! \\ = \underline{\underline{2.797 \times 10^{18}}}$$

10) In how many ways one can arrange the letters in the word  
 DO CORRESPONDENTS so that

- (i) there is no pair of consecutive identical letters.
- (ii) there are exactly 2 pairs of consecutive identical letters.
- (iii) there are atleast 3 " "

Soln:-  $|S| = \frac{14!}{2! 2! 2! 2! 2!}$   $\because$  given word has 1 C, 2 O's, 2 R's, 2 E's, 2 S's, 1 P, 2 N's, 1 D, 1 T

Let  $A_1, A_2, A_3, A_4, A_5$  be the sets of permutations in a word which contains 2 consecutive O's, R's, E's, S's, N's. Then  $\frac{12!}{(2!)^5}$

$$|A_1| = \frac{13!}{(2!)^4} = |A_2| = |A_3| = |A_4| = |A_5|.$$

$$|A_i \cap A_j| = \frac{12!}{(2!)^3}$$

$$|A_i \cap A_j \cap A_k| = \frac{11!}{(2!)^2}$$

$$|A_i \cap A_j \cap A_k \cap A_l| = \frac{10!}{(2!)^1}$$

$$|A_i \cap A_j \cap A_k \cap A_l \cap A_m| = \frac{9!}{(1!)^1} = 9!$$

$$\therefore S_0 = |S| = \frac{14!}{(2!)^5},$$

$$S_1 = 5C_1 \times \frac{13!}{(2!)^4}, \quad S_2 = 5C_2 \times \frac{12!}{(2!)^3},$$

$$S_3 = 5C_3 \times \frac{11!}{(2!)^2}, \quad S_4 = 5C_4 \times \frac{10!}{(2!)^1}, \quad S_5 = 5C_5 \times 9!$$

$$(i) |\bar{A}_1 \cup A_2 \cup A_3 \cup A_4 \cup A_5| = |\bar{A}_1 \cap \bar{A}_2 \cap \bar{A}_3 \cap \bar{A}_4 \cap \bar{A}_5|$$

$$= 18! - s_1 + s_2 - s_3 + s_4 - s_5$$

$$= \frac{14!}{(2!)^5} - \frac{5 \times 13!}{(2!)^4} + \frac{10 \times 12!}{(2!)^3} - \frac{10 \times 11!}{(2!)^2} + \frac{5 \times 10!}{2!} - 9!$$

$$= 1,28,60,46,720$$

=

$$(ii) E_2 = s_2 - \binom{3}{1}s_3 + \binom{4}{2}s_4 - \binom{5}{3}s_5$$

$$= 10 \times \frac{12!}{(2!)^3} - 3 \times \frac{10 \times 11!}{(2!)^2} + 6 \times \frac{5 \times 10!}{2!} - 10 \times 9!$$

$$= 35,01,79,200$$

$$(iii) L_2 = s_3 - \binom{3}{2}s_4 + \binom{4}{2}s_5$$

$$= 10 \times \frac{11!}{(2!)^2} - 3 \times 5 \times \frac{10!}{2!} + 6 \times 9!$$

$$= 7,475,3280$$

# VTUPulse.com

- 10 integers 1, 2, 3, ..., 10 be arranged in a line so that no even integer is in its natural place.
- Sols-  $S = \{1, 2, \dots, 10\} \Rightarrow |S| = 10! \quad (\because \text{permutations})$
- Let  $A_1$  be the set of all permutations of the given integers, where 2 is in its natural place.
- $A_2$  be the set of all permutations in which 4 is in its natural place

4 so on.

To find  $|\bar{A}_1 \cap \bar{A}_2 \cap \bar{A}_3 \cap \bar{A}_4 \cap \bar{A}_5|$

The permutations in  $A_1$  are all of the form  $b_1 b_2 b_3 b_4 \dots b_{10}$ , where  $b_1 b_3 b_4 \dots b_{10}$  is a permutation of 1, 3, 4, 5, ..., 10

$\therefore \text{Q} \rightarrow$

$$\therefore |A_1| = 9!$$

$$\text{why } |A_2| = |A_3| = |A_4| = |A_5| = 9!$$

$$\therefore s_1 = \sum |A_i| = 5 \times 9! \text{ (or) } 5C_1 \times 9!$$

~~X~~ {The permutations in  $A_1 \cap A_2$  are all of the form  
 $b_1 b_2 b_3 b_4 b_5 b_6 \dots b_{10}$ , where  $b_1, b_2, b_3, b_4, \dots, b_{10}$  is a  
permutation of  $1, 3, 5, 6, \dots, 10$ .} X

$$\therefore |A_1 \cap A_2| = 8!$$

$$② ④ \frac{8}{8}$$

$$\text{Hence } |A_i \cap A_j| = 8! \quad \forall i, j.$$

$$\therefore s_2 = \sum |A_i \cap A_j| = 5C_2 \times 8!$$

$$\text{Hence } s_3 = 5C_3 \times 7!, \quad s_4 = 5C_4 \times 6!, \quad s_5 = 5C_5 \times 5!$$

$$\therefore \text{Req. no.} = |\bar{A}_1 \cap \bar{A}_2 \cap \bar{A}_3 \cap \bar{A}_4 \cap \bar{A}_5|$$

$$= s_0 - s_1 + s_2 - s_3 + s_4 - s_5$$

$$= 10! - 5 \times 9! + 5C_2 \times 8! - 5C_3 \times 7! + 5C_4 \times 6! - 5C_5 \times 5!$$

$$= 21,70,680$$

12) Find the no. of non-negative integer solutions of the eq

~~X~~  $x_1 + x_2 + x_3 + x_4 = 18$  under the cond'  $x_i \leq 7$  for  $i = 1, 2, 3, 4$ .

Soln:- Let  $S$  be the set of non-negative integer solutions of the given eq. The no. of such solutions is  $C(4+18-1, 18) =$

$$|S| = C(21, 18) \Rightarrow \boxed{|S| = 1330}$$

Let  $A_1$  be the subset of  $S$ , that contains non-negative integer solns of the eq under the cond'  $x_1 > 7, x_2 > 0, x_3 > 0, x_4 > 0$ .

$$A_1 = \left\{ (x_1, x_2, x_3, x_4) \in S \mid \begin{matrix} x_1 > 7 \\ x_2 > 0 \end{matrix} \right\}$$

$$\text{Hence } A_2 = \left\{ (x_1, x_2, x_3, x_4) \in S \mid \begin{matrix} x_2 > 7 \\ x_3 > 0 \end{matrix} \right\}$$

$$A_3 = \left\{ (x_1, x_2, x_3, x_4) \in S \mid \begin{matrix} x_3 > 7 \\ x_4 > 0 \end{matrix} \right\}$$

$$A_4 = \left\{ (x_1, x_2, x_3, x_4) \in S \mid \begin{matrix} x_4 > 7 \\ x_1 > 0 \end{matrix} \right\}$$

To find  $|A_1 \cup A_2 \cup A_3 \cup A_4|$  :-

Let  $y_1 = x_1 - 8$ , then  $x_1 \geq 7$  (or)  $x_1 \geq 8 \Rightarrow y_1 \geq 0$ .

$\therefore x_1 + x_2 + x_3 + x_4 = 18$  becomes

$$y_1 + 8 + x_2 + x_3 + x_4 = 18$$

$$\Rightarrow y_1 + x_2 + x_3 + x_4 = 10$$

$\therefore$  No. of non-negative integer solns of this Eqn is

$$c(4+10-1, 10) = c(13, 10) = |A_1|.$$

Why  $|A_2| = |A_3| = |A_4| = c(13, 10)$ .

$$\therefore S_1 = 4c_1 \times |A_1| = 4c_1 \times c(13, 10) \Rightarrow [S_1 = 1144]$$

Let  $y_1 = x_1 - 8$ ,  $y_2 = x_2 - 8$ , then

$$x_1 \geq 7 \Rightarrow y_1 \geq 0 \quad \& \quad x_2 \geq 7 \Rightarrow y_2 \geq 0.$$

$\therefore x_1 + x_2 + x_3 + x_4 = 18$  becomes

$$y_1 + 8 + y_2 + 8 + x_3 + x_4 = 18 \quad (\text{or}) \quad y_1 + y_2 + x_3 + x_4 = 2$$

$\therefore$  No. of non-negative integer solns of this Eqn  $= c(4+2-1, 2)$

$$= c(5, 2) = |A_1 \cap A_2| = |A_2 \cap A_3| = |A_2 \cap A_4| = |A_1 \cap A_3| =$$

$$= |A_1 \cap A_4| = |A_3 \cap A_4|$$

$$\therefore S_2 = 4c_2 \times |A_1 \cap A_2| = 6 \times c(5, 2) \Rightarrow [S_2 = 60]$$

$|A_1 \cap A_2 \cap A_3| = \text{no. of non-negative integer solns of the Eqn with } x_1 \geq 7, x_2 \geq 7,$   
 $x_3 \geq 7$ . But it is not possible since the sum is 18.

$$\therefore |A_1 \cap A_2 \cap A_3| = 0 = |A_1 \cap A_2 \cap A_4| = |A_1 \cap A_3 \cap A_4| = 0$$

$$|A_2 \cap A_3 \cap A_4| = 0 \Rightarrow [S_3 = 0]$$

Also  $|A_1 \cap A_2 \cap A_3 \cap A_4| = 0 \Rightarrow [S_4 = 0]$

$$\therefore \text{Req. no.} = |A_1 \cup A_2 \cup A_3 \cup A_4| = S_0 - S_1 + S_2 - S_3 + S_4$$

$$\begin{aligned} &= |S_1| - \sum |A_i| + \sum |A_i \cap A_j| - \sum |A_i \cap A_j \cap A_k| + |A_1 \cap A_2 \cap \\ &\quad A_3 \cap A_4| \\ &= 21c_{18} - 4c_1 \times 13c_{10} + 4c_2 \times 5c_2 \end{aligned}$$

$$= 246$$

13. Find the no. of integer solutions of the eqn

$x_1 + x_2 + x_3 = 20$  such that  $2 \leq x_1 \leq 5$ ,  $4 \leq x_2 \leq 7$ ,  $-2 \leq x_3 \leq 9$ .

Soln:- Let  $y_1 = x_1 - 2$ ,  $y_2 = x_2 - 4$ ,  $y_3 = x_3 + 2$ .

then  $y_1 \geq 0$ ,  $y_2 \geq 0$ ,  $y_3 \geq 0$ .

$\therefore$  Given Eqn becomes  $y_1 + 2 + y_2 + 4 + y_3 - 2 = 20$

$$y_1 + y_2 + y_3 = 16.$$

Let  $|S| = \text{no. of non-negative integer solutions of the Eqn}$   
 $y_1 + y_2 + y_3 = 16$ . No. of such solns =  $C(3+16-1, 16) = C(18, 16)$ .

$$\therefore |S| = C(18, 16)$$

$$A_1 = \{(y_1, y_2, y_3) \mid \begin{array}{l} y_1 \geq 3 \\ y_1 \geq 4 \end{array}\}$$

$$A_2 = \{(y_1, y_2, y_3) \mid \begin{array}{l} y_2 \geq 3 \\ y_2 \geq 4 \end{array}\}$$

$$A_3 = \{(y_1, y_2, y_3) \mid \begin{array}{l} y_3 \geq 11 \\ y_3 \geq 12 \end{array}\}$$

$\therefore$  when  $x_1 \leq 5$ ,  $y_1 \leq 3$ .  
 when  $x_2 \leq 7$ ,  $y_2 \leq 3$ .  
 when  $x_3 \leq 9$ ,  $y_3 \leq 11$

Let  $z_1 = y_1 - 4$  then  $z_1 \geq 0$  for  $y_1 \geq 3$  (or  $y_1 \geq 4$ )

$\therefore y_1 + y_2 + y_3 = 16$  becomes

$$z_1 + 4 + y_2 + y_3 = 16 \Rightarrow z_1 + y_2 + y_3 = 12$$

$\therefore$  non-negative integer solns of  $z_1 + y_2 + y_3 = 12$  is  $C(3+12-1, 12)$

$$= C(14, 12)$$

$$\therefore |A_1| = C(14, 12) = |A_2|.$$

$\therefore$   $z_2 = y_2 - 4$ , then  $z_2 \geq 0$  for  $y_2 \geq 4$ .

Let  $z_3 = y_3 - 12$ , then  $z_3 \geq 0$  for  $y_3 \geq 12$

$\therefore y_1 + y_2 + y_3 = 16$  becomes

$$y_1 + y_2 + z_3 + 12 = 16$$

$$y_1 + y_2 + z_3 = 4$$

$\therefore$  non negative integer solns of  $y_1 + y_2 + z_3 = 4$  is

$$C(3+4-1, 4) = C(6, 4).$$

$$\therefore |A_3| = C(6, 4)$$

$|A_1 \cap A_2|$  = no. of non negative integer solns of the Eq?

$$z_1 + 4 + z_2 + 4 + z_3 = 16$$

$$z_1 + z_2 + 4z_3 = 8$$

$$= C(3+8-1, 8) = \underline{C(10, 8)}$$

$$|A_1 \cap A_3| = \text{no. of non-negative int solns of } z_1 + z_2 + z_3 + 12 = 16$$

$z_1 + z_2 + z_3 = 0$

$$= c(3+0-1, 0) = \underline{c(2,0)}$$

$$|A_2 \cap A_3| = \text{no. of non-negative int. solns of } z_1 + z_2 + z_3 + 1 = 16$$

*i.e.*  $y_1 + z_2 + z_3 = 0$

$$= C(2, 0).$$

$|A_1 \cap A_2 \cap A_3| = \text{no. of non-negative int soln of the Eqn}$   
 $y_1 + y_2 + y_3 = 16$  with  $y_1 \geq 3, y_2 \geq 3, y_3 \geq 11$   
But it is not possible, since the sum is 16.

$$\therefore |A_1 \cap A_2 \cap A_3| = 0$$

$$P(\text{恰好 } n_0 \text{ 次}) = |\overline{A_1} \cap \overline{A_2} \cap \overline{A_3}|$$

$$\therefore \text{Required } \underline{\underline{n}} = \sum |A_i \cap A_j \cap A_k|$$

$$= |S| - \sum_{i=1}^n |A_i| + \sum_{i=1}^n |A_i \cap S_j| = 2.$$

$$= 18c_{16} - [2x^{14}c_{12} + 6c_4] + [{}^{10}c_8 + 2x^2c_0]$$

. = 3 .

- \* In how many ways can one distribute 10 distinct prizes among 4 students with (a) exactly 2 students getting nothing (b) atleast 2 students getting nothing.

Soln:- we have to find  $E_2$  and  $L_2$ .

$$\text{we have } E_2 = S_2 - \binom{3}{1} S_3 + \binom{4}{2} S_4 + \dots \rightarrow (1)$$

$$L_2 = S_2 - \binom{2}{1} S_3 + \binom{3}{1} S_4 + \dots \rightarrow (2)$$

Let  $A_1, A_2, A_3, A_4$  be 4 students among which 10 distinct prizes are to be distributed.

$$\therefore S_2 = 4C_2 \times |A_i \cap A_j|$$

where  $|A_i \cap A_j| = \frac{\text{no. of ways of distributing 10 distinct prizes among 4 students}}{\text{so that 2 students get nothing}}$

$= \frac{\text{no. of ways of distributing 10 distinct prizes among 2 students}}{\text{Prize 1 - 2 studs} \Rightarrow 2 \text{ ways}}$

$$= 2^{10}$$

$$\therefore S_2 = 4C_2 \times 2^{10} = 6144$$

$\overline{2 \ 2 \ 2 \ 2 \ 2 \ 2 \ 2 \ 2 \ 2 \ 2}$

$\text{Prize 2 - 11 studs} \Rightarrow 2 \text{ ways}$

$\text{Prize 10 - 2 studs} \Rightarrow 2 \text{ ways}$

$$\therefore \text{total} = 2 \times 2 \times \dots \times 2 \text{ (10 times)}$$

$$= 2^{10}$$

$$\text{Also } S_3 = 4C_3 \times |A_i \cap A_j \cap A_k|$$

where  $|A_i \cap A_j \cap A_k| = \frac{\text{no. of ways of distributing 10 distinct prizes among 4 students}}{\text{so that 3 students get nothing}}$

$= \frac{\text{no. of ways of distributing 10 distinct prizes among 1 student}}{\text{Prize 10 - 1 stud} \Rightarrow 1 \text{ way}}$

$$= 1^{10}$$

$$\therefore S_3 = 4C_3 \times 1^{10} = 4$$

$\overline{2 \ 2 \ 2 \ 2 \ 2 \ 2 \ 2 \ 2 \ 2 \ 2}$

Note that  $S_4, S_5, \dots$  are all zero's.

$$\textcircled{1} \text{ & } \textcircled{2} \Rightarrow E_2 = 6144 - 3 \times 4 \Rightarrow$$

$$L_2 = 6144 - 2 \times 4 \Rightarrow$$

$$E_2 = 6132$$

$$L_2 = 6136$$

Derangements :- A permutation of 'n' objects in which none of the objects is in its natural place (original place) is called a derangement.

Ex:- Permutation of 'n' distinct objects  $1, 2, 3, \dots, n$  in which 1 is not in the 1st place, 2 is not in the 2nd place, ...,  $n$  is not in the  $n$ th place is a derangement. The no. of possible derangements of 'n' distinct objects ~~1, 2, 3, ..., n~~ is denoted by  $d_n$  and is given by the formula

Note :-  $d_1 = 0, d_2 = 1, d_3 = 2$

$$d_n = n! \sum_{k=0}^n \frac{(-1)^k}{k!}$$

$$\Rightarrow d_n = n! \left[ 1 - \frac{1}{1!} + \frac{1}{2!} - \frac{1}{3!} + \dots + \frac{(-1)^n}{n!} \right] \rightarrow ①$$

Note :-  $\Rightarrow d_1 = 0, d_2 = 1, d_3 = 2$  etc.  
we have  $e^x = 1 + x + \frac{x^2}{2!} + \dots$

$$\therefore e^{-1} = 1 - \frac{1}{1!} + \frac{1}{2!} - \frac{1}{3!} + \dots \approx 0.3679$$

$$\therefore d_n = n! \times e^{-1} = \cancel{n!} \times \cancel{0.3679} \text{ for } n > 7.$$

$$(\text{for } n > 7, 1 - \frac{1}{1!} + \frac{1}{2!} - \dots + \frac{1}{7!} \approx 0.36786)$$

Problem :-

1) find the no. of derangements of 1, 2, 3, 4. List all derangements

$$\begin{aligned} \text{Sols :- } d_4 &= 4! \times \left[ 1 - \frac{1}{1!} + \frac{1}{2!} - \frac{1}{3!} + \frac{1}{4!} \right] \\ &= 4! \times \left[ 1 - 1 + \frac{1}{2} - \frac{1}{6} + \frac{1}{24} \right] \\ &= 24 \times \frac{(12 - 4 + 1)}{24} \end{aligned}$$

2	2	6	24
3	1	3	12
1	1	4	4

$d_4 = 9$

The derangements are :

2 3 4 1

3 4 1 2

4 1 2 3

2 4 1 3

3 4 2 1

4 3 1 2

2 1 4 3

3 1 4 2

4 3 2 1

2) How many derangements are there for  $n = 1, 2, 3, 4, 5$

$$\begin{aligned}\text{Soln:- } d_5 &= 5! \times \left\{ 1 - \frac{1}{1!} + \frac{1}{2!} - \frac{1}{3!} + \frac{1}{4!} - \frac{1}{5!} \right\} \\ &= 120 \times \left[ \frac{1}{2} - \frac{1}{6} + \frac{1}{24} - \frac{1}{120} \right] \\ &= 120 \times \frac{(60 - 20 + 5 - 1)}{120} \\ &= 44.\end{aligned}$$

3) In how many ways one can arrange the no's 1, 2, 3... 10 so that 1 is not in 1st place, 2 is not in 2nd place... 10 is not in 10th place?

$$\begin{aligned}\text{Soln:- } d_{10} &= 10! \left\{ 1 - \frac{1}{1!} + \frac{1}{2!} - \frac{1}{3!} + \dots + \frac{1}{10!} \right\} \\ &= 10! \times e^1 \approx 13,35,036. \\ (\because e^x &= 1 + \frac{x}{1!} + \frac{x^2}{2!} + \dots \\ e^1 &= 1 - \frac{1}{1!} + \frac{1}{2!} - \dots \approx 0.3679).\end{aligned}$$

4) List all derangements of no's 1, 2, 3, 4, 5, 6 where first 3 no's are 1, 2, 3 in some order.

Soln:- The no of derangements of 1, 2, 3 in some order is  $d_3$ .  
" " of 4, 5, 6 is  $d_3$ .

$\therefore$  Total no of derangements of given no's where first 3 no's are 1, 2, 3 in some order is  $d_3 \times d_3 = d_3^2 = 2^2 = 4$

# List of <sup>such</sup> derangements are:

2	3	1	5	6	4
3	1	2	6	4	5
2	3	1	6	4	5
3	1	2	5	6	4

5) For the integers  $1, 2, 3, \dots, n$ , there are 11660 derangements where  $1, 2, 3, 4, 5$  appear in the first 5 positions. What is the value of  $n$ ? (10)

Soln:- The integers  $1, 2, 3, 4, 5$  can be deranged in the first 5 places in  $d_5$  ways. The remaining  $n-5$  integers in  $d_{n-5}$  ways.

$$\therefore \text{No. of derangements} = d_5 \times d_{n-5} = 11660 \text{ (given)}$$

$$\Rightarrow d_{n-5} = \frac{11660}{d_5} = \frac{11660}{44} = 265.$$

$$\Rightarrow (n-5)! \times e^{-1} = 265.$$

$$\Rightarrow (n-5)! = e \times 265$$

$$\Rightarrow (n-5)! = 720 = 6!$$

$$\Rightarrow n-5 = 6 \Rightarrow \boxed{n=11}$$

6) There are 8 letters to 8 distinct people to be placed in 8 different addressed envelopes. Find the no. of ways of doing this so that atleast one letter reaches the right person.

Soln:- The no. of ways of placing 8 letters in 8 envelopes is  $8!$ . The no. of ways of placing 8 letters in 8 envelopes such that no letter is in the right envelope is  $d_8$ .

$\therefore$  no. of ways of placing 8 letters in 8 envelopes such that atleast one letter reaches the right person is

$$\begin{aligned} 8! - d_8 &= 8! - [8! \times e^{-1}] \\ &= 8! [1 - e^{-1}] = 8! [1 - 0.3679] \\ &= 25486. \end{aligned}$$

7) Each of the  $n$  students is given a book. The ~~one~~ books are to be returned & redistributed to the same student. In how many ways can the 2 distributions be made so that no student will get the same book in both the distributions.

Soln:- first time, distribution can be made in  $n!$  ways.

No of ways of redistribution so that no student gets the same book =  $d_n$ .

No of ways of 2 distributions such that no student gets the same book in both distribution

$$= n! \times d_n$$

$$= n! \times n! \sum_{k=0}^n \frac{(-1)^k}{k!}$$

$$= (n!)^2 \sum_{k=0}^n \frac{(-1)^k}{k!}$$

8) from the set of all permutations of  $n$  distinct objects, one permutation is chosen at random. what is the probability that it is not a derangement?

Soln:- No of permutations of  $n$  distinct objects is  $n!$  (possible outcomes)

No of derangements of these objects is  $d_n$  (favourable outcomes)

Prob that a permutation chosen is not a derangement is

$$P = 1 - \frac{d_n}{n!} = 1 - \left\{ 1 - \frac{1}{1!} + \frac{1}{2!} - \frac{1}{3!} + \dots + \frac{(-1)^n}{n!} \right\}$$

$$P = 1 - \frac{1}{2!} + \frac{1}{3!} - \dots + \frac{(-1)^n}{n!}$$

=

P.T.O.

Q. There are 'n' pairs of children's gloves in a box. Each pair is of a different color. Suppose the right gloves are distributed at random to 'n' children, and thereafter left gloves are also distributed to them in random. Find the probability that:

(i) no child gets a matching pair

(ii) every child gets a matching pair

(iii) exactly one child gets a matching pair.

(iv) at least 2 children get matching pairs.

Soln:- The left gloves can be distributed to  $n$  children in  $n!$  ways.

(i) The event of no child getting a matching pair occurs if the distribution of the left gloves is a derangement. The no. of derangements =  $d_n$ .

$$\therefore \text{req. prob. is } p_1 = \frac{d_n}{n!} = 1 - \frac{1}{1!} + \frac{1}{2!} - \dots + \frac{(-1)^n}{n!}$$

(ii) The event of every child getting a matching pair occurs in only one distribution of left gloves.

$$\therefore \text{Required prob. } p_2 = \frac{1}{n!}$$

(iii) The event of exactly one child getting a matching pair occurs when only one left glove is in the natural place & all others in wrong places. The no. of such distributions is  $d_{n-1}$ .

$$\therefore \text{Req. prob. } p_3 = p_3 = \frac{d_{n-1}}{n!} = \frac{1}{n!} \left[ (n-1)! \left\{ 1 - \frac{1}{1!} + \frac{1}{2!} - \dots + \frac{(-1)^{n-1}}{(n-1)!} \right\} \right]$$

$$p_3 = \frac{1}{n!} \left[ 1 - \frac{1}{1!} + \frac{1}{2!} - \dots + \frac{(-1)^{n-1}}{(n-1)!} \right] \quad [\because n! = n(n-1)!]$$

(iv) The event of atleast 2 children getting a matching pair occurs if the event of no child (or) one child getting

a matching pair does not occur.

$$\therefore \text{Req. Prob} = p_4 = 1 - (p_1 + p_3).$$

- 10) Find the no. of derangements of the integers from 1 to  $2n$  satisfying the cond' that the elements in first 'n' places are
- $1, 2, 3, \dots, n$  in some order.
  - $n+1, n+2, \dots, 2n$  in some order.

Sol:- i) The no. of derangements of  $1, 2, 3, \dots, n$  in some order is  $d_n$ .  
and ii) \_\_\_\_\_ of  $(n+1), (n+2), \dots, 2n$  is  $d_{n+1}$ .  
 $\therefore$  Total no. of derangements =  $d_n \times d_{n+1} = d_n^2$ .

ii) The no. of derangements of  $(n+1), (n+2), \dots, 2n$  in first 'n'  
places <sup>in some order</sup> is  $n!$ .  
and no. of derangements of  $1, 2, \dots, n$  is  $d_n$ .  
 $\therefore$  Total no. of derangements =  $n! \times d_n$ .  
=  $(n!)^2$ .  
(Ex:- 1, 2, 3, 4, 5, 6.  
Que:- 4, 5, 6 in first  
3 places.  
then every arrangement  
of 4, 5, 6 in first  
3 places is a derangement  
so this can be done in  
 $3!$  ways.)

Rock Polynomials :-

- Consider a board that represents a full chess board or a part of a chess board.
- Let 'n' be the no. of squares present in the board.
- Pawns (Rooks) are placed on the board such that not more than one pawn occupies a square. Then we cannot use more than 'n' pawns.
- Two pawns <sup>(rooks)</sup> placed on a board are said to capture (or take) each other if they are in the same row or same column of the board.
- Let  $r_K$  denote the no. of ways in which 'K' pawns can be placed on a board such that no two pawns capture each other.
- If the board is denoted by 'C', then the rock polynomial is given by  $r(C, x) = 1 + r_1 x + r_2 x^2 + \dots + r_n x^n$ .  
Always  $r_1 = n$  where (~~These  $n=0$~~ )
- ∴  $r_1$  denotes the no. of ways 1 pawn can be placed on a board [ $\because r_1$  denotes the no. of ways 1 pawn can be placed anywhere on the board.  $\therefore r_1 = n$ ]
- Rock polynomial is defined for  $r_{\geq 2}$ . If  $n=1$ , then the board contains only 1 square so  $r_2, r_3, \dots$  are zeroes.  
 $\therefore r(C, x) = 1 + x$ .
- Rock polynomial for  $n \times n$  board is given by:  

$$r(C_{n \times n}, x) = 1 + \binom{n}{1}^2 x + 2! \times \binom{n}{2}^2 x^2 + 3! \times \binom{n}{3}^2 x^3 + \dots + n! \times \binom{n}{n}^2 x^n.$$

Expansion formula :-

In a given board 'C', suppose we choose a particular square & mark it as  $\textcircled{1}$ . Let 'D' be the board obtained from 'C' by deleting the row & column containing the square  $\textcircled{1}$  and 'E' be the board obtained from C by deleting only the square  $\textcircled{1}$ , then the rock polynomial for the board 'C' is given by

$$r(C, x) = x r(D, x) + r(E, x).$$

This is known as Expansion formula for  $r(C, x)$ .

Product formula :- Suppose a board is made up of 2 parts  $C_1$  &  $C_2$  where  $C_1$  &  $C_2$  have no square in the same row or column of  $C$ . Such parts are called disjoint subboards of  $C$ . Then the rook polynomial for the board  $C$  is given by

$$r(C, x) = r(C_1, x) \times r(C_2, x).$$

This is known as product formula for  $r(C, x)$ .

(If a board is made up of pairwise disjoint subboards  $C_1, C_2, \dots, C_n$  then  $r(C, x) = r(C_1, x) \times r(C_2, x) \times \dots \times r(C_n, x)$ )

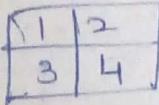
Arrangements with forbidden positions :-

Suppose 'm' objects are to be arranged in 'n' places where  $n \geq m$ . Suppose there are constraints under which some objects cannot occupy certain places. Such places are called the forbidden positions for the said objects. The no. of ways of carrying out this task is given by the following rule:

$$N = s_0 - s_1 + s_2 - s_3 + \dots + (-1)^n s_n.$$

where  $s_0 = n!$ ,  $s_k = (n-k)! \times r_k$  for  $k=1, 2, \dots, n$ .  
 where  $r_k$  is the coefficient of  $x^k$  in the rook polynomial of the board of  $m$  rows &  $n$  columns whose squares represent the forbidden places.

Problems :-

- 1) Consider the board  find the rook polynomial.

Soln:- Here  $n = m = 4$ .

The positions of 2 non-capturing rooks are:  $(1, 4), (2, 3)$

$$\therefore r_2 = 2.$$

The board has no positions for more than 2 non-capturing rooks.

$$\therefore r_3 = r_4 = 0.$$

Rook polynomial is  $r(c, x) = 1 + 4x + 2x^2$ .

2)

1	2	3
4		5

Here  $n = m = 5$

Positions of 2 non-capturing rooks are:  $(1, 5), (2, 4), (2, 5), (3, 4)$

$$\therefore r_2 = 4.$$

$$r_3 = r_4 = r_5 = 0.$$

Rook polynomial is  $r(c, x) = 1 + 5x + 4x^2$ .

3)

/	1	2
/	3	4
5	6	7

Here  $n = m = 7$ .

Positions of 2 non-capturing rooks are:  
 $(1, 4), (1, 5), (1, 7), (2, 3), (2, 5), (2, 6), (3, 5), (3, 7), (4, 5)$

$$(4, 6) \quad \therefore r_2 = 10.$$

~~1 2 3 4 5 6 7~~

Positions of 3 non-capturing rooks are:

$$(1, 4, 5), (2, 3, 5) \quad \therefore r_3 = 2.$$

$$r_4 = \dots = r_7 = 0.$$

Rook polynomial is  $r(c, x) = 1 + 7x + 10x^2 + 2x^3$ .

4)

1	2	3
4		5
6	7	8

Here  $n = m = 8$ .

Positions of 2 non-capturing rooks are:

$(1, 5), (1, 7), (1, 8), (2, 4), (2, 5), (2, 6), (2, 8), (3, 4), (3, 6), (3, 7), (4, 7), (4, 8), (5, 6), (5, 7) \Rightarrow r_2 = 14.$

Positions of 3 non-capturing rooks are:  $(1, 5, 7), (2, 4, 8), (2, 5, 6), (3, 4, 7)$

$$\therefore r_3 = 4, r_4 = \dots, r_8 = 0. \text{ Rook Poly is}$$

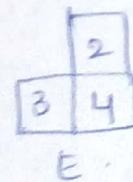
$$r(c, x) = 1 + 0x + 1x^2 + 1x^3.$$

5) Find the rook polynomial for the  $2 \times 2$  board by using expansion formula:

Soln:-

4	2
3	4

4
---



$$r(D, x) = 1 + x.$$

for the board E,  $n=3$ ,  $r_2=1$  [ $\because (2, 3)$ ]

$$r(E, x) = 1 + 3x + x^2.$$

$\therefore$  Rook polynomial is  $r(C, x) = x r(D, x) + r(E, x)$

$$\begin{aligned} r(C, x) &= x(1+x) + 1 + 3x + x^2 \\ &= x + x^2 + 1 + 3x + x^2 \\ &= \underline{\underline{1 + 4x + 2x^2}}. \end{aligned}$$

6) Find the rook polynomial for  $3 \times 3$  board using the Expansion formula.

Soln:-

1	2	3
4	5*	6
7	8	9

1	3
7	9

1	2	3
4		6
7	8	9

for the board 'D',

$$n=4, r_2=2 \quad [\because (1, 9)(3, 7)], r_3=r_4=0.$$

$$\therefore r(D, x) = 1 + 4x + 2x^2.$$

for the board 'E',

$$r_1=8, r_2=14, r_3=4, r_4=\dots, r_8=0. \text{ (Problem ④)}$$

$$\therefore r(E, x) = 1 + 8x + 14x^2 + 4x^3$$

Thus Rook polynomial for  $3 \times 3$  board is

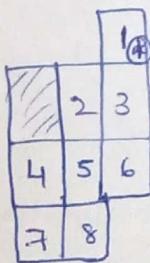
$$\begin{aligned} r(C, x) &= x r(D, x) + r(E, x) = x(1 + 4x + 2x^2) + 1 + 8x + 14x^2 + 4x^3 \\ &= x + 4x^2 + 2x^3 + 1 + 8x + 14x^2 + 4x^3 \\ &= \underline{\underline{1 + 9x + 18x^2 + 6x^3}} \end{aligned}$$

Verification :- we have for  $n \times n$  board, Expansion formula is (14)

$$r(c_{n \times n}, x) = 1 + \binom{n}{1}^2 x + 2b \times \binom{n}{2}^2 x^2 + 3b \times \binom{n}{3}^3 x^3$$

$$\therefore r(c_{3 \times 3}, x) = 1 + \binom{3}{1}^2 x + 2b \times \binom{3}{2}^2 x^2 + 3b \times \binom{3}{3}^3 x^3 \\ = 1 + 9x + 18x^2 + 6x^3$$

- 7) Using Expansion formula, obtain the rook polynomial for the board 'C' shown below :



Soln:-

	2
4	5
7	8

D

	2	3
4	5	6
7	8	

E

for the board 'D',

$r_1 = n = 5$ . Positions for 2 non-capturing rooks are:

$$(2,4)(2,7)(4,8)(5,7) \quad \therefore r_2 = 4. \quad r_3 = 0 = r_4 = r_5.$$

$$\therefore r(D, x) = 1 + 5x + 4x^2$$

for the board 'E',

Positions for 2 non-capturing rooks are:

$$(2,4)(2,6)(2,7)(3,4)(3,5)(3,7)(3,8)(4,8)(5,7)(6,7)(6,8)$$

∴  $r_2 = 11$ . Positions for 3 non-capturing rooks are:

$$(3,5,7)(2,6,7)(3,4,8) \quad \therefore r_3 = 3.$$

$$r_4 = \dots = r_7 = 0.$$

$$\therefore r(E, x) = 1 + 7x + 11x^2 + 3x^3$$

$$\therefore r(C, x) = x r(D, x) + r(E, x) = x \{ 1 + 5x + 4x^2 \} + 1 + 7x + 11x^2 + 3x^3 \\ = 1 + 8x + 16x^2 + 7x^3$$

8) Using Expansion formula, find the rook polynomial for the board C as shown below:

1	2
3	4
6	

Soln:-

		2
		6

1	2
4	5
6	

$$\text{In } D, \pi_1 = n = 2, \pi_2 = 1 \quad [\because (2, 6)]$$

$$\therefore r(D, x) = 1 + 2x + x^2.$$

In E,  $\pi_1 = n = 5$ , The positions for 2 non-capturing rooks

$$\text{are : } (1, 4)(1, 5)(1, 6)(2, 4)(2, 6)(5, 6)$$

$$\therefore \pi_2 = 6.$$

$$\text{Also } \pi_3 = 1 \quad [\because (1, 5, 6)]$$

$$\therefore r(E, x) = 1 + 5x + 6x^2 + x^3.$$

$$\begin{aligned} \text{Thus } r(C, x) &= x r(D, x) + r(E, x) \\ &= x [1 + 2x + x^2] + [1 + 5x + 6x^2 + x^3] \\ &= x + 2x^2 + x^3 + 1 + 5x + 6x^2 + x^3 \\ &= 1 + 6x + 8x^2 + 2x^3. \end{aligned}$$

9) obtain the rook polynomial for the full chess board:

1	2
3	
4	5
6	7
8	

1	2
3	

$C_2$ :

3	4
5	
6	7

3	4
5	
6	7

$$\text{In } Q, \pi_1 = 2, \pi_2 = 0.$$

$$\therefore r(Q, x) = 1 + 2x.$$

In C<sub>2</sub>, let us mark square 4 as (4) then the board (15)

D & E are as below:

6	7	8
D		

5		
E	6	7
	8	

In D,  $n = m = 3$ .  $\tau_2 = \tau_3 = 0$ .

$$\therefore r(D, x) = 1 + 3x.$$

In E,  $n = 5$ . Positions for 2 non-capturing rooks are:

$$(3, 5) (3, 6) (3, 7) (3, 8) (5, 7) (5, 8). \therefore \tau_2 = 6.$$

Positions for 3 non-capturing rooks are:

$$(3, 5, 7) (3, 5, 8) \therefore \tau_3 = 2.$$

$$\text{Thus } r(E, x) = 1 + 5x + 6x^2 + 2x^3.$$

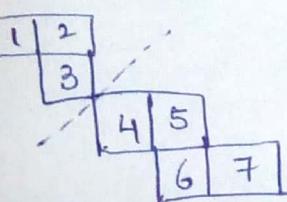
$$\begin{aligned} \therefore r(C_2, x) &= x r(D, x) + r(E, x) \\ &= x(1 + 3x) + 1 + 5x + 6x^2 + 2x^3 \\ &= 1 + 6x + 9x^2 + 2x^3. \end{aligned}$$

$$\begin{aligned} \text{Thus } r(C, x) &= r(C_1, x) \times r(C_2, x) \\ &= (1 + 2x)(1 + 6x + 9x^2 + 2x^3) \\ &= 1 + 6x + 9x^2 + 2x^3 + 2x + 12x^2 + 18x^3 + 4x^4 \\ &= 1 + 8x + 21x^2 + 20x^3 + 4x^4. \end{aligned}$$

---

10) Find the rook polynomial for the board C:

1	2	
3		
	4	5

C: 

$$\text{Soln: } C_1: \begin{array}{|c|c|} \hline 1 & 2 \\ \hline 3 & \\ \hline \end{array}$$

$$C_2: \begin{array}{|c|c|} \hline 4 & 5 \\ \hline 6 & 7 \\ \hline \end{array}$$

$$\text{In } C_1, n = m = 3. \tau_2 = 1. \Rightarrow r(C_1, x) = 1 + 3x + x^2.$$

$$\text{In } C_2, n = m = 4, \tau_2 = 3 \Rightarrow r(C_2, x) = 1 + 4x + 3x^2.$$

$$\therefore r(c, x) = r(c_1, x) \times r(c_2, x)$$

$$\begin{aligned} \Rightarrow r(c, x) &= (1+3x+x^2)(1+4x+3x^2) \\ &= 1+4x+3x^2+3x+12x^2+9x^3+x^2+4x^3+3x^4 \\ &= 1+7x+16x^2+13x^3+3x^4 \end{aligned}$$

11) find the rook polynomial of:  
the

1	2	
3	4	
④6	7	8

$$\rightarrow r(c, x) = 1+8x+16x^2+5x^3$$

12) find the rook poly for the board made up of the shaded squares in the figure.

	1	2		
3		4		
	5		6	7
				8

	1	2	
3		4	④
	5		6
			7

c:

Mark the square 6  
as ④ if proceed  
(see prob 15)

Soln:- Let us mark the board square  $\text{numbered } 4$  as ④, then the boards D & E are as below:

1		
5	6	7

D:

	1	2	
3			
	5		6
			7

E:

	1	2	
3			
	5		6
			7

8

$$\text{In D, } r_1 = 5, r_2 = 5 \quad [(1, 6) (1, 7) (1, 8) (5, 8) (\text{④}, 8)]$$

$$r_3 = 1 \quad [(1, 7, 8)]$$

$$\therefore r(D, x) = 1+5x+5x^2+x^3$$

In E, let us mark the board square 6 as ④, then the boards  $E_1$  &  $E_2$  are as below:

	1	2	
3			

$E_1$ :

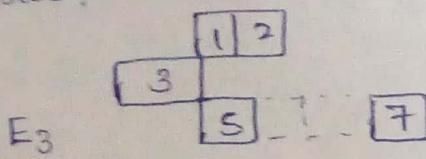
$E_2$ :

	1	2	
3			
	5		7
			8

I E<sub>1</sub>,  $x_1 = 3$ ,  $x_2 = 2$ ,  $x_3 = 0$ .

$$\therefore r(E_1, x) = 1 + 3x + 2x^2.$$

The board E<sub>2</sub> can be split into 2 disjoint boards as follows:



E<sub>4</sub> :



$$\text{In } E_3, \quad x_1 = 5, \quad x_2 = 7 \quad [(1, 3)(1, 7)(2, 3)(2, 5)(2, 7)(3, 5)(3, 7)] \\ x_3 = 3 \quad [(1, 3, 7)(2, 3, 5)(2, 3, 7)]$$

$$\therefore r(E_3, x) = 1 + 5x + 7x^2 + 3x^3.$$

$$\text{Also } r(E_4, x) = 1 + x.$$

$$\therefore r(E_2, x) = (1 + 5x + 7x^2 + 3x^3)(1 + x) \\ = 1 + x + 5x + 5x^2 + 7x^2 + 7x^3 + 3x^3 + 3x^4 \\ = 1 + 6x + 12x^2 + 10x^3 + 3x^4.$$

$$\text{Thus } r(E, x) = x \cdot r(E_1, x) + r(E_2, x) \\ = x[1 + 3x + 2x^2] + 1 + 6x + 12x^2 + 10x^3 + 3x^4 \\ r(E, x) = 1 + 7x + 15x^2 + 12x^3 + 3x^4.$$

$$\text{Hence } r(C, x) = x \cdot r(D, x) + r(E, x)$$

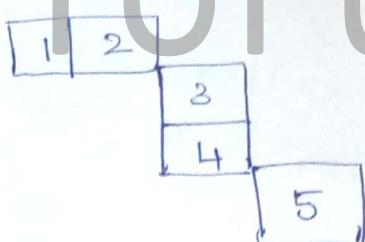
$$\Rightarrow r(C, x) = x[1 + 5x + 5x^2 + x^3] + 1 + 7x + 15x^2 + 12x^3 + 3x^4 \\ = 1 + 8x + 20x^2 + 17x^3 + 4x^4$$

13) An apple, a banana, a mango and an orange are to be distributed to 4 boys  $B_1, B_2, B_3, B_4$ . The Boys  $B_1 \& B_2$  do not want to have an apple, the boy  $B_3$  does not want banana (or) mango, and  $B_4$  refuses orange. In how many ways can the distribution be made so that no boy is displeased.

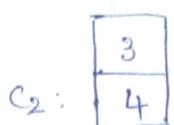
Soln:- Let us construct a board (table) in which rows represent apple, banana, mango & orange respectively, and columns represents Boys  $B_1, B_2, B_3, B_4$  respectively. Shaded square represents forbidden positions in distribution.

	$B_1$	$B_2$	$B_3$	$B_4$
A	X	X		
B			X	X
M			X	
O				X

Consider the board 'C' consisting of shaded square:



'C' can be divided into 3 disjoint subparts  $C_1, C_2, C_3$  as shown below:



$C_3:$



$$\therefore r(C, x) = r(C_1, x) \times r(C_2, x) \times r(C_3, x) \rightarrow ①$$

$$\text{In } C_1, r_1 = n = 2, r_2 = 0 \Rightarrow r(C_1, x) = 1 + 2x.$$

$$\text{In } C_2, r(C_2, x) = 1 + 2x.$$

$$r(C_3, x) = 1 + x.$$

$$\begin{aligned} ① \Rightarrow r(C, x) &= (1+2x)^2(1+x) \\ &= (1+4x^2+4x)(1+x) \end{aligned}$$

$$r(c, x) = 1 + x + 4x^2 + 4x^3 + 4x + 4x^2$$

$$r(c, x) = 1 + 5x + 8x^2 + 4x^3.$$

Thus for the board C,

$$r_1 = 5, \quad r_2 = 8, \quad r_3 = 4.$$

$$\text{we have } S_0 = 4! = 24, \quad S_1 = (4-1)! \times r_1 = 6 \times 5 = 30.$$

$$S_2 = (4-2)! \times r_2 = 2 \times 8 = 16, \quad S_3 = (4-3)! \times r_3 = 1 \times 4 = 4$$

$$\therefore \bar{N} = S_0 - S_1 + S_2 - S_3 \\ = 24 - 30 + 16 - 4$$

$$\bar{N} = 6.$$

e. There are 6 ways of distributing fruits so that no one is displeased.

- 14) Four persons  $P_1, P_2, P_3, P_4$  who arrive late for a dinner party find that only one chair at each of 5 tables  $T_1, T_2, T_3, T_4, T_5$  is vacant.  $P_1$  will not sit at  $T_1$  or  $T_2$ ,  $P_2$  will not sit at  $T_2$ ,  $P_3$  will not sit at  $T_3$  or  $T_4$  and  $P_4$  will not sit at  $T_4$  or  $T_5$ . find the no. of ways they can occupy the vacant chairs.

Soln:- Consider the board which represents the given situation.  
Let the rows represents 4 persons  $P_1, P_2, P_3, P_4$ , and columns represents the tables  $T_1, \dots, T_5$ . The shaded squares represent the forbidden positions.

	$T_1$	$T_2$	$T_3$	$T_4$	$T_5$
$P_1$	X	X			
$P_2$		X			
$P_3$			X	X	
$P_4$			X		X

consider the board 'c' consisting of shaded squares :

1	2	
	3	
		4
		5
		6
		7

Refresher Problem 10

$$r(c,x) = 1 + 7x + 16x^2 + 13x^3 + 3x^4.$$

Thus for the board 'C',

$$r_1 = 7, r_2 = 16, r_3 = 13, r_4 = 3.$$

S. Required no. of ways =  $s_0 - s_1 + s_2 - s_3 + s_4$

$$= 5! - (5-1)! \times r_1 + (5-2)! \times r_2 - (5-3)! \times r_3 + (5-4)! \times r_4$$

$$= 5! - 24 \times 7 + 6 \times 16 - 2 \times 13 + 1 \times 3$$

$$= 120 - 168 + 96 - 26 + 3$$

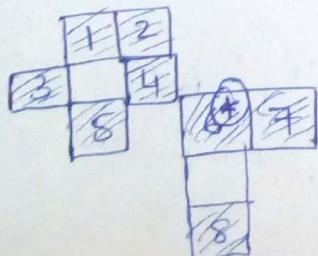
$$= 25.$$

15) A girl student has sarees of 5 different colors blue, green, red, white & yellow. On Monday, she does not wear green, on Tuesday blue or red, on Wednesday blue or green, on Thursday red or yellow, on Friday red. In how many ways can she dress without repeating a color from Monday to Friday.

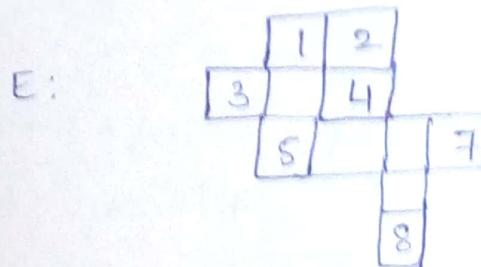
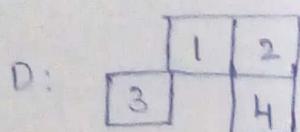
Soln:- The situation can be represented by the foll. board where shaded squares represents the forbidden positions.

	M	T	W	T	F
B					
G	X	X	X		
R	X			X	X
W					
Y			X		

Consider the board C containing the shaded squares:



Mark the square 6 as ④, so that the boards D, E  
are as shown below:



$$\therefore r(c, x) = x r(D, x) + r(E, x) \rightarrow ①$$

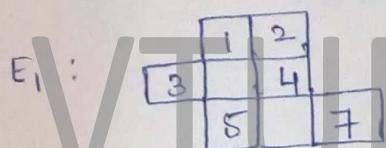
for the board D,

$$r_1 = n = 4, \quad r_2 = 3.$$

$$\therefore r(D, x) = 1 + 4x + 3x^2.$$

The board E can be divided into 2 disjoint subparts

$E_1$  &  $E_2$  as below:



$$\text{for } E_1, \quad r_1 = n = 6, \quad r_2 = 10$$

-ring books are  $(1, 3)(1, 4)(1, 7)(2, 3)(2, 5)(2, 7)(3, 5)(3, 7)$   
 $(4, 5)(4, 7)$

positions of 3 non-capturing books are  $(1, 3, 7)(1, 4, 7)$

$$(2, 3, 5)(2, 3, 7) \Rightarrow r_3 = 4$$

$$\therefore r(E_1, x) = 1 + 6x + 10x^2 + 4x^3.$$

$$\& r(E_2, x) = 1 + x.$$

$$\therefore r(E, x) = r(E_1, x) \times r(E_2, x)$$

$$= (1 + 6x + 10x^2 + 4x^3)(1 + x)$$

$$= 1 + 6x + 10x^2 + 4x^3 + x + 6x^2 + 10x^3 + 4x^4$$

$$= 1 + 7x + 16x^2 + 14x^3 + 4x^4.$$

$$\text{thus } ① \Rightarrow r(c, x) = x(1 + 4x + 3x^2) + 1 + 7x + 16x^2 + 14x^3 + 4x^4$$

$$= 1 + 8x + 20x^2 + 17x^3 + 4x^4.$$

for the board C,

$$r_1 = 8, r_2 = 20, r_3 = 17, r_4 = 4$$

$$\therefore \text{Required no. } N = s_0 - s_1 + s_2 - s_3 + s_4 \\ = 5! - (5-1)! \times 8 + (5-2)! \times 20 - (5-3)! \times 17 \\ + (5-4)! \times 4 \\ = 18.$$

16) Five teachers  $T_1, \dots, T_5$  are to be made class teachers for 5 classes  $C_1, C_2, \dots, C_5$  - one teacher for each class.

~~How~~  $T_1$  &  $T_2$  do not wish to become class teachers for  $C_1$  or  $C_2$ .  $T_3$  &  $T_4$  for  $C_4$  or  $C_5$  and  $T_5$  for  $C_3$  or  $C_4$  or  $C_5$ . In how many ways can the teachers be assigned the work without displeasing any teacher.

$$\rightarrow r(x) = 1 + 11x + 40x^2 + 56x^3 + 28x^4 + 4x^5.$$

$$\therefore N = 8.$$

VTUPulse.com

17) A pair of dice one red & other green is rolled six times. Find the probability that we obtain 6 values on both the red die & green die under the restriction that the ordered pairs  $(1,1), (1,5), (2,4), (3,6), (4,2), (4,4), (5,1)$  &  $(5,5)$  do not occur. [Here an ordered pair  $(a,b)$  indicates 'a' on the red die & 'b' on the green]

Soln:- Consider the foll table representing the situation in which rows represent the value appearing on red die & columns represent values appearing on green die.

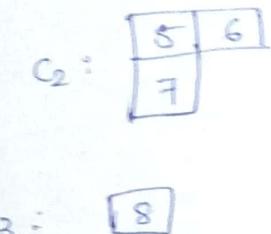
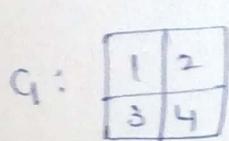
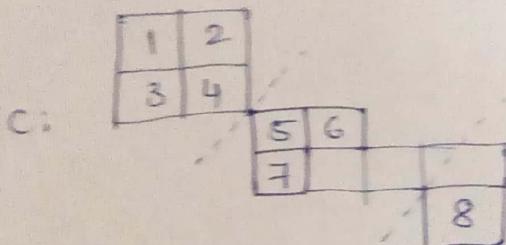
	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

Let us redraw the table as follows:-

(Since all shaded region are scattered, we put them together as below)



The board 'C' is as shown below:



$$r(C, x) = r(C_1, x) \times r(C_2, x) \times r(C_3, x) \rightarrow ①$$

$$r(C_1, x) = 1 + 4x + 2x^2$$

$$r(C_2, x) = 1 + 3x + x^2$$

$$r(C_3, x) = 1 + x$$

$$\begin{aligned} ① \Rightarrow r(C, x) &= (1+4x+2x^2)(1+3x+x^2)(1+x) \\ &= (1+4x+2x^2)(1+3x+x^2) + x + 3x^2 + x^3 \\ &= (1+4x+2x^2)(1+4x+4x^2+x^3) \\ &= 1+4x+4x^2+x^3+4x+16x^2+16x^3+4x^4 \\ &\quad + 2x^2+8x^3+8x^4+2x^5 \\ &= 1+8x+22x^2+25x^3+12x^4+2x^5 \end{aligned}$$

$$\therefore r_1 = 8, r_2 = 22, r_3 = 25, r_4 = 12, r_5 = 2.$$

$$\therefore \bar{N} = s_0 - s_1 + s_2 - s_3 + s_4 - s_5 = 160.$$

$\therefore$  No. of favourable outcomes =  $6 \times 160$ .  
The sample space 'S' contains the set of all outcomes such that the 8 pairs do not occur.

$$\therefore |S| = (36-8)^6 = 28^6.$$

$$\therefore \text{Required Probability} = \frac{68 \times 160}{(28)^6}$$
$$= 2.391 \times 10^{-4}$$

VTUPulse.com

## Recurrence Relations

### + first order Recurrence relations:

A 1 order recurrence relation with constant coefficient is of the form

$$a_n = c a_{n-1} + f(n) \rightarrow ① \quad \text{for } n \geq 1.$$

where  $c \rightarrow$  a known constant.

$f(n) \rightarrow$  a known function of  $f$ .

If  $f(n) = 0$ , then ① is called a homogeneous recurrence relation; otherwise it is called a non-homogeneous recurrence relation.

Note:-) The General soln of a homogeneous R.R is  $a_n = C^n a_0$  for  $n \geq 1$ .

2) The General soln of a non-homogeneous R.R of order 1 is given by  $a_n = C^n a_0 + \sum_{k=1}^n C^{n-k} f(k)$ , for  $n \geq 1$ .

### Problems:-

i) Solve the recurrence relation  $a_n = 7a_{n-1}$ , where  $n \geq 1$  given that  $a_2 = 98$ .

Soln :-  $a_n = 7a_{n-1} \rightarrow ①$  is a homogeneous 1st order recurrence relation.

General soln is given by

$$a_n = C^n a_0.$$

$$a_n = 7^n a_0 \rightarrow ②$$

$$\text{for } n=2; a_2 = 7^2 a_0 \Rightarrow a_2 = 49 a_0$$

$$\Rightarrow 98 = 49 a_0 \Rightarrow \boxed{a_0 = 2}$$

Sub in ②,  $\boxed{a_n = 2 \cdot 7^n}$  is the General soln.

2) Solve the recurrence relation  $a_n = n a_{n-1}$  for  $n \geq 1$

given that  $a_0 = 1$ .

Soln:-  $a_n = n a_{n-1}$

$$n=1; a_1 = 1 \times a_0$$

$$n=2; a_2 = 2 \times a_1 = (2 \times 1) \times a_0$$

$$n=3; a_3 = 3 \times a_2 = (3 \times 2 \times 1) \times a_0.$$

$$n=4; a_4 = 4 \times a_3 = (4 \times 3 \times 2 \times 1) \times a_0. \text{ and so on.}$$

$\therefore$  General soln is

$$a_n = n! a_0 \text{ for } n \geq 1.$$

using  $a_0 = 1 \Rightarrow [a_n = n!]$  is the required soln.

3) Solve the recurrence relation  $a_n - 3a_{n-1} = 5 \times 3^n$  for  $n \geq 1$ ,

given that  $a_0 = 2$ .

Soln:- Given  $a_n = 3a_{n-1} + (5 \times 3^n) \rightarrow ①$  is a non-homo. relation with  $c = 3$ ,  $f(n) = 5 \times 3^n$ .

General soln is given by

$$a_n = 3^n a_0 + \sum_{k=1}^n 3^{n-k} f(k)$$

$$a_n = 3^n a_0 + 3^{n-1} f(1) + 3^{n-2} f(2) + \dots + 3^0 f(n).$$

$$\Rightarrow a_n = 3^n \times 2 + 3^{n-1} (5 \times 3^1) + 3^{n-2} (5 \times 3^2) + \dots + 3^0 \times (5 \times 3^n)$$

$$= 2 \times 3^n + 5 \times [3^n + 3^{n-1} + \dots + 3^0] \text{ (n times)}$$

$$= 2 \times 3^n + 5 \times n \times 3^n$$

$[a_n = 3^n (2 + 5n)]$  is the required soln.

4) Solve the recurrence relation  $a_n - 3a_{n-1} = 5 \times 7^n$ , for  $n \geq 1$ ,

given that  $a_0 = 2$ .

P.T.O.

Soln: Given:  $a_n = 3a_{n-1} + (5 \times 7^n) \rightarrow ①$  is a non-homo.  
 recurrence relation with  $c=3$ ,  $f(n) = 5 \times 7^n$ .

The general soln is given by

$$a_n = 3^n a_0 + \sum_{k=1}^n 3^{n-k} f(k).$$

$$= 3^n \times 2 + \sum_{k=1}^n 3^{n-k} \times (5 \times 7^k)$$

$$= 2 \times 3^n + (5 \times 3^n) \sum_{k=1}^n 3^{-k} \cdot 7^k.$$

$$= 2 \times 3^n + (5 \times 3^n) \sum_{k=1}^{\infty} \left(\frac{7}{3}\right)^k.$$

$$= 2 \times 3^n + (5 \times 3^n) \left[ \frac{7}{3} + \left(\frac{7}{3}\right)^2 + \dots + \left(\frac{7}{3}\right)^n \right]$$

$$= 2 \times 3^n + (5 \times 3^n) \times \frac{7}{3} \left[ 1 + \left(\frac{7}{3}\right) + \left(\frac{7}{3}\right)^2 + \dots + \left(\frac{7}{3}\right)^{n-1} \right]$$

$$a+ar+ar^2+\dots = \frac{a(r^n-1)}{r-1}; r>1$$

here  $a=1, r=\frac{7}{3}$

$$\therefore a_n = 2 \times 3^n + (35 \times 3^{n-1}) \left[ \frac{\left(\frac{7}{3}\right)^n - 1}{\left(\frac{7}{3} - 1\right)} \right]$$

$$= (2 \times 3^n) + (35 \times 3^{n-1}) \times \frac{3}{4} \left[ \frac{7^n - 3^n}{3^n} \right]$$

$$= (2 \times 3^n) + \left( \frac{35}{4} \right) (7^n - 3^n)$$

$$= 3^n \left[ 2 - \frac{35}{4} \right] + \frac{35}{4} \cdot 7^n$$

$$= -3^n \times \frac{27}{4} + \frac{5 \times 7 \times 7^n}{4}$$

$$= -\frac{1}{4} \cdot 3^{n+3} + \frac{5}{4} \cdot 7^{n+1}$$

$$a_n = \frac{1}{4} \left[ 5 \times 7^{n+1} - 3^{n+3} \right]$$

is the required soln.

5) Solve the recurrence relation

$$a_n = 2a_{n/2} + (n-1) \quad \text{for } n = 2^k, k \geq 1, \text{ given } a_1 = 0.$$

Soln:..  $a_n = 2a_{n/2} + (n-1)$

$$\Rightarrow a_n - 2a_{n/2} = (n-1).$$

we obtain the following successive eqns

$$a_{n/2} - 2a_{n/4} = \left(\frac{n}{2} - 1\right)$$

$$a_{n/4} - 2a_{n/8} = \left(\frac{n}{4} - 1\right)$$

⋮

$$a_{n/2^{k+1}} - 2a_{n/2^k} = \left(\frac{n}{2^{k+1}} - 1\right)$$

These can be written as

$$a_n - 2a_{n/2} = (n-1).$$

$$2a_{n/2} - 2^2a_{n/4} = (n-2)$$

$$2^2a_{n/4} - 2^3a_{n/8} = (n-2^2)$$

⋮  
$$2^k a_{n/2^k} - 2^{k+1} a_{n/2^{k+1}} = (n - 2^{k+1})$$

adding these we get

$$a_n - 2^k a_{n/2^k} = (n-1) + (n-2) + (n-2^2) + \dots + (n-2^{k+1})$$

since  $n = 2^k$ ,  $a_{n/2^k} = a_1 = 0$  (given)

$$\therefore a_n = (n+n+\dots+n)_{k \text{ times}} - (1+2+2^2+\dots+2^{k+1}) \\ = kn - \underbrace{(1)(2^{k+1}-1)}_{2-1}$$

$$= kn - (2^k - 1) = kn - (n-1) \quad (\because n = 2^k)$$

$$= 1 + (k-1)n$$

$$\boxed{a_n = 1 + [\log_2 n - 1]n}$$

$$\begin{aligned} & \because 2^k = n \\ & \log_2 2^k = \log_2 n \\ & k \cdot \log_2 2 = \log_2 n \\ & k = \frac{\log_2 n}{\log_2 2} = \log_2 n \end{aligned}$$

6) Find the recurrence relation and the initial cond<sup>n</sup> for  
Q8 the sequence 0, 2, 6, 12, 20, 30, 42 ... hence find the general term of the sequence.

Soln:- Given  $a_0 = 0$ ,  $a_1 = 2$ ,  $a_2 = 6$ ,  $a_3 = 12$ ,  $a_4 = 20$  ....

$$\text{Consider } a_1 - a_0 = 2 - 0 = 2 = 2 \times 1$$

$$a_2 - a_1 = 6 - 2 = 4 = 2 \times 2$$

$$a_3 - a_2 = 12 - 6 = 6 = 2 \times 3$$

$$a_4 - a_3 = 20 - 12 = 8 = 2 \times 4$$

!

$a_n - a_{n-1} = 2 \times n$  is the R.R with the initial cond<sup>n</sup>  
 $a_0 = 0$ .

adding all these,

$$a_n - a_0 = (2 \times 1) + (2 \times 2) + (2 \times 3) + (2 \times 4) + \dots + (2 \times n-1) + (2 \times n)$$

$$a_n - 0 = 2 [1 + 2 + 3 + \dots + n]$$

$$a_n = 2 \frac{n(n+1)}{2}$$

$$\boxed{a_n = n(n+1)}$$

7) The number of virus affected files in a system is 1000 (to start with) and this increases 250% every 2 hours. Use a recurrence relation to determine the no. of virus affected files in the system after one day.

Soln:- Let  $a_0 = 1000$

Let  $a_n$  denote the no. of virus affected files after  $2n$  hours.  
It is given that the no. increases by 250% every 2 hours.

$$\therefore a_1 = a_0 + 250\% a_0$$

$$a_2 = a_1 + 250\% a_1$$

!

$$a_n = a_{n-1} + 250\% a_{n-1}$$

$$\begin{aligned} \therefore a_n &= a_{n-1} [1 + 25\%] \\ &= a_{n-1} \left[1 + \frac{25}{100}\right] \\ &= a_{n-1} (1+2.5) \\ \boxed{a_n = 3.5 a_{n-1}} \quad &\forall n \geq 1 \end{aligned}$$

This is the recurrence relation for the no. of virus affected files.

∴ General soln of the recurrence relation is given by

$$a_n = c^n a_0$$

$$a_n = (3.5)^n \times 1000$$

This gives the no. of virus affected files after  $2n$  hours.

∴ No. of virus affected files after 24 hrs (1 day)  
(when  $n=12$ ) is

$$a_{12} = (3.5)^{12} \times 1000 = 3379220508$$

- 8) A person invests Rs. 10,000 at 10.5% interest (per year) compounded monthly. find and solve the recurrence relation for the value of the investment at the end of  $n$  months. what is the value of the investment at the end of the 1 year? How long will it take to double the investment?

Soln:- Let  $a_0$  denote the initial investment.

Let  $a_1, a_2, \dots, a_n$  denote the investments after 1, 2, 3, ...,  $n$  months respectively.

Given : annual rate of interest = 10.5%.

$$\therefore \text{Monthly rate of interest} = \frac{10.5\%}{12} = 0.875\%$$

$$\text{Thus } a_0 = 10000$$

$$a_1 = a_0 + (0.875\%) a_0$$

$$a_2 = a_1 + (0.875\%) a_1$$

:

$$a_n = a_{n-1} + (0.875\%) a_{n-1}$$

$$a_n = a_{n-1} [1 + 0.875\%]$$

$$\Rightarrow a_n = a_{n-1} \left[ 1 + \frac{0.875}{100} \right]$$

$$a_n = 1.00875 a_{n-1}, \quad n > 1.$$

This is the Recurrence relation at the end of 'n' months.

$\therefore$  General soln of the recurrence relation is given by

$$a_n = c^n a_0.$$

$$a_n = (1.00875)^n \times 10000$$

$\therefore$  Investment at the end of first year is ( $n=12$ )

$$a_{12} = (1.00875)^{12} \times 10000$$

$$= 11102.03$$

$$\underline{a_{12} \approx 11102}$$

Next, to find  $n$  given that

$$a_n = 2 a_0.$$

$$\Rightarrow (1.00875)^n \times 10000 = 2 \times 10000$$

$$\Rightarrow (1.00875)^n = 2$$

$$\Rightarrow n \log_e (1.00875) = \log_e 2$$

$$\Rightarrow n = \frac{\log_e 2}{\log_e (1.00875)} = 79.56.$$

$$\boxed{n \approx 80}.$$

Thus the investment will be doubled in about 80 months  
time ie 6 years and 8 months.

- q) A bank pays a certain % of annual interest on deposits,  
compounding the interest once in 3 months. If a deposit  
doubles in 6 years and 6 months, what is the annual  
% of interest paid by the bank?

Soln: Let the annual rate of interest be  $x\%$ .

$\therefore$  Quarterly rate of interest is  $\left(\frac{x}{4}\right)\%$ .

Let  $a_0$  be the initial deposit and  $a_n$  be the deposit after  
at the end of  $n^{\text{th}}$  quarter.

$$a_1 = a_0 + \left(\frac{x}{4}\right)a_0$$

$$a_2 = a_1 + \left(\frac{x}{4}\right)a_1$$

$$a_n = a_{n-1} + \left(\frac{x}{4}\right)a_{n-1}$$

$$\therefore a_n = a_0 \left[ 1 + \frac{x}{4} \right]^n$$

$$\boxed{a_n = a_0 \left( 1 + \frac{x}{400} \right)^n} \rightarrow \textcircled{1} \quad \text{is the recurrence relation.}$$

General soln of \textcircled{1} is

$$a_n = C^n a_0$$

$$\Rightarrow a_n = \left( 1 + \frac{x}{400} \right)^n a_0$$

Given that the deposit doubles in 6 yrs, 6 months ( $\frac{14}{3}$  months)  $\Rightarrow$  deposit doubles in 26 quarters ( $\because \frac{78}{3} = 26$ )  
 $\therefore n=26$ .

we have  $a_n = 2 a_0$ ,

i.e.  $a_{26} = 2 a_0$ ,

$$\Rightarrow \left( 1 + \frac{x}{400} \right)^{26} \% = 2\%$$

$$\Rightarrow 26 \log_e \left( 1 + \frac{x}{400} \right) = \log_e 2$$

$$\Rightarrow \log_e \left( 1 + \frac{x}{400} \right) = 0.0266595$$

$$\Rightarrow 1 + \frac{x}{400} = e^{0.0266595} = 1.027$$

$$\Rightarrow \frac{x}{400} = 0.027 \Rightarrow \boxed{x = 10.8}$$

Thus the annual rate of interest paid by the bank is 10.8%  
(compounding the interest once in 3 months).

10) A bank pays 6% interest compound quarterly. If Laura invests Rs.100 then how many months must she wait for her money to double?

HINT:- 3 months - 6% interest  
1 month - ?  
 $1 \times \frac{6\%}{3} = 2\%$

$$\begin{array}{l|l} a_0 = 100. & a_n = 2a_0 \\ a_n = a_{n-1} (1+2\%) & \Rightarrow n = 35 \text{ months} \\ \hline a_n = 1.02 a_{n-1} & \end{array}$$

## Second Order Homogeneous Recurrence Relation

A second order homogeneous recurrence relation is of the form  $c_n a_n + c_{n-1} a_{n-1} + c_{n-2} a_{n-2} = 0 \quad \forall n \geq 2 \rightarrow \textcircled{1}$  where  $c_n, c_{n-1}, c_{n-2}$  are real constants.

The auxiliary equation of eq<sup>n</sup>  $\textcircled{1}$  is given by

$$c_n k^2 + c_{n-1} k + c_{n-2} = 0$$

Suppose  $k_1$  and  $k_2$  are the roots of A.E

Case (i): If  $k_1$  and  $k_2$  are real and distinct, then general soln of eq<sup>n</sup>  $\textcircled{1}$  is given by

$$a_n = A k_1^n + B k_2^n; \text{ where } A \neq B \text{ are arbitrary constant}$$

Case (ii): If  $k_1 = k_2 = K$ , then general soln of eq<sup>n</sup>  $\textcircled{1}$  is given by

$$a_n = (A + Bn) K^n.$$

Case (iii): If  $k_1$  and  $k_2$  are imaginary  $\Leftrightarrow$  if  $k_1 = p + iq$ , and  $k_2 = p - iq$ , then the general soln of eq<sup>n</sup>  $\textcircled{1}$  is given by  $a_n = r^n [A \cos n\theta + B \sin n\theta]$ , where  $r = \sqrt{p^2 + q^2}$   $\theta = \tan^{-1} \left( \frac{q}{p} \right)$ .

Solve the following Recurrence relations:

Q1)  $a_n + a_{n-1} - 6a_{n-2} = 0 \quad \forall n \geq 2$  given  $a_0 = -1, a_1 = 8$ .

$\hookrightarrow \textcircled{1}$

Soln:- comparing with  $c_n a_n + c_{n-1} a_{n-1} + c_{n-2} a_{n-2} = 0$ , we have

$$c_n = 1, c_{n-1} = 1, c_{n-2} = -6.$$

A.E i.e  $c_n k^2 + c_{n-1} k + c_{n-2} = 0$ .

$$\Rightarrow k^2 + k - 6 = 0$$

$$\Rightarrow (k+3)(k-2) = 0.$$

$\Rightarrow$  Roots are  $k_1 = -3, k_2 = 2$  real & distinct roots.

$\therefore$  General soln of  $\textcircled{1}$  is given by

$$a_n = A \cdot (-3)^n + B \cdot 2^n \rightarrow \textcircled{2}.$$

Given  $a_0 = -1$ ,  $a_1 = 8$ .

Sub  $n=0$  in ②,

$$a_0 = A(-3)^0 + B(2)^0$$

$$-1 = A + B \rightarrow ③$$

Sub  $n=1$  in ②

$$a_1 = A(-3)^1 + B(2)^1$$

$$8 = -3A + 2B \rightarrow ④$$

Solving ③ & ④,  $\boxed{-A = -2}$ ,  $\boxed{B = 1}$

Sub in ②,  $a_n = -2(-3)^n + 1 \cdot (2)^n$

$$\underline{\underline{a_n = 2^n - 2(-3)^n}}$$

2)  $2a_n = 7a_{n-1} - 3a_{n-2}$ ,  $n \geq 2$ ,  $a_0 = 2$ ,  $a_1 = 5$ .

Soln:-  $2a_n - 7a_{n-1} + 3a_{n-2} = 0 \rightarrow ①$

$$\text{AE: } 2k^2 - 7k + 3 = 0$$

Roots are  $k_1 = 3$ ,  $k_2 = \frac{1}{2}$  (real & distinct)

General soln is given by

$$a_n = A \cdot 3^n + B \cdot \left(\frac{1}{2}\right)^n \rightarrow ②$$

given  $a_0 = 2$ ,  $a_1 = 5$

Sub  $n=0$  in ②,  $a_0 = A + B$

$$\Rightarrow 2 = A + B \rightarrow ③$$

Sub  $n=1$  in ②,  $a_1 = 3A + \frac{1}{2}B$

$$\Rightarrow 5 = \frac{6A + B}{2} \quad (\text{or}) \quad 6A + B = 10 \rightarrow ④$$

Solving ③ & ④,  $\boxed{A = \frac{8}{5}}$ ,  $\boxed{B = \frac{2}{5}}$ .

Sub in ②,  $\underline{\underline{a_n = \left(\frac{8}{5}\right)3^n + \left(\frac{2}{5}\right)\left(\frac{1}{2}\right)^n}}$

3)  $a_n - 6a_{n-1} + 9a_{n-2} = 0$ ,  $n \geq 2$ ,  $a_0 = 5$ ,  $a_1 = 12$ .

Soln:-

$$\text{AE: } k^2 - 6k + 9 = 0$$

$$\Rightarrow [k=3, 3]$$

Roots are real & repeated.

∴ General soln of ① is

$$a_n = (A + BN) 3^n \rightarrow ②$$

$$\text{Given } a_0 = 5, a_1 = 12$$

$$\text{sub } n=0 \text{ in } ② \Rightarrow a_0 = A \cdot 3^0$$

$$[5 = A]$$

$$\text{sub } n=1 \text{ in } ② \Rightarrow a_1 = (A + B) 3^1$$

$$12 = (5 + B) 3$$

$$12 = 15 + 3B$$

$$3B = -3 \Rightarrow [B = -1]$$

$$\text{sub in } ①, [a_n = (5 - n) 3^n]$$

$$4) 4a_n + 2a_{n-1} + a_{n-2} = 0.$$

$$\text{Soln: AE: } 4k^2 + 2k + 1 = 0.$$

$$k = \frac{-2 \pm \sqrt{4-16}}{8} = \frac{-2 \pm \sqrt{-12}}{8} = \frac{-2 \pm 2i\sqrt{3}}{8}$$

$$[k = \frac{-1 \pm i\sqrt{3}}{4}]$$

$$\text{Roots are } k_1 = -\frac{1+i\sqrt{3}}{4}, k_2 = -\frac{1-i\sqrt{3}}{4} \quad (\text{imaginary roots})$$

$$\text{Comparing with } p \pm iq, \quad p = -\frac{1}{4}, \quad q = \frac{\sqrt{3}}{4}.$$

$$\therefore r = \sqrt{p^2+q^2} = \sqrt{\frac{1}{16} + \frac{3}{16}} = \sqrt{\frac{4}{16}} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

$$\theta = \tan^{-1}\left(\frac{q}{p}\right) = \tan^{-1}\left(\frac{\sqrt{3}/4}{-1/4}\right) = \tan^{-1}(-\sqrt{3}) = -60^\circ = -\frac{\pi}{3}$$

∴ General soln of ① is

$$a_n = r^n [A \cos n\theta + B \sin n\theta]$$

$$a_n = \left(\frac{1}{2}\right)^n \left[ A \cos\left(-\frac{n\pi}{3}\right) + B \sin\left(-\frac{n\pi}{3}\right) \right].$$

=====

$$5) a_n = 2(a_{n-1} - a_{n-2}), \quad \text{for } n \geq 2 \quad \text{given that } a_0 = 1 \text{ & } a_1 = 2.$$

$$\text{Ans: } a_n = (\sqrt{2})^n \left[ \cos \frac{n\pi}{4} + \sin \frac{n\pi}{4} \right].$$

Given  $D_n = bD_{n-1} - b^2 D_{n-2}$  for  $n \geq 3$ , given  $D_1 = b > 0$ ,  $D_2 = 0$

Soln:-  $D_n - bD_{n-1} + b^2 D_{n-2} = 0 \rightarrow ①$

A.E:  $k^2 - bk + b^2 = 0$

$$k = \frac{b \pm \sqrt{b^2 - 4b^2}}{2} = \frac{b \pm \sqrt{-3b^2}}{2} = \frac{b \pm i\sqrt{3}b}{2}$$

$$\therefore k_1 = \frac{b}{2} + i\frac{\sqrt{3}b}{2} \text{ and } k_2 = \frac{b}{2} - i\frac{\sqrt{3}b}{2} \text{ (imaginary roots)}$$

Q. General soln for  $D_n$  is

$$D_n = r^n [A \cos n\theta + B \sin n\theta] \rightarrow ②$$

where A and B are arbitrary constants.

$$r = \sqrt{p^2 + q^2} = \sqrt{\frac{b^2}{4} + \frac{3b^2}{4}} = \sqrt{\frac{4b^2}{4}} = b. \quad p = \frac{b}{2}, q = \frac{\sqrt{3}b}{2}$$

$$\theta = \tan^{-1}\left(\frac{q}{p}\right) = \tan^{-1}\left(\frac{\sqrt{3}b/2}{b/2}\right) = \tan^{-1}\sqrt{3} = \pi/3.$$

②  $\Rightarrow D_n = b^n \left[ A \cos \frac{n\pi}{3} + B \sin \frac{n\pi}{3} \right] \rightarrow ③$  is the g. soln.

given  $D_1 = b$ ,  $D_2 = 0$ .

Put  $n=1$  in ③,  $D_1 = b \left[ A \cos \frac{\pi}{3} + B \sin \frac{\pi}{3} \right]$

$$b = b \left[ A \cdot \frac{1}{2} + B \cdot \frac{\sqrt{3}}{2} \right]$$

$$\Rightarrow \boxed{1 = \frac{1}{2}A + \frac{\sqrt{3}}{2}B} \rightarrow ④$$

Put  $n=2$  in ③,  $D_2 = b^2 \left[ A \cos \frac{2\pi}{3} + B \sin \frac{2\pi}{3} \right]$

$$0 = b^2 \left[ A \cos(180^\circ - 60^\circ) + B \sin(180^\circ - 60^\circ) \right]$$

$$\Rightarrow 0 = -A \cos 60^\circ + B \sin 60^\circ$$

$$\Rightarrow \boxed{0 = -\frac{1}{2}A + \frac{\sqrt{3}}{2}B} \rightarrow ⑤$$

Solving ④ & ⑤,  $\boxed{A = 1, B = \sqrt{3}}$

Sub in ③,

$$D_n = b^n \left[ \cos \frac{n\pi}{3} + \frac{1}{\sqrt{3}} \sin \frac{n\pi}{3} \right].$$

$$\text{Q) } f_{n+2} = f_{n+1} + f_n \quad \text{for } n \geq 0, \text{ given } f_0 = 0, f_1 = 1.$$

Soln:- Rewriting as  $f_n = f_{n-1} + f_{n-2}$

$$\Rightarrow f_n - f_{n-1} - f_{n-2} = 0 \quad \text{for } n \geq 2. \quad \rightarrow ①$$

$$\text{AE: } k^2 - k - 1 = 0.$$

$$k = \frac{1 \pm \sqrt{1+4}}{2} = \frac{1 \pm \sqrt{5}}{2} \quad (\text{real & distinct roots})$$

$$k_1 = \frac{1+\sqrt{5}}{2}, \quad k_2 = \frac{1-\sqrt{5}}{2}$$

General soln of ① is

$$f_n = A \left( \frac{1+\sqrt{5}}{2} \right)^n + B \left( \frac{1-\sqrt{5}}{2} \right)^n, \quad \text{where } A \text{ & } B \text{ are arbitrary constants.} \quad \rightarrow ②$$

$$\text{Given } f_0 = 0, f_1 = 1.$$

$$\text{sub } n=0 \text{ in } ②, \quad f_0 = A + B$$

$$\boxed{0 = A + B} \rightarrow ③$$

$$\begin{aligned} \text{sub } n=1 \text{ in } ②, \quad f_1 &= A \left( \frac{1+\sqrt{5}}{2} \right) + B \left( \frac{1-\sqrt{5}}{2} \right) \\ \Rightarrow \boxed{1 = A \left( \frac{1+\sqrt{5}}{2} \right) + B \left( \frac{1-\sqrt{5}}{2} \right)} &\rightarrow ④ \end{aligned}$$

$$\text{Eqn } ③ \times \left( \frac{1+\sqrt{5}}{2} \right) \text{ gives } 0 = \left( \frac{1+\sqrt{5}}{2} \right) A + \left( \frac{1+\sqrt{5}}{2} \right) B \rightarrow ⑤$$

$$④ - ⑤ \Rightarrow 1 = B \left( \frac{1-\sqrt{5}}{2} - \frac{1+\sqrt{5}}{2} \right)$$

$$1 = B \left( -\frac{2\sqrt{5}}{2} \right) \Rightarrow \boxed{B = -\sqrt{5}}$$

$$\text{from } ③, \quad A = -B \Rightarrow \boxed{A = \sqrt{5}}$$

sub in ②,

$$f_n = \frac{1}{\sqrt{5}} \left[ \left( \frac{1+\sqrt{5}}{2} \right)^n - \left( \frac{1-\sqrt{5}}{2} \right)^n \right]$$

=