

Permutations and Combinations

- **Fundamental Principle of Counting:** If an event occurs in m different ways, following which another event occurs in n different ways, then the total number of occurrence of the events in the given order is $m \times n$. This is called the fundamental principle of counting.

Example: Find the number of 5-letter words, with or without meaning, which can be formed out of the letters of the word MATHS, where the repetition of digits is not allowed.

Solution: There are as many words as there are ways of filling 5 vacant places $\square\square\square\square\square$ by the 5 letters.

The first place can be filled with any of the 5 letters in 5 different ways, following which the second place can be filled with any of the remaining 4 letters in 4 different ways, following which the third place can be filled in 3 different ways, following which the fourth place can be in 2 different ways, following which the fifth place can be filled in 1 way. Thus, the number of ways in which the 5 places can be filled, by the multiplication principle, is $5 \times 4 \times 3 \times 2 \times 1 = 120$.

Note: If repetition of letters had been allowed, then the required number of words would be $5 \times 5 \times 5 \times 5 \times 5 = 3125$.

- **Factorial notation:** The notation $n!$ represents the product of the first n natural numbers, i.e. $n! = n \times (n-1) \times (n-2) \times \dots \times 5 \times 4 \times 3 \times 2 \times 1$
 $0! = 1$

Example:

$$\begin{aligned}\frac{12!}{8!} &= \frac{12 \times 11 \times 10 \times 9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1}{8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1} \\ &= 12 \times 11 \times 10 \times 9 \\ &= 11880\end{aligned}$$

- **Permutation when all objects are distinct:** A permutation is an arrangement in a definite order of a number of objects taken some or all at a time. The number of permutations of n different things taken r at a time, when

- repetition is not allowed, is ${}^n P_r = \frac{n!}{(n-r)!}$, where $0 \leq r \leq n$.
- repetition is allowed, is n^r , where $0 \leq r \leq n$.

Example 1: Twenty five students are participating in a competition. In how many ways, can the first three prizes be won in such a way that a prize cannot be shared by more than one student?

Solution: The total number of ways in which first three prizes can be won is the number of arrangements of 25 different things taken 3 at a time.

So, required number of ways = ${}^{25}P_3$

$$= \frac{25!}{(25-3)!}$$

$$= \frac{25!}{22!}$$

$$= \frac{25 \times 24 \times 23 \times 22!}{22!}$$

$$= 25 \times 24 \times 23 = 13800$$

Example 2: Find the total number of four digit numbers that can be formed by using the digits 0, 2, 5, and 6?

Solution: A four digit number has four places i.e., units, tens, hundreds and thousands. Units, tens and hundreds place can be filled with either 0, 2, 5, or 6 where as thousands place can be filled with 2, 5 or 6 only.

Number of ways to fill the units place = 4

Number of ways to fill the tens place = 4

Number of ways to fill the hundreds place = 4

Number of ways to fill the thousands place = 3 ways.

$\therefore$ Total number of four digit numbers = $4 \times 4 \times 4 \times 3 = 192$

- **Concept of permutations when all objects are not distinct**

- The number of permutations of n objects, when p objects are of the same kind and the rest are all different, is $\frac{n!}{p!}$.

- In general, the number of permutations of n objects, when p_1 objects are of one kind, p_2 are of the second kind, ..., p_k are of the k^{th} kind and the rest, if any, are of different kinds, is $\frac{n!}{p_1! p_2! \dots p_k!}$.

Example: Find the number of permutations of the letters of the word ARRANGEMENT.

Solution: Here, there are 11 objects (letters) of which there are 2A's, 2R's, 2N's, 2E's and the rest are all different.

$\therefore$ Required number of arrangements

$$= \frac{11!}{2! 2! 2! 2!}$$

$$= \frac{11 \times 10 \times 9 \times 8 \times 7 \times 6 \times 5 \times 3 \times 2}{2 \times 2 \times 2 \times 2}$$

$$= 2494800$$

- **Combinations:** The number of combinations of n different things taken r at a time is denoted by nC_r , which is given by

$${}^nC_r = \frac{n!}{r!(n-r)!}, \text{ where } 0 \leq r \leq n.$$

In particular, ${}^nC_0 = {}^nC_n = 1$

Example 1: A box contains 8 red bulbs and 5 blue bulbs. Determine the number of ways in which 4 red and 2 blue bulbs can be selected.

Solution: It is given that a box contains 8 red bulbs and 5 blue bulbs.

Now, 4 red bulbs can be selected from 8 red bulbs in 8C_4 number of ways, and 2 blue bulbs can be selected from 4 blue bulbs in 4C_2 number of ways.

Hence, 4 red bulbs and 2 blue bulbs can be selected from a box containing 8 red bulbs and 4 blue bulbs in ${}^8C_4 \times {}^4C_2$ number of ways.

Now,

$$\begin{aligned} & {}^8C_4 \times {}^4C_2 \\ &= \frac{8!}{4! \times (8-4)!} \times \frac{4!}{2! \times (4-2)!} \\ &= \frac{8!}{4! \times 4!} \times \frac{4!}{2! \times 2!} \\ &= \frac{8 \times 7 \times 6 \times 5}{4 \times 3 \times 2 \times 1} \times \frac{4 \times 3}{2 \times 1} \\ &= 70 \times 6 \\ &= 420 \end{aligned}$$

Thus, the number of ways of selecting the bulbs is 420.

$${}^nC_{n-r} = \frac{n!}{(n-r)![n-(n-r)]!} = \frac{n!}{(n-r)!r!} = {}^nC_r$$

- In other words, selecting r objects out of n objects is the same as rejecting $(n-r)$ objects.
- ${}^nC_a = {}^nC_b \Rightarrow a = b$ or $a = n$, i.e., $n = a + b$

Example 2: If ${}^{19}C_{3r} = {}^{19}C_{2r+4}$, then find the value of r .

Solution:

$$\begin{aligned} & {}^{19}C_{3r} = {}^{19}C_{2r+4} \\ & \Rightarrow 3r + (2r + 4) = 19 \quad \text{or} \quad 3r = 2r + 4 \\ & \Rightarrow 3r + (2r + 4) = 19 \quad \Rightarrow r = 4 \\ & \Rightarrow 5r + 4 = 19 \\ & \Rightarrow 5r = 19 - 4 = 15 \\ & \Rightarrow r = 3 \end{aligned}$$

$\therefore$ The value of r is either 3 or 4.

- ${}^nC_{r-1} + {}^nC_r = {}^{n+1}C_r$

Example 3: If ${}^nC_{r-1} + {}^nC_r + {}^{n+1}C_{r+1} + {}^{n+2}C_{r+2} = {}^{n+a}C_{r+(a-1)}$, then find the value of a.

Solution:

$${}^nC_{r-1} + {}^nC_r + {}^{n+1}C_{r+1} + {}^{n+2}C_{r+2}$$

$$= {}^{n+1}C_r + {}^{n+1}C_{r+1} + {}^{n+2}C_{r+2}$$

$$= {}^{n+1}C_{r+1} + {}^{n+2}C_{r+2}$$

$$= {}^{n+3}C_{r+2}$$

$$\therefore {}^{n+3}C_{r+2} = {}^{n+a}C_{r+(a-1)}$$

$$\Rightarrow a = 3$$

$$(\because {}^nC_{r-1} + {}^nC_r = {}^{n+1}C_r)$$