

Application of Marks to Computation of Ranks and Subdegrees of the Symmetric Group Acting on Ordered 4-Element and 5-Element Subsets

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Abstract

Ranks and subdegrees can be computed using combinatorial arguments, the Cauchy-Frobenius lemma and use of the concept of marks. However the concept of Marks has been given very little attention. In this paper we will apply the concept of marks to compute the ranks and subdegrees of the symmetric group S_n ($n = 7, 8, 9$) acting on ordered 4-element subsets and S_n ($n = 8, 9, 10$) acting on ordered 5-element subsets.

Keywords: Ranks, Subdegrees, Marks

1. Introduction

Let G be transitive on a set X and let G_x be the stabilizer in G of a point $x \in X$. The orbits of G_x on X are known as suborbits of G . The number of these suborbits is known as the rank of G on X and the lengths of the suborbits is known as the subdegrees of G on X . If G acts on X transitively, then its action is equivalent to the action on the cosets of $H = G_x$, while that of H on any suborbit is equivalent to its action on the cosets of some subgroup F of H .

2. Notations and Preliminary Results

Notation 2.1

In this paper, $X^{[r]}$, $[a_1, a_2, \dots, a_n]$, $R(G)$ and $m(A, B, G)$ denote the set of all ordered r -element subsets from the set X , ordered r -element subset of X the rank of a permutation Group G and the mark of subgroup A in the representation of G on the cosets of subgroup B respectively.

Theorem 2.1(Rose [5])

Let G act on the set X , and let $x \in X$. Then

$$|Orb_G(x)| = |G:Stab_G(x)|.$$

Definition 2.2(Ivanov [2])

If $G_j \leq G_i \leq G$ and $(G_{j_1}, G_{j_2}, \dots, G_{j_n})$ is a complete set of conjugacy class representatives of subgroups of G_i that are conjugate to G_j in G , then

$$m(G_j, G_i, G) = \sum_{k=1}^n |N_G(G_{j_k}) : N_{G_i}(G_{j_k})|.$$

Definition 2.3

Let H_1, H_2, \dots, H_t be a set of representatives of all distinct conjugacy classes of subgroups of H in G , ordered such that $|H_1| \leq |H_2| \leq \dots \leq |H_t| = |H|$ Form a matrix $M = (m_{ij})$, where

$m_{ij} = m(H_j, H_i, H)$. We call M the table of marks of H ;

If we denote by Q_i the number of suborbits Δ_j on which the action of H is equivalent to its action on the cosets of H_i ($i = 1, 2, \dots, t$), by computing all Q_i we get the subdegrees of G on X .

Theorem 2.4 (Ivanov [2])

The numbers Q_i satisfy the system of linear equations

$$\sum_{i=j}^t Q_i m(H_j, H_i, H) = m(H_j, H, G), \text{ for each } j = 1, 2, \dots, t.$$

Theorem 2.5 (Rimberia [4])

Let G be the symmetric group S_n , then G acts transitively on $X^{[r]}$.

Theorem 2.6(Rimberia [4])

Let $G = S_n$ be the symmetric group on the set $X = \{a_1, a_2, \dots, a_n\}$. The stabilizer of an ordered subset $[a_1, a_2, \dots, a_r]$ in G is isomorphic to S_{n-r} , the symmetric group on the set $\{a_{r+1}, a_{r+2}, \dots, a_n\}$.

3. Ranks And Subdegrees Of The Symmetric Group S_n ($n = 7,8,9$) Acting On $X^{[2]}$

3.1 Rank and Subdegrees of S_7 acting on $X^{[4]}$

We first construct the table of marks of $H = \text{Stab}_G\{[1,2,3,4]\}$, where $G = S_7$. Then by Theorem 2.6, H is isomorphic to S_3 , the symmetric group on the set $\{5,6,7\}$. We will use GAP software to determine the conjugacy classes of subgroups and construct the table of marks by using the algorithms shown on the Appendix 1. The conjugacy classes of subgroups of S_3 are as shown below and its table of marks is as shown in Table 1

- i) H_1 Identity
- ii) H_2 3 conjugate subgroups of order 2
- iii) H_3 A normal cyclic group of order 3
- iv) H_4 H

For $F \leq H$, with the order they are represented in Table 1, the values of $m(F, H, G) = m(F)$ are displayed in Table 3.1.1.

Table 3.1.1: Marks of F in G(H), where $G = S_5$ and $H = \text{Stab}_G\{[1, 2, 3, 4]\}$

F	H_1	H_2	H_3	H_4
$m(F)$	840	120	24	24

Let $Q = (Q_1, Q_2, Q_3, Q_4)$ and the matrix obtained from Table 1 be M . By Theorem 2.3 and using Table 1 we obtain the following system of linear equations,

$$\begin{aligned} 6Q_1 + 3Q_2 + 2Q_3 + Q_4 &= 840 \\ Q_2 + Q_4 &= 120 \\ 2Q_3 + Q_4 &= 24 \\ Q_4 &= 24 \dots \dots \dots (1) \end{aligned}$$

On solving (1), we get $Q = (88, 96, 0, 24)$.

Therefore the subdegrees of G acting on $X^{[4]}$ are as shown in Table 3.1.2.

Table 3.1 2: subdegrees of S_7 acting on $X^{[4]}$

Suborbit length	1	3	6
No. of suborbits	24	96	88

From Table 3.1.2 we obtain, the rank of $G, R(G) = 24 + 96 + 88 = 208$.

We now apply the same procedure for the other actions.

3.2. Rank and Subdegrees of $G = S_8$ acting on $X^{[4]}$

Let $H = \text{Stab}_G\{[1,2,3,4]\}$, where $G = S_8$. By Theorem 3.1.1 H is isomorphic to S_4 which has 11 conjugacy classes of subgroups. These are;

- i). H_1 identity.
- ii). H_2 conjugate subgroups of order 2 generated by permutations of the form (ab)(cd).
- iii). H_3 conjugate subgroups of order 2 generated by permutations of the form (ab).
- iv). H_4 conjugate cyclic subgroups of order 3.
- v). H_5 a normal subgroups of order 4 generated by permutations of the form (ab)(cd) and (ac)bd).
- vi). H_6 3 conjugate subgroups of order 4 generated by permutations of the form (ab)(cd) and (cd).
- vii). H_7 3 conjugate cyclic subgroups of order 4.

- viii). H_8 4 conjugate subgroups of order 6 isomorphic to S_3 generated by permutations of the form (abc) and (cd).
- ix). H_9 3 conjugate subgroups of order 8 generated by permutations of the form (ab)(cd), (ac)(bd) and (bd).
- x). H_{10} a normal subgroup of order 12 isomorphic to A_4
- xi). H_{11} S_4

Its table of marks is as shown Table 2.

For $F \leq H$, the values of $m(F, H, G) = m(F)$ are displayed in Table 3.

Table 3.2.1: Marks of F in G(H), where $G = S_8$ and $H = Stab_G\{[1, 2, 3, 4]\}$

F	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	H_{10}	H_{11}
$m(F)$	1680	24	360	120	24	24	24	120	24	24	24

Let $Q = (Q_1, Q_2, \dots, Q_{11})$ By Theorem 2.3 and using Table 3 we obtain the following system of linear equations in matrix form,

$$\begin{pmatrix} 24 & 12 & 12 & 8 & 6 & 6 & 6 & 4 & 3 & 2 & 1 \\ 0 & 2 & 0 & 0 & 0 & 0 & 2 & 2 & 1 & 0 & 1 \\ 0 & 0 & 4 & 0 & 2 & 6 & 2 & 0 & 3 & 2 & 1 \\ 0 & 0 & 0 & 2 & 0 & 0 & 0 & 1 & 0 & 2 & 1 \\ 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 6 & 0 & 0 & 3 & 2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \\ Q_5 \\ Q_6 \\ Q_7 \\ Q_8 \\ Q_9 \\ Q_{10} \\ Q_{11} \end{pmatrix} = \begin{pmatrix} 1680 \\ 24 \\ 360 \\ 120 \\ 24 \\ 24 \\ 24 \\ 120 \\ 24 \\ 24 \\ 24 \end{pmatrix} \dots\dots\dots(2)$$

On solving (2), we obtain $Q = (17,0,72,0,0,0,0,96,0,0,24)$.

Therefore subdegrees of S_8 acting on $X^{[4]}$ are as shown in Table 3.2.2.

Table 3.2.2: Subdegrees of $G = S_8$ acting on $X^{[4]}$

Suborbit length	1	4	12	24
No. of suborbits	24	96	72	17

From Table 4 we see that, the rank of $G, R(G) = 24 + 96 + 72 + 17 = 209$.

3.3 Rank and Subdegrees of $G = S_9$ acting on $X^{[4]}$

Let $H = Stab_G\{[1,2,3,4]\}$, where $G = S_9$. By Theorem 2.6 H is isomorphic to S_5 which has 19 conjugacy classes of subgroups (See Appendix 3). Its table of marks is as shown by Table 3.

For $F \leq H$, with the order they are represented in Table 3, the values of $m(F, H, G) = m(F)$ are displayed in Table 3.3.1.

Table 3.3.1: Marks of F in G(H) where $G = S_9$ and $H = Stab_G\{[1, 2, 3, 4]\}$

F	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	H_{10}
$m(F)$	3024	840	120	360	120	120	120	24	360	24

F	H_{11}	H_{12}	H_{13}	H_{14}	H_{15}	H_{16}	H_{17}	H_{18}	H_{19}
$m(F)$	24	120	24	120	24	24	120	24	24

Let $Q = (Q_1, Q_2, \dots, Q_{19})$. By Theorem 2.3 and using Table 5, we obtain the following system of linear equations in matrix form,

$$\begin{pmatrix} 120 & 60 & 60 & 40 & 30 & 30 & 30 & 24 & 20 & 20 & 20 & 15 & 12 & 10 & 10 & 6 & 5 & 2 & 1 \\ 0 & 6 & 0 & 0 & 0 & 0 & 6 & 0 & 6 & 2 & 0 & 3 & 0 & 0 & 4 & 0 & 3 & 0 & 1 \\ 0 & 0 & 4 & 0 & 2 & 6 & 2 & 0 & 0 & 0 & 4 & 3 & 4 & 2 & 2 & 2 & 1 & 2 & 1 \\ 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 2 & 2 & 0 & 0 & 4 & 1 & 0 & 2 & 2 & 1 \\ 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 2 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 6 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 2 & 0 & 0 & 1 & 2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 2 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 1 & 0 & 2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 2 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} Q_1 \\ Q_2 \\ \vdots \\ Q_{18} \\ Q_{19} \end{pmatrix} = \begin{pmatrix} 3024 \\ 840 \\ 120 \\ 360 \\ 120 \\ 120 \\ 120 \\ 120 \\ 24 \\ 360 \\ 24 \\ 24 \\ 24 \\ 120 \\ 24 \\ 120 \\ 24 \\ 120 \\ 24 \\ 24 \\ 120 \\ 24 \\ 24 \end{pmatrix} \dots(3)$$

On solving (3) we obtain $Q = (1,16,0,0,0,0,0,0,0,72,0,0,0,0,0,0,0,96,0,24)$.

Therefore, the Subdegrees of G acting on $X^{[4]}$ are as shown in Table 3.3.2.

Table 3.3.2: Subdegrees of $G = S_7$ acting on $X^{[4]}$

Suborbit length	1	5	20	60	120
No. of suborbits	24	96	72	16	1

From Table 6 we see that the Rank of $G, R(G) = 24 + 96 + 72 + 16 + 1 = 209$.

4. Ranks and Subdegrees of S_n ($n = 8, 9, 10$) Acting On $X^{[5]}$

4.1 Rank and Subdegrees of $G = S_8$ acting on $X^{[5]}$

Let $H = \text{Stab}_G\{[1,2,3,4,5]\}$, where $G = S_8$. By Theorem 2.6, H is isomorphic to S_3 , the symmetric group on the set $\{6,7,8\}$. Its table of marks is as shown by Table 1.

For $F \leq H$, with the order they are represented in Table 1, the values of $m(F, H, G) = m(F)$ are displayed in Table 4.1.1.

Table 4.1.1: Marks of F in $G(H)$, where $G = S_8$ and $H = \text{Stab}_G\{[1, 2, 3, 5]\}$

F	H_1	H_2	H_3	H_4
$m(F)$	6720	720	360	360

Let $Q = (Q_1, Q_2, Q_3, Q_4)$. By Theorem 2.3 and using Table 4.1.1, we obtain the following system of linear equations.

$$\begin{aligned} 6Q_1 + 3Q_2 + 2Q_3 + Q_4 &= 6720 \\ Q_2 + Q_4 &= 720 \\ 2Q_3 + Q_4 &= 360 \\ Q_4 &= 360 \dots\dots\dots(4) \end{aligned}$$

On solving (4) we obtain $Q = (800, 600, 0, 120)$.

Therefore the subdegrees of G acting on $X^{[5]}$ are as shown in Table 4.1.2.

Table 4.1.2: subdegrees of $G = S_8$ acting on $X^{[5]}$

Suborbit length	1	3	6
No. of suborbits	120	600	800

From Table 8 we see that the rank of $G, R(G) = 120 + 600 + 800 = 1520$.

4.2. Rank and Subdegrees of $G = S_9$ acting on $X^{[5]}$

Let $H = \text{Stab}_G\{[1,2,3,4,5]\}$, where $G = S_9$. By Theorem 2.6 H is isomorphic to S_4 , the symmetric group on the set $\{6,7,8,9\}$. Its table of marks is as shown by Table 2.

For $F \leq H$, with the order they are represented in Table 2. The values of $m(F, H, G) = m(F)$ are displayed in Table 4.2.1.

Table 4.2.1: Marks of F in $G (H)$, where $G = S_9$ and $H = \text{Stab}_G\{[1, 2, 3, 4, 5]\}$

F	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8	H_9	H_{10}	H_{11}
m(F)	15120	120	2520	720	120	120	120	720	120	120	120

Let $Q = (Q_1, Q_2, \dots, Q_{11})$. By Theorem 2.3 and using Table 4.2.1, we obtain the following system of linear equations in matrix form.

$$\begin{pmatrix} 24 & 12 & 12 & 8 & 6 & 6 & 6 & 4 & 3 & 2 & 1 \\ 0 & 2 & 0 & 0 & 0 & 0 & 2 & 2 & 1 & 0 & 1 \\ 0 & 0 & 4 & 0 & 2 & 6 & 2 & 0 & 3 & 2 & 1 \\ 0 & 0 & 0 & 2 & 0 & 0 & 0 & 1 & 0 & 2 & 1 \\ 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 6 & 0 & 0 & 3 & 2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \\ Q_5 \\ Q_6 \\ Q_7 \\ Q_8 \\ Q_9 \\ Q_{10} \\ Q_{11} \end{pmatrix} = \begin{pmatrix} 15120 \\ 120 \\ 2520 \\ 720 \\ 120 \\ 120 \\ 120 \\ 720 \\ 120 \\ 120 \\ 120 \end{pmatrix} \dots\dots\dots(5)$$

On solving (5) we obtain $Q = (225, 0, 600, 0, 0, 0, 0, 600, 0, 0, 120)$.

Therefore the subdegrees of G acting on $X^{[5]}$ are as shown in Table 4.2.2.

Table 4.2.2: Subdegrees of $G = S_9$ acting on $X^{[5]}$

Suborbit length	1	4	12	24
No. of suborbits	120	600	600	225

From Table 4.2.2 we see that the rank of $G, R(G) = 120 + 600 + 600 + 225 = 1545$.

4.3 Rank and Subdegrees of $G = S_{10}$ acting on $X^{[5]}$

Let $H = \text{Stab}_G\{[1,2,3,4,5]\}$, where $G = S_{10}$. By Theorem 2.6 H is isomorphic to S_5 , the symmetric group on the set $\{6,7,8,9,10\}$. Its table of marks is as shown by Table 3.

For $F \leq H$, with the order they are represented in Table 3, the values of $m(F, H, G) = m(F)$ are as displayed in Table 4.3.1.

Table 4.3.1: Marks of F in G(H), where G = S₁₀ and H = Stab_G{[1, 2, 3, 4, 5]}

F	H ₁	H ₂	H ₃	H ₄	H ₅	H ₆	H ₇	H ₈	H ₉	H ₁₀
m(F)	30240	6720	720	2520	720	720	720	120	2520	120

F	H ₁₁	H ₁₂	H ₁₃	H ₁₄	H ₁₅	H ₁₆	H ₁₇	H ₁₈	H ₁₉
m(F)	120	720	120	720	120	120	720	120	120

Let $Q = (Q_1, Q_2, \dots, Q_{19})$. By Theorem 2.3 and using Table 4.3.1, we obtain the following system of linear equations in matrix form,

$$\begin{pmatrix}
 120 & 60 & 60 & 40 & 30 & 30 & 30 & 24 & 20 & 20 & 20 & 15 & 12 & 10 & 10 & 6 & 5 & 2 & 1 \\
 0 & 6 & 0 & 0 & 0 & 0 & 6 & 0 & 6 & 2 & 0 & 3 & 0 & 0 & 4 & 0 & 3 & 0 & 1 \\
 0 & 0 & 4 & 0 & 2 & 6 & 2 & 0 & 0 & 0 & 4 & 3 & 4 & 2 & 2 & 2 & 1 & 2 & 1 \\
 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 2 & 2 & 2 & 0 & 0 & 4 & 1 & 0 & 2 & 2 & 1 \\
 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 2 & 1 & 0 & 1 \\
 0 & 0 & 0 & 0 & 0 & 6 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 2 & 0 & 0 & 1 & 2 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 2 & 0 & 1 & 0 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 1 & 0 & 2 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 2 & 0 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 1 & 0 & 0 & 2 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 1 & 0 & 2 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 1 & 2 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 1 \\
 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
 \end{pmatrix}
 \begin{pmatrix}
 Q_1 \\
 Q_2 \\
 \vdots \\
 Q_{18} \\
 Q_{19}
 \end{pmatrix}
 =
 \begin{pmatrix}
 30240 \\
 6720 \\
 720 \\
 2520 \\
 720 \\
 720 \\
 720 \\
 120 \\
 2520 \\
 120 \\
 120 \\
 720 \\
 120 \\
 720 \\
 120 \\
 120 \\
 720 \\
 120 \\
 120 \\
 720 \\
 120 \\
 120 \\
 720 \\
 120 \\
 120
 \end{pmatrix} \dots (6)$$

On solving (6) we obtain $Q = (26, 200, 0, 0, 0, 0, 0, 0, 600, 0, 0, 0, 0, 0, 0, 600, 0, 120)$

Therefore the subdegrees of S₁₀ acting on X^[5] are as shown in the Table 4.3.2.

Table 4.3.2: Subdegrees of G = S₁₀ acting on X^[5]

Suborbit length	1	5	20	60	120
No. of suborbits	120	600	600	200	26

From Table 12, we see that rank of G, $R(G) = 120 + 600 + 600 + 200 + 26 = 1546$

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*******APPENDICES*******

Appendix 1: GAP algorithms used to generate conjugacy classes and table of marks of $H = S_3$

To generate $H = S_3$ the symmetric group on the set $\{3,4,5\}$ on the GAP, we have used its generators; $(5,6,7)$ and $(5,6)$ and the command;

```
gap> H:=Group([(5,6,7),(5,6)]);
Group([ (5,6,7), (5,6) ])
```

To get the conjugacy classes of subgroups of H. here we use the command;

```
gap> ConjugacyClassesSubgroups(H);
[ Group( () )^G, Group( [ (6,7) ] )^G, Group( [ (5,6,7) ] )^G, Group( [ (5,6,7),
(6,7) ] )^G ]
```

To construct the table of marks of H, we use the command;

```
gap> Tom1:=TableOfMarks(H);
TableOfMarks( Sym( [ 5 .. 7 ] ) )
```

To view it we use the command;

```
gap> Display(Tom1);
```

```
1: 6
2: 3 1
3: 2 . 2
```

4: 1 1 1 1..... **Table 1: Table of marks of S_3**

To get the sizes number of conjugate subgroups in each conjugacy class of subgroups we use the following command;

```
gap> LengthsTom(Tom1);
[ 1, 3, 1, 1 ]
```

To get the orders of the conjugacy classes of subgroups we use the following command;

```
gap> OrdersTom(Tom1);
[ 1, 2, 3, 6 ]
```

Let the matrix obtained from expressing T in matrix form be M. to get M we use the command;

```
gap> M:=MatTom(Tom1);
[ [ 6, 0, 0, 0 ], [ 3, 1, 0, 0 ], [ 2, 0, 2, 0 ], [ 1, 1, 1, 1 ] ]
```

To solve the system of linear equation, we use the command;

```
gap> SolutionMat(M,[840,120,24,24]);
[ 88, 96, 0, 24 ]
```

For the other cases the similar algorithms were used to generate the other results.

Appendix 2: GAP algorithms used to generate conjugacy classes and table of marks of $H = S_4$

S_4 can be generated by (ab) and $(abcd)$. To generate $H = S_4$ the symmetric group on the set $\{5,6,7,8\}$ on the GAP, we have used its generators; $(5,6,7,8)$ and $(5,6)$ and the command;

```
gap> H:=Group([(5,6,7,8),(5,6)]);
Group([ (5,6,7,8), (5,6) ])
```

We now use a similar procedure as in Appendix 1.

```
gap> ConjugacyClassesSubgroups(H);
[ Group( () )^G, Group( [ (5,7)(6,8) ] )^G, Group( [ (7,8) ] )^G, Group( [ (6,8,7)
] )^G,
Group( [ (5,8)(6,7), (5,7)(6,8) ] )^G, Group( [ (7,8), (5,6)(7,8) ] )^G, Group( [
(5,7,6,8), (5,6)(7,8) ] )^G,
Group( [ (7,8), (6,8,7) ] )^G, Group( [ (5,8)(6,7), (5,7)(6,8), (7,8) ] )^G,
Group( [ (5,8)(6,7), (5,7)(6,8), (6,8,7) ] )^G, Group( [ (5,8)(6,7), (5,7)(6,8),
(6,8,7), (7,8) ] )^G ]
```

```
gap> Tom2:=TableOfMarks(H);
TableOfMarks( Sym( [ 5 .. 8 ] ) )
```

```
gap> Display(Tom2);
```

```
1: 24
2: 12 4
3: 12 . 2
4: 8 . . 2
5: 6 6 . . 6
6: 6 2 2 . . 2
7: 6 2 . . . 2
8: 4 . 2 1 . . . 1
9: 3 3 1 . 3 1 1 . 1
10: 2 2 . 2 2 . . . 2
11: 1 1 1 1 1 1 1 1 1 1.....
```

Table 2: Table of marks of S_4

```
gap> LengthsTom(Tom2);
[ 1, 3, 6, 4, 1, 3, 3, 4, 3, 1, 1 ]
gap> OrdersTom(Tom2);
[ 1, 2, 2, 3, 4, 4, 4, 6, 8, 12, 24 ]
```

Appendix 3: GAP algorithms used to generate conjugacy classes and table of marks of $H = S_5$

S_4 can be generated by (ab) and (abcd,e). To generate $H = S_5$ the symmetric group on the set {5,6,7,8,9} on the GAP, we have used its generators; (5,6,7,8,9) and (5,6) using the command;

```
gap> H:=Group( [ (5,6,7,8,9), (5,6) ] );
Group([ (5,6,7,8,9), (5,6) ])
gap> ConjugacyClassesSubgroups(H);
[ Group( () )^G, Group( [ (8,9) ] )^G, Group( [ (6,7)(8,9) ] )^G, Group( [ (7,8,9) ] )^G,
  Group( [ (6,7)(8,9), (6,8)(7,9) ] )^G, Group( [ (6,7)(8,9), (6,8,7,9) ] )^G,
  Group( [ (8,9), (6,7) ] )^G,
  Group( [ (5,6,7,8,9) ] )^G, Group( [ (7,8,9), (8,9) ] )^G, Group( [ (7,8,9),
  (5,6)(8,9) ] )^G,
  Group( [ (8,9), (5,6,7) ] )^G, Group( [ (8,9), (6,7), (6,8)(7,9) ] )^G, Group( [
  (5,6,7,8,9), (6,9)(7,8) ] )^G,
  Group( [ (6,7)(8,9), (6,8)(7,9), (7,8,9) ] )^G, Group( [ (8,9), (5,6,7), (6,7) ]
  )^G,
  Group( [ (5,6,7,8,9), (6,9)(7,8), (6,7,9,8) ] )^G, Group( [ (6,9)(7,8),
  (6,7)(8,9), (7,8,9), (8,9) ] )^G,
  Group( [ (5,6,7,8,9), (7,8,9) ] )^G, SymmetricGroup( [ 5 .. 9 ] )^G ]
gap> Tom3:=TableOfMarks(H);
TableOfMarks( sym( [ 5 .. 9 ] ) )
gap> Display(T);
1: 120
2: 60 6
3: 60 . 4
4: 40 . . 4
5: 30 . 6 . 6
6: 30 . 2 . . 2
7: 30 6 2 . . . 2
8: 24 . . . . . 4
9: 20 6 . 2 . . . . 2
10: 20 . 4 2 . . . . . 2
11: 20 2 . 2 . . . . . 2
12: 15 3 3 . 3 1 1 . . . . 1
13: 12 . 4 . . . . 2 . . . . 2
14: 10 . 2 4 2 . . . . . 2
15: 10 4 2 1 . . 2 . 1 1 1 . . . 1
16: 6 . 2 . . 2 . 1 . . . . 1 . . 1
17: 5 3 1 2 1 1 1 . 2 . . 1 . 1 . . 1
18: 2 . 2 2 2 . . 2 . 2 . . 2 2 . . . 2
19: 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 .....
```

Table 3: Table of marks of S_5

```
gap> LengthsTom(Tom3);
[ 1, 10, 15, 10, 5, 15, 15, 6, 10, 10, 10, 15, 6, 5, 10, 6, 5, 1, 1 ]
gap> OrdersTom(Tom3);
[ 1, 2, 2, 3, 4, 4, 4, 5, 6, 6, 6, 8, 10, 12, 12, 20, 24, 60, 120 ]
```


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