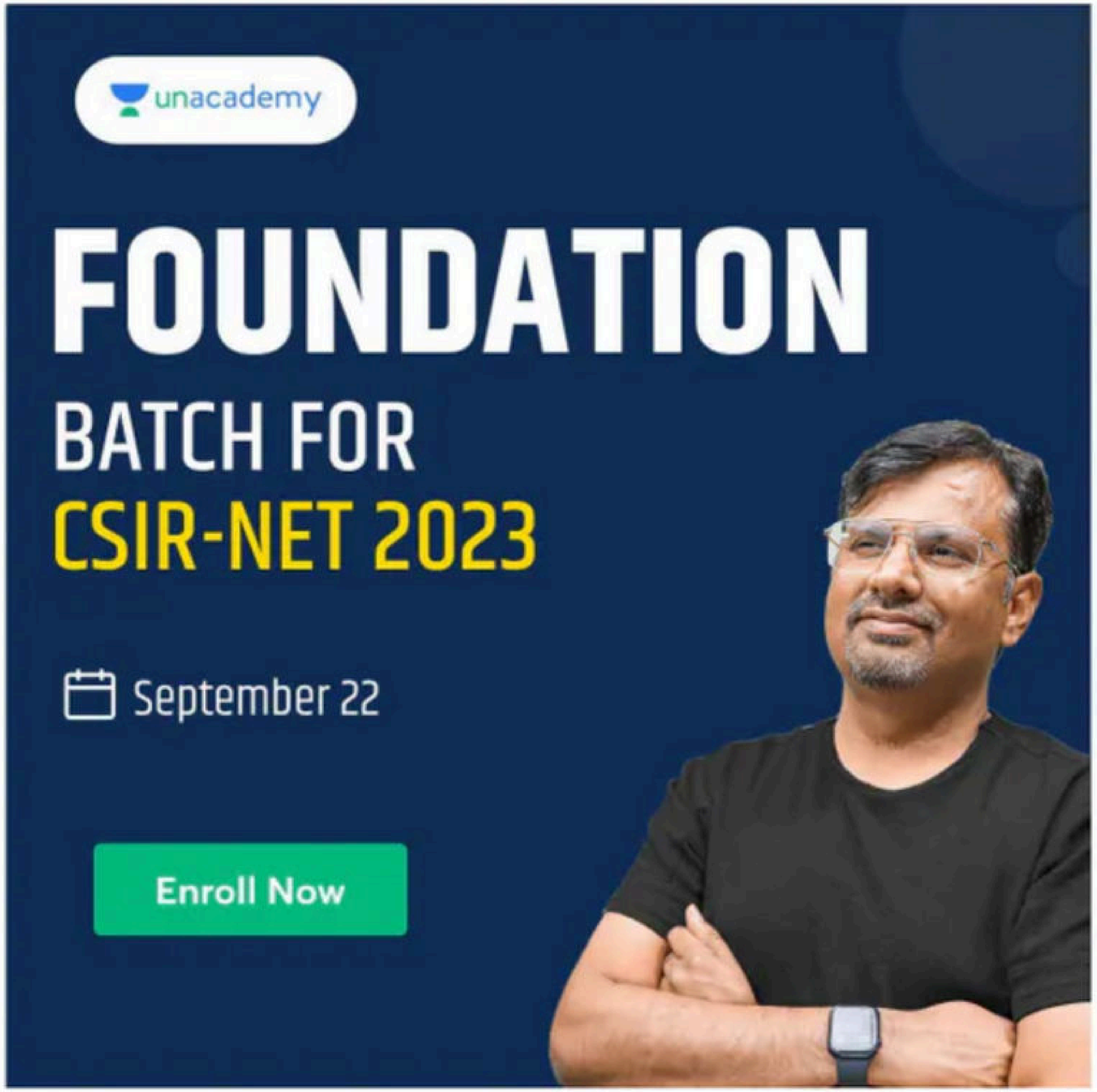

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1. **<u>Order of Group</u>** -: Number of elements in G Group is called Order of group. It is denoted by $o(G) = |G|$

OR

Let $(G,*)$ be a group. The cardinality of G (finite or Infinite) is defined as the order of the group.

Order of some special group.

i. $o(\mathbb{R}) = o(\mathbb{C}) = o(\mathbb{Z}) = o(\mathbb{Q}) = \infty$

ii. $o(\mathbb{R}^*) = o(\mathbb{Q}^*) = \infty$

iii. $o(U_n) = \emptyset(n)$, where Ø is a euler's function.

iv. $o(D_n) = 2n$

$o(P_4) = 8$

$o(P_{10}) = 20$

v. $o(Q_8) = 8$

vi. $o(K_4) = 4$

vii. $o[Gl_n(\mathbb{R})] = o[Sl_n(\mathbb{R})] = \infty$

viii. $o[Gl_n(\mathbb{Z}_p)] = (p^n - p^{n-1})\,(p^n - p^{n-2})\,(p^n - p^{n-3})\ldots\ldots(p^n - 1)$

ix. $o[Sl_n(\mathbb{Z}_p)]$

$$= \frac{(p^n - p^{n-1})(p^n - p^{n-2})(p^n - p^{n-3})\ldots\ldots\ldots(p^n - 1)}{(p-1)}$$

x. $o(S_n) = n!$, (S_n will be covered in the next lecture.)

xi. $o(Z_n) = n$

$o(S_3)$ 3!

$o(S_4) =$ 4!

$o(\{1,2,7,9\})$

$o[GL_3(Z_5)]$

$= \{A = (a_{ij})_{3\times 3}\ a_{ij} \in Z_5$

$|A| \neq 0]$

$o(SL_3(Z_5)] = \langle$

$|A| \neq$

$\frac{(5^3 - 5^2)(5^3 - 5^1)(5^3 - 5^0)}{(5-1)}$

$o(Z_4) = 4$

2. Order of Elements-: Let G be a group, the order of an elements $a \in G$ is the least positive integer n such that $a^n = e$ if such n does not exist then order of element a is infinite.

The order of element $a \in G$ is denoted by o(a).

$a^n = e$

$+$ $\qquad$ $\times$

$a + a + a - - a = 0$ $\qquad$ $a \times a \times a - - a = 1$

$(\mathbb{Z}, +)$ $\{\ldots -2, -1, 0, 1, 2 \ldots\}$

$o(0) = 1$

$o(n) = \infty$ $n \neq 0$

$(\mathbb{Q}, +)$, $(\mathbb{R}, +)$, $(\mathbb{C}, +)$

$(\mathbb{Z}^*, \times)$ $<$ $(\mathbb{Q}^*, \times)$, $(\mathbb{R}^*, \times)$ $(\mathbb{C}^*, \times)$

$o(1) = 1$, $o(-1) = 2$

$o(n) = \infty$ $n \neq 1, -1$

$G = (\mathbb{Z}_6, +_6) = \langle 0, 1, 2, 3, 4, 5 \rangle$

$o(5) = 6$

$o(0) = 1$

$o(1) = 6$

$o(2) = 3$

$o(3) = 2$

$o(4) = 3$

$o(5) = 6$

4

$\mathbb{Z}_6$

1

2

3

6

$\phi(1) = 1$

$\phi(2) = 2 - 2^0 = 1$

$\phi(3) = 3 - 3^0 = 2$

$\phi(6) = \phi(3 \times 2)$

$= \phi(3) \times \phi(2)$

$= 2 \times 1$

Basic example of order of elements of some special Group-

(i) Possible Order of Each Element of $(\mathbb{Z}, +)$

$\mathbb{Z} = \{ \ldots, -3, -2, -1, 0, 1, 2, 3, \ldots\}$

$0 \in \mathbb{Z}$ is identity of $\mathbb{Z}$

$o(0) = 1$

$n \in \mathbb{Z}$; $|n| \geq 1$. It is not possible; order of n

can't belongs to any natural number.

Then $o(n) = \infty$, $n \in \mathbb{Z} - \{0\}$

Similarly, order of elements of $(\mathbb{Q}, +), (\mathbb{R}, +)$ & $(\mathbb{C}, +)$ are 1 &

∞.

(ii) Possible Order of elements of $(\mathbb{Z}^*, .)$

Order of element of identity, $o(1) = 1$

Order of element, -1 is 2 i.e. $o(-1) = 2$

All other elements are of order ∞

(iii) Possible Order of elements of $(\mathbb{Q}^*, .)$

$1 \in \mathbb{Q}^*$ is identity of $\mathbb{Q}^*$, then $o(1) = 1$

$o(-1) = 2$; $o(a) = \infty$, $a \in \mathbb{Q}^* - \{1, -1\}$

Similarly, order of elements of $(\mathbb{R}^*, .)$ are 1, 2 and ∞.

(iv) Possible Order of each element in $\mathbb{Z}_n$.

NOTE-:

a) In $\mathbb{Z}_n$, possible order of elements are $d \mid n$ [n is divisble by d].

b) If $d \mid n$ then numbers of elements of order d in $\mathbb{Z}_n$ $= \phi(d)$.

Properties of order in Product

i. If G_1 is group with identity e_1 and G_2 is group with identity e_2 then $G_1 \times G_2$ is group with identity (e_1, e_2) and with inverse (a_1^{-1} in G_1, a_2^{-1} in G_2).

ii. If $G_1, G_2, G_3, \ldots G_n$ are finite groups. Then $o(G_1 \times G_2 \times G_3 \times \ldots \times G_n) = o(G_1) \times o(G_2) \times o(G_3) \times \ldots \times o(G_n)$.

iii. $(a_1, a_2, a_3, \ldots, a_n) \in (G_1 \times G_2 \times G_3 \times \ldots \times G_n)$ then $o(a_1, a_2, a_3, \ldots, a_n) = \text{L.C.M.}\,[\,o(a_1) \text{ in } G_1, o(a_2) \text{ in } G_2, o(a_3) \text{ in } G_3, \ldots, o(a_4) \text{ in } G_n.]$

iv. No. of elements of order d in $\mathbb{Z}_n \times \mathbb{Z}_m = \Sigma\phi(d_1).\phi(d_2)$. where $d_1 | n$, $d_2 | m$ & $\text{L.C.M.}(d_1, d_2) = d$

$\mathbb{Z}_2 \times \mathbb{Z}_2 = (0,1) \times (0,1)$

$\mathbb{Z}_2 = \{0,1\}$

$(0,1) \times (0,1)$

$+_2$	$(0,0)$	$(0,1)$	$(1,0)$	$(1,1)$
$e=(0,0)$	$(0,0)$	$(0,1)$	$(1,0)$	$(1,1)$
$(0,1)$	$(0,1)$	$\boxed{(0,0)}$	$(1,1)$	$(1,0)$
$(1,0)$	$(1,0)$	$(1,1)$	$\boxed{(0,0)}$	$(0,1)$
$(1,1)$	$(1,1)$	$(1,0)$	$(0,1)$	$\boxed{(0,0)}$

$(0,0)^{-1} = (0,0)$

$(0,1)^{-1} = (0,1)$

$(1,0)^{-1} = (1,0)$

$(1,1)^{-1} = (1,1)$

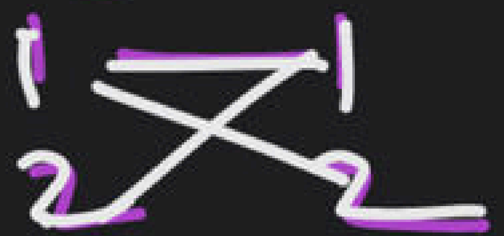
$O(0,0) = 1$

$O(0,1) = 2$

$O(1,0) = 2$

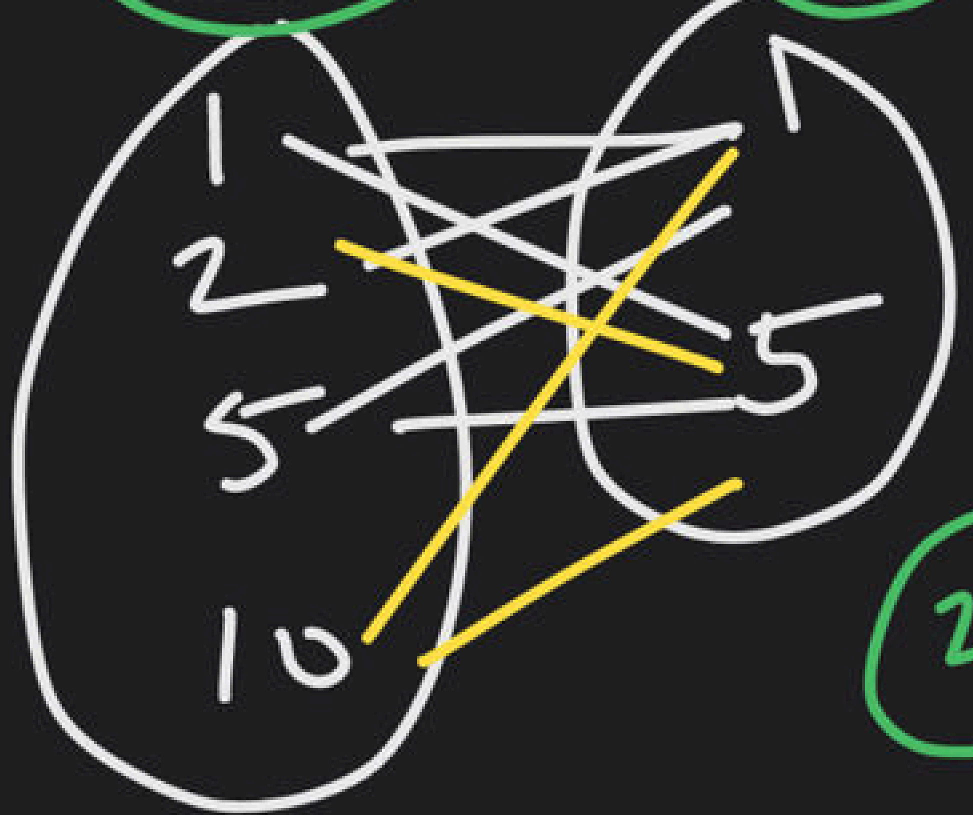
$O(1,1) = 2$

$\mathbb{Z}_2 \times \mathbb{Z}_2$



1, 1	$\varphi(1)\ \varphi(1)$	1
1, 2	$\varphi(1)\ \varphi(2)$	1
2, 1	$\varphi(2)\ \varphi(1)$	1
2, 2	$\varphi(2)\ \varphi(2)$	1

$\mathbb{Z}_{10} \times \mathbb{Z}_5$ 1



$o(1) = (1,1)$

$o(2) = (2,1)$

1

$o(5)$ — $(5,1)$, $(1,5)$, $(5,5)$

24

24 $o(10)$ ← $(10,1)$, $(10,5)$, $(2,5)$

$\phi(1)\phi(1) = 1$

$\phi(2)\phi(1) = 1$

$\phi(5)\phi(1) = 4 \times 1 = 4$

$\phi(1)\phi(5) = 1 \times 4 = 4$

$\phi(5)\phi(5) = 4 \times 4 = 16$

$\phi(10)\phi(1) = 4 \times 1 = 4$

$\phi(10)\phi(5) = 4 \times 4 = 16$

$\phi(2)\phi(5) = 1 \times 4 = 4$

24

$\phi(5) = 5^1 - 5^0$
$= 5 - 1 = 4$

$\phi(10) = \phi(2)\phi(5) = 1 \times 4$

(6) $\mathbb{Z}_2 \times \mathbb{Z}_3 = \{0,1\} \times \{0,1,2\} = \{(0,0), (0,1), (0,2), (1,0), (1,1), (1,2)\}$

$o(0,0) = 1$

$o(0,1) = 3$

$o(0,2) = 3$

$o(1,0) = 2$

$o(1,1) = 6$

$o(1,2) = 6$

6

hcf (2,3) = 1

$\mathbb{Z}_2 \times \mathbb{Z}_3$

Abelian

$\mathbb{Z}_6$

HCF

$\mathbb{Z}_{10} \times \mathbb{Z}_3$

$\mathbb{Z}_p \times \mathbb{Z}_q$

gcd (p, q) = 1

$\mathbb{Z}_3 \times \mathbb{Z}_7 = \mathbb{Z}_{21}$

v. $o(a) = o(xax^{-1}) = o(x^{-1}ax)$, where $a, x \in G$ and G is a group.

vi. $o(ba) = o(ab)$, where $a, b \in G$

vii. $o(a) = o(a^{-1})$, where $a \in G$

viii. $(ab)^{-1} = b^{-1}a^{-1}$, where $a, b \in G$

ix. $(a_1, a_2, \ldots, a_{n-1}\ a_n)^{-1} = (a_n^{-1}, a_{n-1}^{-1}, \ldots, a_2^{-1}, a_1^{-1})$, where $a_i \in G$

$o(\mathbb{Z}p) - 1$

Result : Let $G = Z_k \times Z_k \ldots\ldots \times Z_k$ (p-times)

Then G has an element of order either 1 or k.

(1) G has exactly one element of order 1.

(2) Other all elements of G are of order k

i.e. number of elements of order k in G are $k^p - 1$

$$\mathbb{Z}_p \times \mathbb{Z}_p \times \mathbb{Z}_p$$

$$\mathbb{Z}_7 \times \mathbb{Z}_7 \times \mathbb{Z}_7$$

$$1 \qquad 1 \qquad 1$$

$$7 \qquad 7 \qquad 7$$

$$o(1,1,1) = 1$$

$$7^3$$

$$7^3 - 1$$

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Q1. Number of elements of order 7 in $Z_7 \times Z_7 \ldots\ldots Z_7$ (50-times)

(a) 7^{50} (b) $7^{50} - 1$

(c) $7^{50} - 2$ (d) $7^{49} - 1$

$7^{50} - 1$

Abelian Group -: A group G is said to be abelian if $xy = yx$ such that, $x, y \in G$.

Properties of Abelian group-:

(i) If every element of G has self-inverse then G is abelian but converse need not be true.

Example : K_4 is abelian because every elements of K_4 has self-inverse. $\mathbb{Z}_6$ is abelian but every elements of $\mathbb{Z}_6$ is not self-inverse.

(ii) Let G_1 and G_2 are two groups $G_1 \times G_2$ is abelian iff G_1 and G_2 are abelian.

(iii) $G_1 \times G_2 \times G_3 \times \ldots\ldots G_{n-1} \times G_n$ is abelian iff each G_i, $1 \leq i \leq n$ is abelian

(iv) Let G be a group and $(ab)^{-1} = a^{-1}b^{-1}$ $\forall$ a, b $\in$ G iff G is abelian.

(v) Let G be a group and $(ab)^2 = a^2b^2$ $\forall$ a, b $\in$ G iff G is abelian.

(vi) But G is a group and $(ab)^n = a^nb^n$ $(n \geq 3)$ $\forall$ a, b $\in$ G iff G is abelian.

Cyclic Group : A group (G, o) is called a cyclic group if every elements of G is of the form a^n,

for some $a \in G$ where $n \in Z$.

Symbolically, $G = \{a^n \mid n \in Z\}$

$\Rightarrow \quad G = \{..... a^{-2}, a^{-1}, e, a, a^2, ...\}$

The element a is called generator of G.

Note : If G is a cyclic group generated by a, then we write $G = \langle a \rangle$

The element of G will be of the form

$\langle a \rangle = \{.... -2a, -a, 0, a, 2a, ...\}$ for additive composition.

$\langle a \rangle = \{..... a^{-2}, a^{-1}, e, a, a^2 ..... \}$ for multiplication composition.

Result :

(1) Let G be a group of order n and if G have an element of order n, then G must be cyclic group.

Example : Let G = {1, -1, i, -i} is a group of order 4 under multiplicative.

Now, O(1) = 1, O(-1) = 2, O(i) = 4 = O(-i)

Here, order of i & -i are equal to order of group.

So, G is cyclic and i & -i are generator of G.

(2) Every cyclic group is abelian group.

(3) Let G be a cyclic group of order n, then number of generator of group are $\phi(n)$.

Non-Cyclic group: K_4, Q_8, S_n, $(\mathbb{Q}^*, .)$, $(\mathbb{R}^*, .)$, $(\mathbb{C}^*, .)$, $(\mathbb{Q}, +)$, $(\mathbb{R}, +)$, $(\mathbb{C}, +)$, $Gl_n(\mathbb{Z}_p)$, $Sl_n(\mathbb{Z}_p)$ $(n>1)$, D_n

Some important points of cyclic group-:

(i) If G is group under addition then $G = \langle a \rangle = \{na \mid n \in \mathbb{Z}\}$.

(ii) If G is cyclic group and 'a' is generator of G then o(G) = o(a). But Converse need not be true.

Example : $G = (Z ,+)$

All elements other than 1 and -1 are of order infinite which is equal to order of G but they are not generator

(iii) G is a finite cyclic group and 'a' is generator of G iff o(G) = o(a).

(iv) If $a^1, a^2, a^3, \ldots. a^n = e$ are distinct element then G is generated by a.

(v) If G is non abelian then G is non-cyclic group

(vi) If $o(G) = p$(prime number) then G is cyclic group.

(vii) $\mathbb{Z}_m \times \mathbb{Z}_n$ is cyclic group iff $\gcd(m, n) = 1$ then $\mathbb{Z}_m \times \mathbb{Z}_n \approx \mathbb{Z}_{mn}$

(ix) If 'a' is generator of G then a^{-1} is also generator of G.

(x) If G be a finite cyclic group of order n then $G \approx \mathbb{Z}_n$.

(xi) If G be an infinite cyclic group then $G \approx \mathbb{Z}$.

(xii)let $G = \langle a \rangle$ be a cyclic group of order n then $G = \langle a^k \rangle$ iff g.c.d.(k, n) = 1

(xiii) If G_1 and G_2 are cyclic group then $G_1 \times G_2$ need not be cyclic group.

(xiv) If G be infinite cyclic group of order n then G has exactly two generators. Namely {1, -1}

(xv) If $O(G) = p^2$ then G is abelian group but converse need not be true

(xvi) Let G be a finite group of order pq i.e. $O(G) = pq$ (where $p < q$ & p, q are prime)

Case – 1 : If $p \nmid q-1$, then G is cyclic.

Case – 2 : If $p \mid q-1$, then G need not be cyclic.

Q.1. Consider the set of matrices $G = \left\{ \begin{bmatrix} s & b \\ 0 & 1 \end{bmatrix} : b \in \mathbf{Z}\ ,\ s \in \{-1, 1\} \right\}$. Then which of the following is true **CSIR NET JUNE 2019**

(a) G forms a group under addition

(b) G forms a abelian group under multiplication

(c) Every elements in G is diagonalizable over C

(d) G is finitely generated group under multiplication

Q.2. Let G be finite abelian group and $a, b \in G$ with order $(a) = m$, order $(b) = n$. which of the following are necessarily true **CSIR NET DEC. 2017**

(a) Order $(ab) = mn$

(b) Order $(ab) = \text{lcm}\{m,n\}$

(c) There is an elements of G whose order is $\text{lcm}\{a, b\}$

(d) Order$(ab) = \gcd(m, n)$

Q.3. Let G be a non – abelian group. then its order can be

(a) 25 (b) 55

(c) 125 (d) 35

Q.4. The number of generator of the additive group Z_{36} is equal to **IIT - JAM 2017**

(a) 6 (b) 12

(c) 18 (d) 36

Q.5. The value of α for which G = $\{\alpha, 1, 3, 9, 19, 27\}$ is a cyclic group under multiplication modulo 56 is

a) 5

b) 15

c) 25

d) 35

Q.6. Which of the following statements is/are TRUE?

a) If G is abelian then $(ab)^n = a^n b^n \; \forall \; n \in \mathbb{N} \; \& \; \forall \; a, b \in G$

b) If G is abelian then $\forall \; n \in \mathbb{N} \; \& \; \forall \; a, b \in G, (aba^{-1})^n = ab^n a^{-1}$.

c) If G is a group & $\forall \; n \in \mathbb{N} \; \& \; \forall \; a, b \in G, (aba^{-1})^n = ab^n a^{-1}$ then G is abelian.

d) None of these

Q.7 Let $G = Z_{15} \times Z_{10}$ be a group. then which of the following is ~~true~~ False

(a) G has exactly one element of order 2

(b) G has exactly 5 element of order 3

(c) G has exactly 24 element of order 5

(d) G has exactly 24 element of order 10

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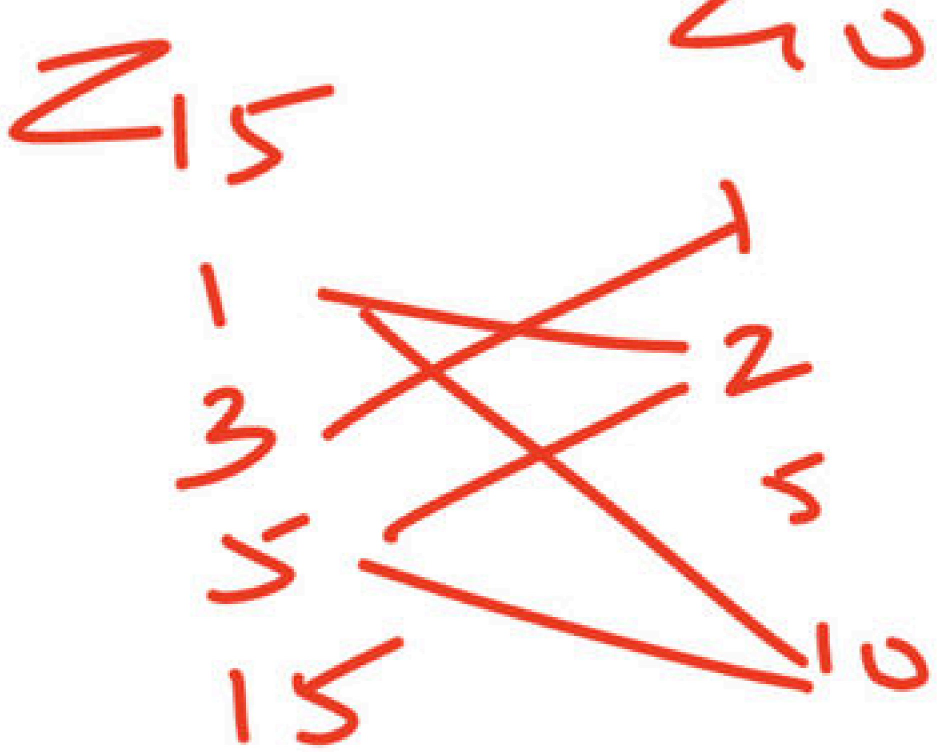


$(5,2)$ $\phi(5)\phi(2) = 4$

$(1,10)$ $\phi(1)\phi(10) = 4$

$(5,10)$ $\phi(5)\phi(10)$ 4×4

Q.8. What is the order of $GL_3(Z_4)$? $= (4^3 - 4^2)(4^3 - 4^1)(4^3 - 4^0)$

(a) $54 \times 72 \times 78 \times 80$

(b) $48 \times 60 \times 63$

(c) $\frac{54 \times 72 \times 78 \times 80}{3}$

(d) $\frac{48 \times 60 \times 63}{3}$

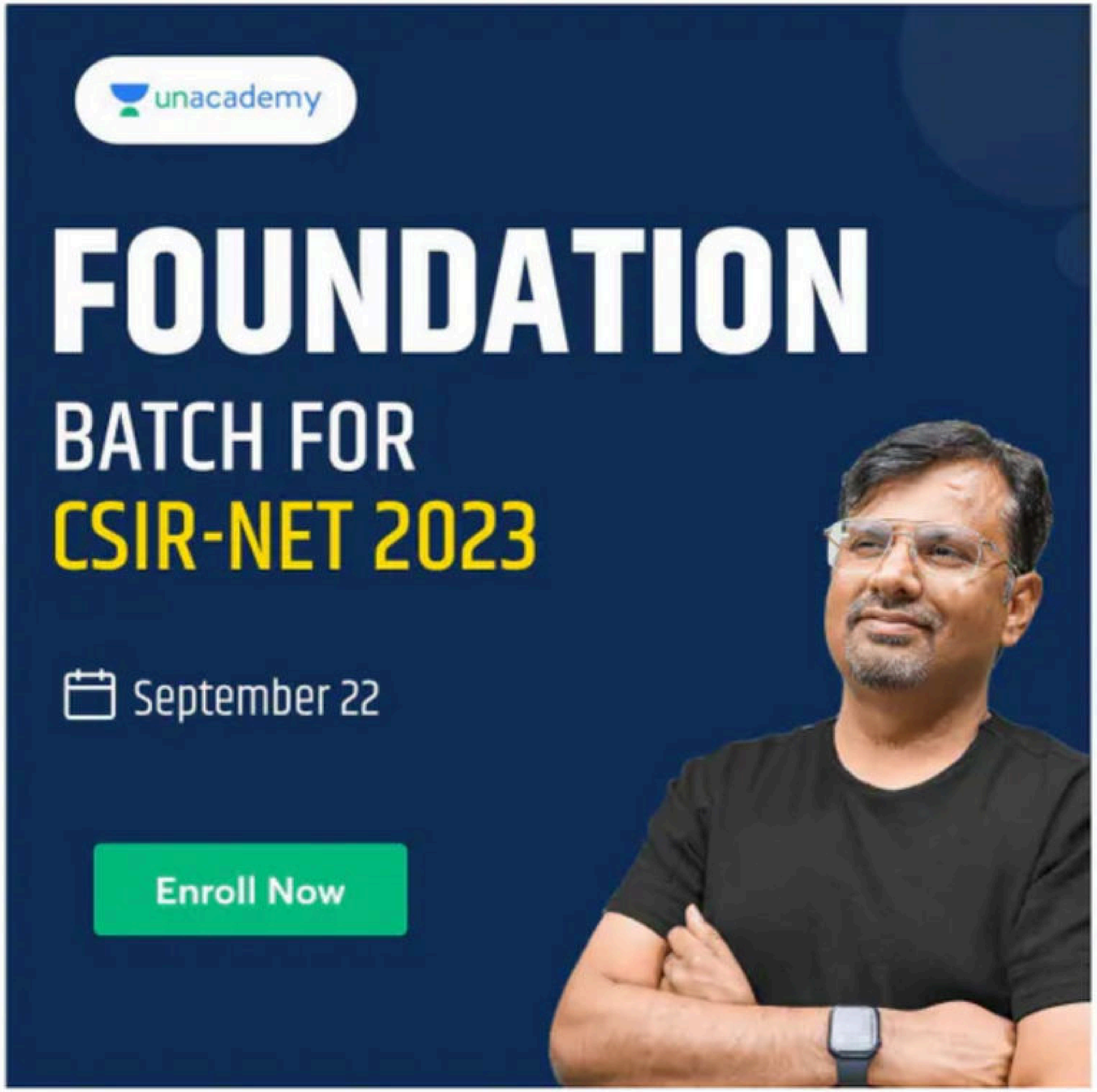
Q G be group of 2×2 matrices over $\mathbb{Z}_p$ with determinant 1 under multiplication. Then $O(G)$ is

(a) $(p-1)p(p+1)$

(b) $p^2(p-1)$

(c) p^3

(d) $p^2(p-1)+p$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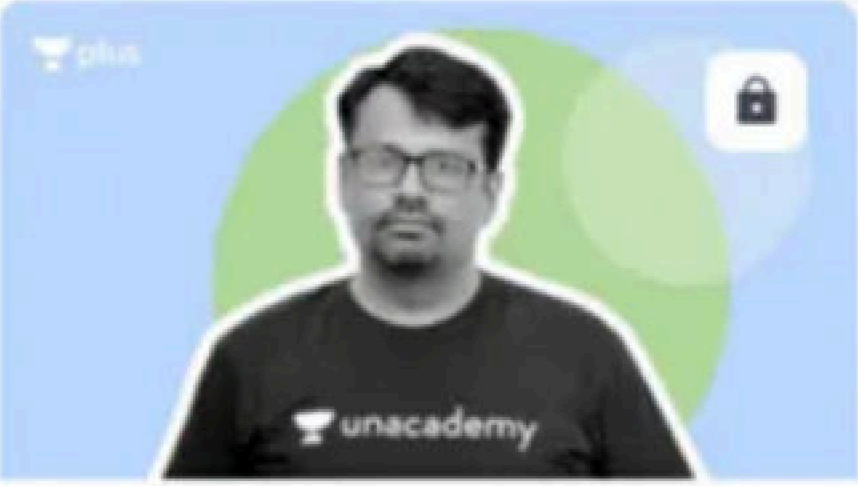

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