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Gamma Graph $\Gamma(Z_n)(\gamma)$ Of Zero Divisor Graph Of A Finite Commutative Ring Z_n

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Abstract: Consider the family of γ-sets of a zero-divisor graph $\Gamma(Z_n)$ of finite commutative ring $\mathbb{Z}_n$ and define the γgraphs $\Gamma(Z_n)$ (γ) = $(V(\gamma), E(\gamma))$ of $\Gamma(Z_n)$ to be the graph whose vertice V(γ) corresponds 1-to-1 with the γ-sets , say S1 and S2, form an edge in E(γ) if there exist a vertex $v \in S_1$ such that (i)v is adjacent to w and (ii) $S_1 = S_2 - \{w\} \cup \{u\}$ and $S_2 = S_1 - \{u\} \cup \{w\}$. Using this definition, we investigate the interplay between the graph theoretic properties of $\Gamma(Z_n)(\gamma)$ and $\Gamma(Z_n)(\gamma)$ and the ring theoretic properties of Z_n. Further, we prove that $\Gamma(Z_n)(\gamma)$ are an Eulerian and Hamiltonian.

Keywords: Finite Commutative Ring, Zero-divisors, Zero-divisor graph, gamma sets, gamma graph.

Mathematical Classification: 05C25, 05C69

1. Introduction

The study of algebraic structures, using the properties of graph, become an exciting research topic in the past twenty years, leading to many fascinating results and questions. In the literature, there are many papers assigning graphs to rings, groups and semigroups. Let R be a commutative ring with identity and $Z(R)^*$ be the set of all non-zero zero-divisors of R. D.F. Anderson and P.S. Livingston[1], associates a graph called zero-divisor graph $\Gamma(R)$ to R with vertex set $Z(R)^*$ and for any two distinct $x, y \in Z(R)^*$, the vertices x and y are adjacent if and only if $xy = 0$ in R.

For $v \in V$, the associate class of v is defined as $A_v = \{uv : u \text{ is unit in } R\}$. Let $n = p_1^{k_1} p_2^{k_2} p_3^{k_3} \dots p_r^{k_r}$, where $p_1, p_2, \dots, p_r$ are primes with $p_1 < p_2 < \dots < p_r$ and $k_1, k_2, \dots, k_r$ are positive integers. Then the set of all non-zero zero- divisors in Z_n, the ring of congruent modulo n classes is given by $Z(Z_n)^* = \{\lambda_i p_i : 1 \le \lambda_i \le \frac{n}{p_i},\ 1 \le i \le r\}$.

A set $D \subseteq V$ of vertices of vertices in a graph $G = (V, E)$ is called a dominating set if for every vertex $u \in V - D$,there exists a vertex $v \in D$ such that v is adjacent to u. A dominating set D is minimal if no proper subset D is a dominating set. The domination number of a graph G, denoted by $\gamma(G)$, is the minimum cardinality of a minimal dominating set of G. A dominating set D in a graph G with cardinality γ is called $\gamma-$set of G.

A path that contains every vertex of G is called a Hamilton path of G. A Hamilton cycle of G is a cycle that contains every vertex of G. A graph is Hamiltonian if it contains a Hamilton cycle. A closed trial containing all points and lines is called an Eulerian trial. A graph having an Eulerian trial is called an Eulerian graph. A graph of size 0 is called an empty graph and so a nonempty graph has one or more edges. A graph is said to be a self-centered graph if the eccentricity of every vertex of the graph is the same.

Definition 1.1: [3] Consider the family of γ-sets of a graph G and define the $\gamma-$graphs $G(\gamma) = (V(\gamma), E(\gamma))$ of G to be the graph whose vertices $V(\gamma)$ correspond 1-to-1 with the γ-sets of G, and two γ sets, say S_1 and S_2, form an edge in $E(\gamma)$ if there exists a vertex $v \in S_1$ and a vertex $w \in S_2$ such that

(i) v is adjacent to w and

(ii) $S_1 = S_2 - \{w\} \cup \{v\}$ and $S_2 = S_1 - \{v\} \cup \{w\}$.

Looking at all these, we are very much interested to introduce a definition Gamma Graph $\Gamma(Z_n)(\gamma)$ of Zero divisor graph of a finite Commutative Ring Z_n.

The following results are used in the subsequent section.

Remark 1.2:[5] Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \ldots {p_r}^{k_r}$, where $r \geq 1$, $p_1, p_2, \ldots, p_r$ are primes with $p_1 < p_2 < \cdots < p_r$ and $n \neq 2p, n \neq 3p, p > 3$ is prime. Then the number of $\gamma -$ sets in $\Gamma(Z_n)$ is $\prod_{i=1}^{r}(p_i - 1)$.

Note 1.3:[5] Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \ldots {p_r}^{k_r}$, where $r \geq 1$, $p_1, p_2, \ldots, p_r$ are primes with $p_1 < p_2 < \cdots < p_r$ and $n = 3p, p > 3$ is prime. Then the number of $\gamma -$ sets in $\Gamma(Z_n)$ is $\prod_{i=1}^{r}(p_i - 1) + 1$.

Note 1.4: [5] Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \ldots {p_r}^{k_r}$, where $r \geq 1$, $p_1, p_2, \ldots, p_r$ are primes with $p_1 < p_2 < \cdots < p_r$ and $n = 2p, p > 3$ is prime. Then the number of $\gamma -$ sets in $\Gamma(Z_n)$ is 1.

Corollary 1.5:[5] Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \ldots {p_r}^{k_r}$, where $r \geq 1$, $p_1, p_2, \ldots, p_r$ are primes with $p_1 < p_2 < \cdots < p_r$ and $n \neq 2p, p \geq 3$ is prime, then $\gamma(\Gamma(Z_n)) = r$.

Throughout this paper, n is a fixed positive integer and not a prime number, $Z_n = \{0,1,2,3, \ldots, n-1\}$, $\Gamma(Z_n)$ is the Zero-divisor graph of Z_n, $\Gamma(Z_n)(\gamma)$ is the gamma graph of $\Gamma(Z_n)$ and $V = V(\Gamma(Z_n)(\gamma))$ is the vertex set of $\Gamma(Z_n)(\gamma)$. Here we introduced a new definition, gamma graph of a zero - divisor graph $\Gamma(Z_n)(\gamma)$ of a finite commutative ring Z_n.

2. Gamma Graph $\Gamma(Z_n)(\gamma)$ of Zero divisor graph

In this section, we introduced a new definition, gamma graph of a zero-divisor graph $\Gamma(Z_n)(\gamma)$ of a finite commutative ring Z_n.

Definition 2.1: Consider the family of γ-sets of a zero-divisor graph $\Gamma(Z_n)$ of finite commutative ring Z_n and define the $\gamma -$graphs $\Gamma(Z_n)(\gamma) = (V(\gamma), E(\gamma))$ of $\Gamma(Z_n)$ to be the graph whose vertices $V(\gamma)$ correspond 1-to-1 with the γ - sets of G, and two γ sets, say S_1 and S_2, form an edge in $E(\gamma)$ if there exists a vertex $v \in S_1$ and a vertex $w \in S_2$ such that

(i) v is adjacent to w and

(ii) $S_1 = S_2 - \{w\} \cup \{v\}$ and $S_2 = S_1 - \{v\} \cup \{w\}$.

With this definition, two γ-sets are said to be adjacent if they differ by one vertex and the two vertices defining this difference are adjacent $\Gamma(Z_n)$.

Example 2.2: Consider the ring Z_{15}.

$$Z_{15} = \{0,1,2,3,4,5,6,7,8,9,10,11,12,13,14\}$$

$$Z(Z_{15})^* = \{3,5,6,9,10,12\}$$

The zero-divisor graph $\Gamma(Z_{15})$:

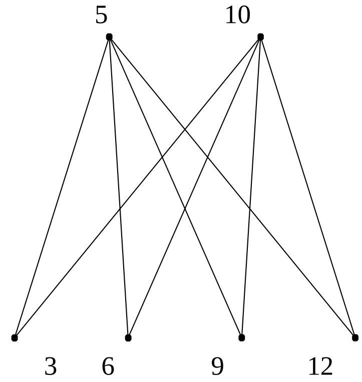

Fig 1: $\Gamma(Z_{15})$

The γ- sets are $D_1 = \{5,10\}$, $D_2 = \{5,3\}$, $D_3 = \{5,6\}$,
$D_4 = \{5,9\}$, $D_5 = \{5,12\}$, $D_6 = \{10,3\}$,
$D_7 = \{10,6\}$, $D_8 = \{10,9\}$, $D_9 = \{10,12\}$

The gamma graph $\Gamma(Z_{15})(\gamma)$:

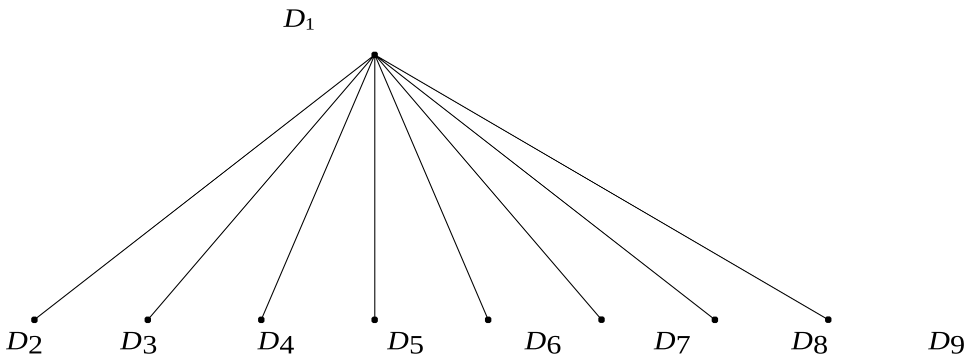

Fig 2: $\Gamma(Z_{15})(\gamma)$

3. Basic properties of the gamma graph $\Gamma(Z_n)(\gamma)$

In this section, we study some basic properties of gamma graph of a zero - divisor graph $\Gamma(Z_n)$ of a finite commutative ring Z_n and the same is denoted by $\Gamma(Z_n)(\gamma)$. Actually, We find the diameter and girth of $\Gamma(Z_n)(\gamma)$. Also, we characterize, when $\Gamma(Z_n)(\gamma)$ is planar, empty graph, Self- centered graph and the $\Gamma(Z_n)(\gamma)$ is connected. Also, we find the Eulerian and Hamiltonian nature of $\Gamma(Z_n)(\gamma)$. First we start the section with the degree of each vertex of the new graph $\Gamma(Z_n)(\gamma)$.

Theorem 3.1 : Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \dots {p_r}^{k_r}$, where $r > 1$, $k_1, k_2, \dots, k_r > 1$ and $p_1, p_2, \dots, p_r$ are primes with $p_1 < p_2 < \cdots < p_r$ and $n \neq 2p, 3p$, $p > 3$ is a prime. For any $v \in V$, $\deg_{\Gamma(Z_n)(\gamma)}(v) = \sum_{i=1}^{r}(p_i - 1) - \gamma(\Gamma(Z_n))$ and hence $\Gamma(Z_n)(\gamma)$ is a regular graph.

Proof: Let $v = \left\{\{a_1, a_2, \dots, a_r\},\ for\ some\ a_i \in A_{\frac{n}{p_i}}, 1 \leq i \leq r\right\}$ be a vertex in $V = V\big(\Gamma(Z_n)(\gamma)\big)$. Take $N[v] = V - \{\{b_1, b_2, \dots, b_r\}$: $a_i = b_i, 1 \leq i \leq r-1$, $b_i \in A_{\frac{n}{p_i}}$, $1 \leq i \leq r$, a_r and b_r are adjacent$\}$. Thus, $\deg_{\Gamma(Z_n)(\gamma)}(v) = \sum_{i=1}^{r}(p_i - 1) - \gamma(\Gamma(Z_n))$ and hence $\Gamma(Z_n)(\gamma)$ is a regular graph.

Corollary 3.2. Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \dots {p_r}^{k_r}$, where $r > 1$, $k_1, k_2, \dots, k_r > 1$ and $p_1, p_2, \dots, p_r$ are primes with $p_1 < p_2 < \cdots < p_r$ and $n \neq 2p, 3p, p > 3$ is a prime. Then

1. $\Gamma(Z_n)(\gamma)$ is connected.
2. $diam(\Gamma(Z_n)(\gamma)) \leq 2$.
3. $gr(\Gamma(Z_n)(\gamma)) = 3$

Proof: The Corollary follows from the above theorem.

Proposition 3.3 : Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \dots {p_r}^{k_r}$, where $r > 1$, $k_1, k_2, \dots, k_r > 1$ and $p_1, p_2, \dots, p_r$are primes with $p_1 < p_2 < \cdots < p_r$ and $n \neq 2p, 3p, p > 3$ is a prime. Then $\Gamma(Z_n)(\gamma)$ is a self-centered graph.

Proof: If $n = p^k$ or $n = 2^{k_1}p^{k_2}$, where p is a prime number, $p > 3$ and $k \geq 2$, $k_1, k_2 > 1$, then $\Gamma(Z_n)(\gamma)$ is a complete graph and $e(v) = 1$, for all $v \in V(\Gamma(Z_n)(\gamma))$. Therefore $\Gamma(Z_n)(\gamma)$ is a self-centered graph.

If $n \neq p^k$ or $n \neq 2^{k_1}p^{k_2}$, where p is a prime number, $p > 3$ and $k \geq 2$, $k_1, k_2 > 1$, then $\Gamma(Z_n)(\gamma)$ is not a complete graph. Since $\Gamma(Z_n)(\gamma)$ is not a complete graph, then $\deg(v) < |V(\Gamma(Z_n)(\gamma))| - 1$, for all $v \in V(\Gamma(Z_n)(\gamma))$. By corollary 3.2, $diam(\Gamma(Z_n)(\gamma)) \leq 2$ and so $e(v) = 2$. Hence $\Gamma(Z_n)(\gamma)$ is a self-centered graph

Proposition 3.4 : Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \dots {p_r}^{k_r}$, where $r > 1$, $k_1, k_2, \dots, k_r > 1$ and $p_1, p_2, \dots, p_r$are primes with $p_1 < p_2 < \cdots < p_r$ and $n \neq 2p, 3p, p > 3$ is a prime. Then $\Gamma(Z_n)(\gamma)$ is Hamiltonian.

Theorem 3.5 : Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \dots {p_r}^{k_r}$, where $r > 1$, $k_1, k_2, \dots, k_r > 1$ and $p_1, p_2, \dots, p_r$are primes with $p_1 < p_2 < \cdots < p_r$ and $n \neq 2p, 3p$, $p > 3$ is a prime. Then $\Gamma(Z_n)(\gamma)$ is Eulerian if and only if n is even and $\gamma(\Gamma(Z_n))$ is odd or n is odd and $\gamma(\Gamma(Z_n))$ is even.

Proof: We know that $\deg_{\Gamma(Z_n)(\gamma)}(v) = \sum_{i=1}^{r}(p_i - 1) - \gamma(\Gamma(Z_n))$.

Case(i). n is even and $\gamma(\Gamma(Z_n))$ is even.

If n is even, $\sum_{i=1}^{r}(p_i - 1)$ is odd. Since $\gamma(\Gamma(Z_n))$ is even, $\deg_{\Gamma(Z_n)(\gamma)}(v)$ is odd. Then $\Gamma(Z_n)(\gamma)$ is not Eulerian.

Case(ii). n is odd and $\gamma(\Gamma(Z_n))$ is odd.

If n is odd, $\sum_{i=1}^{r}(p_i - 1)$is even. Since $\gamma(\Gamma(Z_n))$ is odd, $\deg_{\Gamma(Z_n)(\gamma)}(v)$ is odd. Then $\Gamma(Z_n)(\gamma)$ is not Eulerian.

Case(iii). n is even and $\gamma(\Gamma(Z_n))$ is odd.

If n is even, $\sum_{i=1}^{r}(p_i - 1)$is odd. Since $\gamma(\Gamma(Z_n))$ is odd, $\deg_{\Gamma(Z_n)(\gamma)}(v)$ is even. Then $\Gamma(Z_n)(\gamma)$ is Eulerian.

Case(iv). n is odd and $\gamma(\Gamma(Z_n))$ is even.

If n is odd, $\sum_{i=1}^{r}(p_i - 1)$is even. Since $\gamma(\Gamma(Z_n))$ is even, $\deg_{\Gamma(Z_n)(\gamma)}(v)$ is even. Then $\Gamma(Z_n)(\gamma)$ is Eulerian.

Combining all the four cases, we have $\Gamma(Z_n)(\gamma)$ is Eulerian if and only if n is even and $\gamma(\Gamma(Z_n))$ is odd or n is odd and $\gamma(\Gamma(Z_n))$ is even.

Theorem 3.6: Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \dots {p_r}^{k_r}$, where $r > 1$, $k_1, k_2, \dots, k_r = 1$ and $p_1, p_2, \dots, p_r$are primes with $p_1 < p_2 < \cdots < p_r$. Then $\Gamma(Z_n)(\gamma)$ is planar if and only if $n = p^k$, $p \leq 5$ or $n = 2^{k_1}p^{k_2}, 3 \leq p \leq 5$ or $n = 2p$, $p \geq 3$, where p is a prime.

Proof: If $n = 2^k$ or $n = 2p$, $p \geq 3$ and p is a prime, then $\Gamma(Z_n)(\gamma) = K_1$. If $n = 3^k$ or $n = 2^{k_1}3^{k_2}$, then $\Gamma(Z_n)(\gamma) = K_2$. If n=$5^k$ or $n = 2^{k_1}5^{k_2}$, then $\Gamma(Z_n)(\gamma) = K_4$. In all the cases, then $\Gamma(Z_n)(\gamma)$ is a planar graph.

Conversely, Assume that then $\Gamma(Z_n)(\gamma)$ is a planar graph. If $\Gamma(Z_n)(\gamma) = K_1$, then n=$2^k$ or $n = 2p$, $p \geq 3$ and p is a prime and $k > 1$. Also, if $\Gamma(Z_n)(\gamma) = K_{p-1}$, then by a theorem [7], $n = p^k$ or $n = 2^{k_1}p^{k_2}$. We claim that $p \leq 5$. If $p > 5$, then $\Gamma(Z_n)(\gamma)$ is a complete graph with at least 6 vertices, which is a contradiction to $\Gamma(Z_n)(\gamma)$ is a planar graph. Therefore, $p \leq 5$. Thus, n=3^k or $n = 2^{k_1}3^{k_2}$ or n=5^k or $n = 2^{k_1}5^{k_2}$. We claim that $r = 2$. Suppose $r > 2$. Then $|V| \geq 8$. As in the proof of theorem [7], K_5 is a subgraph of $\Gamma(Z_n)(\gamma)$, a contradiction. Hence $r = 2$ and so $n = {p_1}^{k_1}{p_2}^{k_2}$. We claim that $p_1 = 2$. If not, n is odd. When

$p_1 > 3$, $p_2 > 5$, then K_5 is a subgraph of $\Gamma(Z_n)(\gamma)$, a contradiction. When $p_1 = 3$, $p_2 = 5$, then $\Gamma(Z_n)(\gamma) = K_3K_4$ is non-planar, a contradiction. Thus n is even and so $p_1 = 3$. If $p_2 \geq 7$, then K_5 is a subgraph of $\Gamma(Z_n)(\gamma)$, a contradiction. Therefore, $n = p^k$, $p \leq 5$ or $n = 2^{k_1}p^{k_2}, 3 \leq p \leq 5$ or $n = 2p$, $p \geq 3$, where p is a prime.

Theorem 3.7: Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \dots {p_r}^{k_r}$, where $r > 1$, $k_1, k_2, \dots, k_r = 1$ and $p_1, p_2, \dots, p_r$are primes with $p_1 < p_2 < \cdots < p_r$ and $n \neq 3p, p^k, 2^{k_1}p^{k_2}$ $p > 3$ is a prime. Then $\Gamma(Z_n)(\gamma)$ is a empty graph.
Proof: Let $u, v \in V(\Gamma(Z_n)(\gamma))$ with $u \neq v$. Then $u = \{a_1, a_2, \dots, a_r\}$ and $v = \{b_1, b_2, \dots, b_r\}$, for some $a_i, b_i \in A_{\frac{n}{p_i}}$, for $i = 1,2, \dots, r$. Using the definition 2.1, u and v satisfies first condition that is $a_i = b_i, 1 \leq i \leq r-1$. But the second condition, a_r and b_r are adjacent is not satisfied. So, there is $\prod_{i=1}^{r}(p_i - 1)$ vertices and no edges in $\Gamma(Z_n)(\gamma)$. Thus, $\Gamma(Z_n)(\gamma)$ is a empty graph.

Corollary 3.8. Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \dots {p_r}^{k_r}$, where $r > 1$, $k_1, k_2, \dots, k_r = 1$ and $p_1, p_2, \dots, p_r$are primes with $p_1 < p_2 < \cdots < p_r$ and $n \neq 2p, 3p, p > 3$ is a prime. Then
1. $diam(\Gamma(Z_n)(\gamma)) = \infty$.
2. $gr(\Gamma(Z_n)(\gamma)) = \infty$
3. $\deg(\Gamma(Z_n)(\gamma)) = 0$.
4. $\Gamma(Z_n)(\gamma)$ is non Hamiltonian.
5. $\Gamma(Z_n)(\gamma)$ is not Eulerian.
6. $\omega(\Gamma(Z_n)(\gamma)) = 1$.
7. $\chi(\Gamma(Z_n)(\gamma)) = 1$.

Proof: The Corollary follows from the above theorem.

Theorem 3.9. Let n be a positive integer and not a prime number. Then $\Gamma(Z_n)(\gamma) = K_{1,2(p-1)}$ if and only if $n = 3p$, where $p > 3$ is a prime number.

Proof: Assume that $n = 3p$, where $p \neq 2$ is a prime number. Then $\Gamma(Z_n)(\gamma) = K_{2,(p-1)}$. and so $\gamma(\Gamma(Z_n)) = 2$. Also, the number of $\gamma -$ sets is 2(p-1)+1. Join the vertices that satisfy the two gamma graph $\Gamma(Z_n)(\gamma)$ conditions. Then we get , $\Gamma(Z_n)(\gamma) = K_{1,2(p-1)}$. The converse part is trivial.

Corollary 3.10. Let $n = {p_1}^{k_1}{p_2}^{k_2}{p_3}^{k_3} \dots {p_r}^{k_r}$, where $r > 1$, $k_1, k_2, \dots, k_r = 1$ and $p_1, p_2, \dots, p_r$are primes with $p_1 < p_2 < \cdots < p_r$ and $n \neq 2p, 3p, p > 3$ is a prime. Then
1. $diam(\Gamma(Z_n)(\gamma)) = 2$.
2. $gr(\Gamma(Z_n)(\gamma)) = \infty$
3. $\deg(\Gamma(Z_n)(\gamma)) = 2(p-1)$.
4. $\Gamma(Z_n)(\gamma)$ is non Hamiltonian.
5. $\Gamma(Z_n)(\gamma)$ is not Eulerian.
6. $\omega(\Gamma(Z_n)(\gamma)) = 2$.
7. $\chi(\Gamma(Z_n)(\gamma)) = 2$.

Proof: The Corollary follows from the above theorem.

4. Conclusions

In this paper, we have to find some basic properties on Gamma Graph of a Zero-divisor graph $\Gamma(\mathbb{Z}_n)(\gamma)$. Further, we can find the value of the independent number, clique number, the chromatic Number, the connectivity and some domination parameters of $\Gamma(\mathbb{Z}_n)(\gamma)$. Also, we have to find the gamma graph of

Total graph and its basic properties.

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