

Q-Fuzzification Of Fermatean Fuzzy Points And Local Properties Of Uncertainty Subgroup

R. Nagarajan^{1*}, K. Balamurugan²

¹Department of Mathematics, J.J.College of Engineering and Technology, Tiruchirappalli-620009, Tamilnadu, India.

²Department of Mathematics, M.A.M School of Engineering, Siruganur, Tiruchirappalli-621105, Tamilnadu, India

ABSTRACT

The concept of a fermatean set as first proposed by senapati and yager as the extension of intuitionistic fuzzy set and Pythagorean fuzzy set. In this paper, we studied the notion of a fermatean Q-fuzzy point to study for the first time the notion of fermatean Q-fuzzy subgroups and its local properties. This new concept showed us to reformulate all the mathematical properties of fermatean Q-fuzzy subgroups structure.

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INTRODUCTION

The concept of fuzzy set is first introduced by L.A.Zadeh in 1965 [24]. After the tremendous development intuitionistic fuzzy set [4], pythagorean fuzzy set [23], (3,2) fuzzy set[15], picture fuzzy set [14], Neutrosophic fuzzy set [19] was studied. Recently fermatean fuzzy set [19] was studied by Yager and its application is briefly explained by [23]. Due to the inadequacy of FST in the sense that it admits only the membership grade, intuitionistic fuzzy sets (IFSs) was introduced [5, 6] by incorporating membership and non-membership grades with the chance for hesitation margin. Various properties of IFSs were presented [4,5] and IFSs have been applied in real-life problems [4, 5, 6]. Consequently, Biswas [8, 9] introduced intuitionistic fuzzy subgroups (IFSGs) based on IFSs, Ahn et al. [2] deliberated on sublattice of lattice of IFSGs of a group, some properties of IFSGs were discoursed in [1]. In addition, Yuan et al. [22] shared some light on the description of IFSGs, Bal et al. [7] presented a brief note of kernel subgroups on IFGs and derived some properties of IFGs. Senapati.T [19] introduced fermatean fuzzy sets in 2020, an extension of intuitionistic fuzzy set (IFSs) and pythagorean fuzzy

set (PFSs). AVs and NAVs of fermatean fuzzy sets reveal their dependence on greater powers with sum of cubes is less than 1. Ibrahim.H.Z [15] introduced and applied n, m-rung orthopair fuzzy sets in MCDM.. The concepts of fuzzy modules and fuzzy sub-modules was introduced by Negoita and Ralescu [16] in 1975. The concept of essential fuzzy modules was introduced by Hadi [13] in 2000. Using this idea. Abbas established the concept of essential fuzzy sub-modules and uniform fuzzy modules in 2012 Nagarajan and Solairaju and [17], new Structure and Constructions of Q-fuzzy groups In this paper, we studied the notion of a fermatean Q-fuzzy point to study for the first time the notion of fermatean Q-fuzzy subgroups and its local properties. This new concept showed us to reformulate all the mathematical properties of fermatean Q-fuzzy subgroups structure.

2. Preliminaries

In this section, we will present some notions and results to use them in the sequel.

Definition-2.1: [24] Let X be an universe of discourse. Then a fuzzy set A is an object having the

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following formulation: $A = \{(x, \mu_A(x))/x \in X\}$ where $\mu_A: X \rightarrow [0, 1]$ and $\mu_A(x)$ is called the member degree of x in X .

Example 2.2: Let $X = \{a, b, c\}$. Then the fuzzy set is defined as

x	a	b	c
$\mu_A(x)$	0.3	0.2	0.7

Definition-2.3: [17] A Q-fuzzy set is defined as a mapping $\mu: X \times Q \rightarrow [0, 1]$, assigning a degree of membership between 0 and 1 to each element $x \in X$ for each parameter $q \in Q$.

Definition-2.4:[17] Let X be a non-empty set. An intuitionistic Q-fuzzy set (IQFS for short) of X defined as an object having the form $A = \{(x, J(x, q), K(x, q))/x \in X, q \in Q\}$, where

$J: X \times Q \rightarrow [0, 1]$ and $K: X \times Q \rightarrow [0, 1]$ denote the degree of membership (namely $J(x, q)$) and the degree of non-membership (namely $K(x, q)$) of each element $x \in X$ it to the set A , respectively and $0 \leq J(x, q) + K(x, q) \leq 1$ for each $x \in X$ and $q \in Q$. For the sake of simplicity we shall use the symbol $A = (J, K)$ for the intuitionistic Q-fuzzy set

$$A = \{(x, J(x, q), K(x, q))/x \in X, q \in Q\}.$$

Definition-2.5: [23] Let X be a non-empty set. A pythagorean fuzzy set (PFS) A of an universal set X is of the form $A = \{(x, J(x), K(x))/x \in X\}$ where $J: X \rightarrow [0, 1]$ and $K: X \rightarrow [0, 1]$ and

$$0 \leq J^2(x) + K^2(x) \leq 1 \text{ for each } x \in X.$$

Definition-2.6: [23] Let X be a non-empty set. Let (J_1, K_1) and (J_2, K_2) be two pythagorean fuzzy subsets of X , then

- (i) The intersection set $(J, K) = (J_1, K_1) \cap (J_2, K_2)$ is defined by

$$J = J_1 \wedge J_2 = \min\{J_1, J_2\} \quad \text{and} \quad K = K_1 \vee K_2 = \max\{K_1, K_2\}.$$

- (ii) The intersection set $(J, K) = (J_1, K_1) \cup (J_2, K_2)$ is defined by

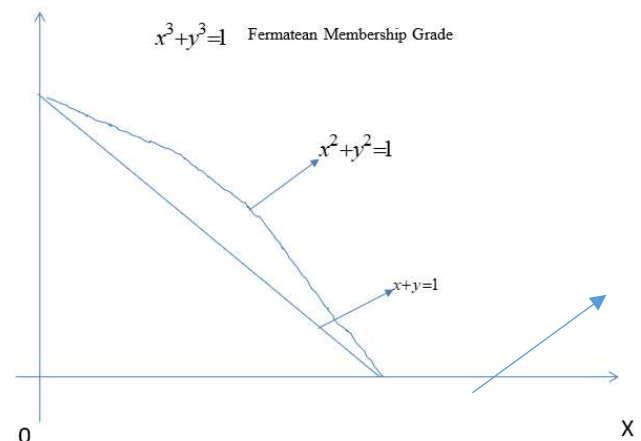
$$J = J_1 \vee J_2 = \max\{J_1, J_2\} \quad \text{and} \quad K = K_1 \wedge K_2 = \min\{K_1, K_2\}.$$

Definition 2.7: [19] Let 'X' be a universe of discourse. A Fermatean fuzzy set "F" in X is an object having the form $F = \{(x, m_F(x), n_F(x))/x \in X\}$, where $m_F(x): X \rightarrow [0, 1]$ and $n_F(x): X \rightarrow [0, 1]$, including the condition

$$0 \leq (m_F(x))^3 + (n_F(x))^3 \leq 1, \text{ for all } x \in X.$$

The numbers $m_F(x)$ denotes the degree of membership and $n_F(x)$ denotes the non-membership of the element 'x' in the set F. Throughout this paper, we will denote a fermatean fuzzy set is FFS. For any FFS 'F' and $x \in X$,

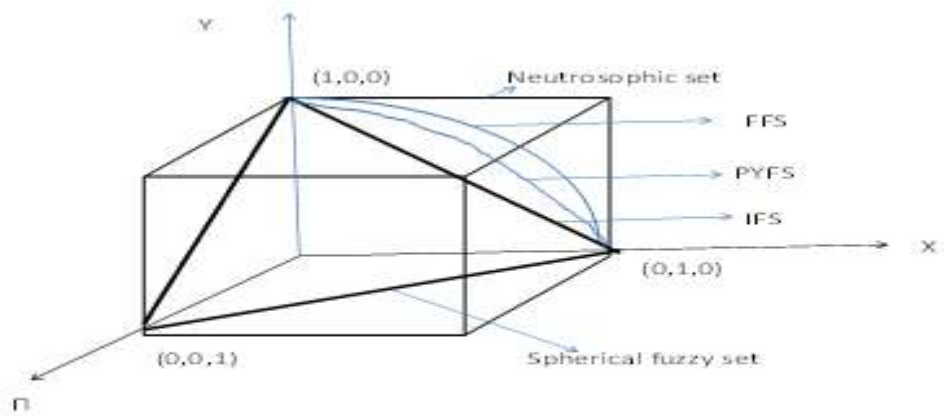
$\pi_F(x) = \sqrt[3]{1 - (m_F(x))^3 - (n_F(x))^3}$ is identified as the degree of indeterminacy of 'x' to F. For convenience, Senapati and Yager called $(m_F(x), n_F(x))$ a fermatean fuzzy number (FFN) denoted by $F = (m_F, n_F)$.



We shall point out the membership Grades (MG's) related Fermatean fuzzy sets as Fermatean membership grades.

Theorem 2.8: [19] The set of FMG's is greater than the set of pythagorean membership grades (PMG's) and intuitionistic membership grades (IMG's).

Proof: This development can be evidently recognized in the following figure.



Here we notice that IMG's are all points beneath the line $x + y \leq 1$, the PMG's are all points with $x^2 + y^2 \leq 1$. We see that the FMG's enable the presentation of a bigger body of non-standard membership grades than IMG's and PMG's.

3. Main Results

Definition-3.1: Let $(G, +)$ be a group and (J, K) be a fermatean fuzzy set (FFS). Then (J, K) is said to be a fermatean Q-fuzzy subgroup (FQFSG) of G if for all $x, y \in G$, the following conditions hold;

$$(FQFSG1): J^3(x + y)_q \geq \min\{J^3(x, q), J^3(y, q)\}$$

$$(FQFSG2): K^3(x + y)_q \leq \max\{K^3(x, q), K^3(y, q)\}$$

$$(FQFSG3): J^3(-x)_q \geq J^3(x, q)$$

$$(FQFSG4): K^3(-x)_q \leq K^3(x, q), \text{ where } q \in Q.$$

Example-3.2: Let $X = \{x, 0.3, 0.4\}$.

$$\text{Here } J^3(x) + K^3(x) = (0.3)^3 + (0.4)^3 = 0.027 + 0.064 = 0.091 < 1.$$

And $\pi_A(x) = 1 - 0.091 < 1$ is called the degree of refusal membership of x in X .

Proposition-3.3: Let $I = (J, K)$ be a FQFSG of a group $(G, +)$. Then the following holds:

$$(i) J^3(e)_q \geq J^3(x, q) \text{ and } K^3(e)_q \leq K^3(x, q) \text{ for all } x \in X, q \in Q.$$

$$(ii) J^3(e)_q = J^3(x, q) \text{ and } K^3(e)_q = K^3(x, q) \text{ for all } x \in X, q \in Q,$$

where 'e' is the identity element in G .

Proposition-3.4: Let $I = (J, K)$ be a FFS of a group $(G, +)$. Then $I = (J, K)$ is a FQFSG of a group $(G, +)$ if and only if

$$J^3(x - y)_q \geq \min\{J^3(x, q), J^3(y, q)\} \text{ and}$$

$$K^3(x - y)_q \leq \max\{K^3(x, q), K^3(y, q)\}, \forall x, y \in G.$$

Definition-3.5: Let 'E' be a set. Let $x \in X, r \in [0, 1]$ and $(\alpha, \beta) \in [0, 1]$ such that

$\alpha^3 + \beta^3 = r^3 \leq 1$. Then the fermatean fuzzy subset $x_{(\alpha, \beta)} = (t_\alpha, 1 - t_{1-\beta})$ is called a fermatean Q-fuzzy point in X with;

$$t_\alpha(y)_q = \begin{cases} \alpha, & \text{if } x = y \\ 0, & \text{if } x \neq y \end{cases} \text{ and } (1 - t_{1-\beta})(y)_q = \begin{cases} \beta, & \text{if } x = y \\ 0, & \text{if } x \neq y \end{cases}$$

with the function $r_{x(\alpha, \beta)}: X \times Q \rightarrow [0, 1]$ given by

$$r_{x(\alpha, \beta)}(y)_q = \begin{cases} r, & \text{if } x = y \\ 1, & \text{if } x \neq y \end{cases}$$

For reasons of simplicity, we can define a fermatean fuzzy point in the following style.

Definition-3.6: Let $\alpha, \beta \in [0, 1]$ with $\alpha^3 + \beta^3 \leq 1$. A fermatean Q-fuzzy point written as

$x_{(\alpha, \beta)}$ is defined to be an fermatean Q-fuzzy subset of X , given by

$$x_{(\alpha, \beta)}(y)_q = \begin{cases} (\alpha, \beta), & \text{if } x = y \\ (0, 1), & \text{if } x \neq y \end{cases}$$

A fermatean Q-fuzzy point $x_{(\alpha, \beta)}$ is said to belong to FFS (J, K) denoted by $x_{(\alpha, \beta)} \in (J, K)$ if

$$J^3(x)_q \geq \alpha \text{ and } K^3(x)_q \leq \beta.$$

Proposition-3.7: Let $(G, +)$ be a group and $H \subset G$, we note by χ_H the characteristic function of the set H . Then, H is the subgroup of G if and only if $(\chi_H, 1 - \chi_H)$ is a non-zero fermatean Q-fuzzy subgroup of G .

Proof: Suppose that H is a subgroup of G . Let 'e' be the neutral element of G , then $e \in H$ and

$$\chi_H(e) = 1.$$

$$\text{So } (\chi_H, 1 - \chi_H) \neq \emptyset.$$

Let $x, y \in H$ and $q \in Q$. If $x \in H$ and $y \in H$, as H is a subgroup of G , then $-y \in H$ and

$$x + y \in H \text{ as result } x - y \in H.$$

$$\text{Therefore, } \chi_H^3(x - y)_q = 1 = \min\{\chi_H^3(x, q), \chi_H^3(y, q)\}.$$

If $x \notin H$ or $y \notin H$, we have $\chi_H^3(x, q) = 0$ or $\chi_H^3(y, q) = 0$.

$$\text{Hence, } \min\{\chi_H^3(x, q), \chi_H^3(y, q)\} = 0 \leq \chi_H^3(x - y)_q.$$

In this same way we show that

$$\begin{aligned} (1 - \chi_H)^3(x - y)_q \\ \leq \min\{(1 - \chi_H)^3(x, q), (1 - \chi_H)^3(y, q)\} \end{aligned}$$

Consequently, $(\chi_H, 1 - \chi_H)$ is a fermatean Q-fuzzy subgroup of G .

There exists $x \in G$ such that $\chi_H(x, q) = 1$, which proves that $H \neq \emptyset$.

$$\text{Moreover, if } x, y \in H, \chi_H^3(x, q) = \chi_H^3(y, q) = 1.$$

Hence, as $\chi_H^3(x - y)_q \geq \min\{\chi_H^3(x, q), \chi_H^3(y, q)\}$, $\chi_H^3(x - y)_q = 1$ and as a result,

$$x - y \in H.$$

Therefore H is a subgroup of G .

Using the definition-3.1, we will have the following theorem.

Theorem-3.8: Let $(G, +)$ be a group and 'A' be a fermatean Q-fuzzy subset of G . Then A is a FQFSG of G . Then A is a FQFSG of G if and only if

$$1. \quad x_{(\alpha_1, \beta_1)} \in A, \quad y_{(\alpha_2, \beta_2)} \in A \quad \text{implies} \quad (x + y)_{(\alpha_1 \wedge \alpha_2, \beta_1 \wedge \beta_2)} \in A.$$

$$2. \quad x_{(\alpha, \beta)} \in A \text{ implies } (-x)_{(\alpha, \beta)} \in A$$

Proof: Sufficient Part:

Let's show that the conditions of the definition of the FQFSG are verified.

$$\text{Let } \alpha = \min\{J_A^3(x, q), J_A^3(y, q)\},$$

$$\beta = \max\{K_A^3(x, q), K_A^3(y, q)\}, \text{ then } \alpha^3 + \beta^3 \leq 1 \text{ and}$$

$$J_A^3(x, q) \geq \alpha, \quad J_A^3(y, q) \geq \alpha \text{ and}$$

$$K_A^3(x, q) \leq \beta, \quad K_A^3(y, q) \leq \beta.$$

$$\text{Then } (x + y)_{(\alpha, \beta)} \in A.$$

$$\text{There fore } J_A^3(x + y)_q \geq \alpha^3 = \min\{J_A^3(x, q), J_A^3(y, q)\} \text{ and}$$

$$\begin{aligned} K_A^3(x + y)_q &\leq \beta^3 = \\ &\max\{K_A^3(x, q), K_A^3(y, q)\}. \end{aligned}$$

As a result, A is a FQFSG of G .

Necessary Part:

Suppose that A is a FQFSG of G .

$$\text{Let } x_{(\alpha_1, \beta_1)} \in A, \quad y_{(\alpha_2, \beta_2)} \in A.$$

$$\text{So, } J_A^3(x, q) \geq \alpha_1, \quad J_A^3(y, q) \geq \alpha_2 \text{ and}$$

$$K_A^3(x, q) \leq \beta_1, \quad K_A^3(y, q) \leq \beta_2.$$

Hence,

$$\begin{aligned} J_A^3(x + y, q) &\geq \min\{J_A^3(x, q), J_A^3(y, q)\} \\ &\geq \min\{\alpha_1, \alpha_2\} \text{ and} \end{aligned}$$

$$\begin{aligned} K_A^3(x + y)_q &\leq \\ \max\{K_A^3(x, q), K_A^3(y, q)\} \\ &\leq \max\{\beta_1, \beta_2\}. \end{aligned}$$

Then $(x + y)_{(\alpha_1 \wedge \alpha_2, \beta_1 \vee \beta_2)} \in A$.

Moreover, $J_A^3(-x, q) \geq J_A^3(x, q)$ and $K_A^3(-x, q) \leq K_A^3(x, q)$.

And because $x_{(\alpha, \beta)} \in A$.

So, $J_A^3(-x, q) \geq J_A^3(x, q) \geq \alpha$ and

$K_A^3(-x, q) \leq K_A^3(x, q) \leq \beta$, as a result $(-x)_{(\alpha, \beta)} \in A$.

Now, we are going to propose some local properties on the FQFSG using the above theorem.

Theorem-3.9: Let $(G, +)$ be a Q-fuzzy subgroup, and let $A(J, K)$ be a fermatean Q-fuzzy subgroup of G . Then the following properties:

1. Let $x_{(\alpha_1, \beta_1)} \in A(J, K)$, $y_{(\alpha_2, \beta_2)} \in A(J, K)$ be two fermatean Q-fuzzy points, then $(x - y)_{(\alpha_1 \wedge \alpha_2, \beta_1 \vee \beta_2)} \in A(J, K)$.
2. Let 'e' be the neutral element of G , then $\forall x_{(\alpha, \beta)} \in A(J, K)$,

$$J_A^3(e) \geq \alpha \text{ and } K_A^3(e) \leq \beta.$$

Proof: 1. Let $x_{(\alpha_1, \beta_1)} \in A(J, K)$, $y_{(\alpha_2, \beta_2)} \in A(J, K)$ be two fermatean Q-fuzzy points. Then, according to the above theorem, we have $y_{(\alpha_1, \beta_1)} \in A(J, K)$ and

$$(x + y)_{(\alpha_1 \wedge \alpha_2, \beta_1 \vee \beta_2)} \in A(J, K).$$

We have $x - y = x + (-y)$.

$$\text{So, } (x - y)_{(\alpha_1 \wedge \alpha_2, \beta_1 \vee \beta_2)} \in A(J, K).$$

2. Let 'e' be the neutral element of G , let $x_{(\alpha, \beta)} \in A(J, K)$ be a fermatean Q-fuzzy point, then $J_A^3(x, q) \geq \alpha$ and $K_A^3(x, q) \leq \beta$.

Then. According to the proposition-3.3, we have

$$J_A^3(e, q) \geq J_A^3(x, q) \text{ and } K_A^3(e, q) \leq K_A^3(x, q).$$

So, $J_A^3(e, q) \geq J_A^3(x, q) \geq \alpha$ and $K_A^3(e, q) \leq K_A^3(x, q) \leq \beta$.

Note-3.10: Note that we have $J_A(e, q) = 1$, $K_A(e, q) = 0$.

$$\text{Let } P = \{(\alpha, \beta) / (\alpha, \beta) \in [0, 1] / \alpha^3 + \beta^3 \leq 1\}.$$

Lemma-3.11: Let 'A' a fermatean Q-fuzzy subset of E , for $(\alpha, \beta) \in P$. Let

$$A_\alpha = \{x \in E / J_A^3(x, q) \geq \alpha\} \text{ and}$$

$$A^\beta = \{x \in E / K_A^3(x, q) \leq \beta\}$$

then $(J_A(x, q), K_A(x, q)) = (\vee\{\alpha/x \in A_\alpha\}, \wedge\{\beta/x \in A^\beta\})$ for all $x \in E$.

Proof: Let $A(J, K)$ be a fermatean Q-fuzzy subset of E . We have

$$A_\alpha = \{x \in E / J_A^3(x, q) \geq \alpha\} \text{ and}$$

$$A^\beta = \{x \in E / K_A^3(x, q) \leq \beta\}.$$

Then, $\vee\{\alpha/x \in A_\alpha\} = \vee\{\alpha \in [0, 1], x \in E, J_A^3(x, q) \geq \alpha\}$ and

$$\wedge\{\beta/x \in A^\beta\} = \wedge\{\beta \in [0, 1], x \in E, K_A^3(x, q) \leq \beta\}.$$

Hence, $(J_A(x, q), K_A(x, q)) = (\vee\{\alpha/x \in A_\alpha\}, \wedge\{\beta/x \in A^\beta\})$ for all $x \in E$.

Theorem-3.12: Let $(G, +)$ be a group and A is a fermatean Q-fuzzy subset of G . Then A is a

fermatean Q-fuzzy subgroup of G if and only if A_α and A^β are subgroups of G for every $(\alpha, \beta) \in P$.

Proof: Let A be a Fermatean Q-fuzzy subgroup of G .

We will show that A_α and A^β are subgroups of G .

Let $x, y \in A^\beta$. Then we have $K_A^3(x, q) \leq \beta$ and $K_A^3(y, q) \leq \beta$.

Therefore, we have

$$\begin{aligned} K_A^3(x - y)_q &\leq \max\{K_A^3(x, q), K_A^3(-y, q)\} \\ &\leq \max\{K_A^3(x, q), K_A^3(y, q)\} \\ &\leq \beta \end{aligned}$$

As a result, $x - y \in A^\beta$.

Therefore, A^β is a subgroup of G .

Similarly, we can show that A_α is a subgroup of G .

Conversely, we have

$$\begin{aligned}
 J_A^3(x+y)_q &= \{V\{\alpha/x+y \in A_\alpha\}\}^3 \\
 &\geq \{V\{\alpha/x \in A_\alpha \text{ and } y \in A_\alpha\}\}^3 \\
 &= \{V\{\alpha/J_A^3(x,q) \geq \alpha, J_A^3(y,q) \geq \alpha\}\}^3 \\
 &= \{V\{\alpha/\min\{J_A^3(x,q), J_A^3(y,q)\} \geq \alpha\}\}^3 \\
 &= \min\{J_A^3(x,q), J_A^3(y,q)\}
 \end{aligned}$$

And

$$\begin{aligned}
 K_A^3(x+y)_q &= \{\wedge\{\beta/x+y \in A^\beta\}\}^3 \\
 &\leq \{\wedge\{\beta/x \in A^\beta \text{ and } y \in A^\beta\}\}^3 \\
 &= \{\wedge\{\beta/K_A^3(x,q) \leq \beta, K_A^3(y,q) \leq \beta\}\}^3 \\
 &= \{\wedge\{\beta/\max\{K_A^3(x,q), K_A^3(y,q)\} \leq \beta\}\}^3 \\
 &= \max\{K_A^3(x,q), K_A^3(y,q)\}
 \end{aligned}$$

And we have

$$\begin{aligned}
 J_A^3(-x)_q &= \{V\{\alpha/-x \in A_\alpha\}\}^3 \\
 &= \{V\{\alpha/x \in A_\alpha\}\}^3 \\
 &= J_A^3(x,q)
 \end{aligned}$$

Also,

$$\begin{aligned}
 K_A^3(-x)_q &= \{\wedge\{\beta/-x \in A^\beta\}\}^3 \\
 &= \{\wedge\{\beta/x \in A^\beta\}\}^3 \\
 &= K_A^3(x,q)
 \end{aligned}$$

Therefore, A is a Fermatean Q-fuzzy subgroup of G .

CONCLUSION

In this paper, we have presented a new definition of fermatean Q-fuzzy subgroups(FQFSG) using the concept of fermatean Q-fuzzy points and with the help of these basic concepts. We have exposed to show

some local properties on fermatean Q-fuzzy subgroups.

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