On Fuzzy γ - Semi Open Sets and Fuzzy γ - Semi Closed Sets in Fuzzy Topological Spaces

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Abstract: The aim of this paper is to introduce the concept of fuzzy γ - semi open and fuzzy γ - semi closed sets of a fuzzy topological space. Some characterizations are discussed, examples are given and properties are established. Also, we define fuzzy γ - semi interior and fuzzy γ - semi closure operators. And we introduce fuzzy γ - t-set, γ - SO extremely disconnected space analyse the relations between them.

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I. Introduction

The concepts of fuzzy sets and fuzzy set operations were first introduced by L.A. Zadeh [6] in his paper. Let X be a non-empty set and I be the unit interval [0,1]. A fuzzy set in X is a mapping from X to I. In 1968, Chang [3] introduced the concept of fuzzy topological space which is a natural generalization of topological spaces. Our notation and terminology follow that of Chang. Azad introduced the notions of fuzzy semi open and fuzzy semi closed sets. And T. Noiri and O.R. Sayed [5] introduced the notion of γ-open sets and γ-closed sets. Swidi Oon [4] studied some of its properties.

Through this paper (X, τ) (or simply X), denote fuzzy topological spaces. For a fuzzy set A in a fuzzy topological space X, cl(A), int(A), A^c denote the closure, interior, complement of A respectively. By 0, and 1, we mean the constant fuzzy sets taking on the values 0 and 1, respectively.

In this paper we introduce fuzzy γ-semi open sets and fuzzy γ-semi closed sets its properties are established in fuzzy topological spaces. The concepts that are needed in this paper are discussed in the second section. The concepts of fuzzy γ-semi open and fuzzy γ-semi closed sets in fuzzy topological spaces and studied their properties in the third and fourth section respectively. Using the fuzzy γ-semi open sets, we introduce the concept of fuzzy γ- SO extremely disconnected space. The section 5 and 6 are dealt with the concepts of fuzzy γ-semi interior and γ-semi closure operators. In the last section, we define fuzzy γ-t-sets and discuss the relations between this set and the sets defined previously.

II. Preliminaries

In this section, we give some basic notions and results that are used in the sequel.

Definition 2.1: A fuzzy set A of a fuzzy topological space X is called:
1) fuzzy semi open (semi closed) [2] if there exists a fuzzy open (closed) set U of X such that U ≤ A ≤ cl U (int U ≤ A ≤ U).
2) fuzzy strongly semi open (strongly semi closed) [4] if A ≤ int(cl(int A)).
3) fuzzy γ-open (fuzzy γ-closed) [5] if A ≤ (int(cl(A)) ∨ cl(int(A)) (A ≤ γ(cl(A)) ∧ (int(cl(A)))).

Definition 2.2 [7]: If λ is a fuzzy set of X and µ is a fuzzy set of Y, then
(λ × µ)(x, y) = min { λ(x), µ(y)}, for each X × Y.

Definition 2.3 [2]: An fuzzy topological space (X, τ) is a product related to an fuzzy topological space (Y, τ) if for fuzzy sets A of X and B of Y whenever C^c ≥ A and D^c ≥ B implies C^c × 1υ 1 × D^c ≥ A × B, where C ∈ τ, and D ∈ τ, there exist C1 ∈ τ and D1 ∈ τ such that C1 ≥ A or D1 ≥ B and C1 ≥ 1υ 1 × D1 ≥ C1 × 1υ 1 × D1.

Lemma 2.4 [2]: Let X and Y be fuzzy topological spaces such that X is product related to Y. Then for fuzzy sets A of X and B of Y,
1) cl(A × B) = cl(A) × cl(B)
2) int(A × B) = int(A) × int(B)

Lemma 2.5 [1]: For fuzzy sets λ, µ, υ and ω in a set S, one has
(λ ∧ µ) × (υ ∧ ω) = (λ × ω) ∧ (µ × υ)
Remark 2.6[5]:
1. Any union of fuzzy γ-open sets in a fuzzy topological space X is a fuzzy γ-open set.
2. Any intersection of fuzzy γ-closed sets is fuzzy γ-closed set.
3. Let \( \{A_\alpha\}_{\alpha \in \mathcal{A}} \) be a collection of fuzzy γ-open sets in a fuzzy topological space X. Then \( \bigcup_{\alpha \in \mathcal{A}} A_\alpha \) is fuzzy γ-open.

Definition 2.7[5]: Let A be any fuzzy set in the fuzzy topological space X. Then we define γ-cl (A) = \( \bigwedge \{B: B \supseteq A, B \text{ is fuzzy γ-closed}\} \) and γ-int (A) = \( \bigvee \{B: B \subseteq A, B \text{ is fuzzy γ-open in } X\} \).

Properties 2.8[5]: Let A be any fuzzy set in the fuzzy topological space X. Then
   a) \( γ-cl(A) = (γ-int(A))^c \)
   b) \( γ-int(A) = (γ-cl(A))^c \)

Properties 2.9[5]: Let A and B be any two fuzzy sets in a fuzzy topological space X. Then
   1) \( γ-cl(0) = 0, γ-cl(1) = 1 \).
   2) \( γ-int(A) \) is fuzzy γ-open in X.
   3) \( γ-int(γ-int(A)) = γ-int(A) \).
   4) if \( A \subseteq B \) then \( γ-int(A) \subseteq γ-int(B). \)
   5) \( γ-int(A \cup B) = γ-int(A) \lor γ-int(B) \).
   6) \( γ-cl(A \cap B) \leq γ-cl(A) \land γ-cl(B) \).

Properties 2.10[5]: Let A and B be any two fuzzy sets in a fuzzy topological space X. Then
   1) \( γ-cl(0) = 0, γ-cl(1) = 1 \).
   2) \( γ-cl(A) \) is fuzzy γ-closed in X.
   3) \( γ-cl(γ-cl(A)) = γ-cl(A) \).
   4) if \( A \subseteq B \) then \( γ-cl(A) \subseteq γ-cl(B) \).
   5) \( γ-cl(A \lor B) = γ-cl(A) \lor γ-cl(B) \).
   6) \( γ-cl(A \land B) \leq γ-cl(A) \land γ-cl(B) \).

III. Fuzzy γ-Semi Open Sets

In this section we introduce the concept of fuzzy γ-semi open sets in a fuzzy topological space.

Definition 3.1: Let A be a fuzzy subset of a fuzzy topological space \((X, \tau)\). Then A is called fuzzy γ-semi open set of X if there exist a fuzzy γ-open set γ-O such that \( γ-O \subseteq A \leq \gamma-cl(A) \).

Theorem 3.2: Let \((X, \tau)\) be a fuzzy topological space. Let A and B be any two fuzzy subsets of X and \( γ-int(A) \leq B \leq γ-cl(A) \). If A is a fuzzy γ-semi open set then so is B.

Proof:
Let A and B be a fuzzy subsets of X and \( γ-int(A) \leq B \subseteq γ-cl(A) \). Let A be fuzzy γ-semi open. By Definition 3.1, there exists a fuzzy γ-open set γ-O such that \( γ-O \subseteq A \leq \gamma-cl(A) \). Hence \( γ-O \leq B \leq γ-cl(A) \) and therefore \( γ-O \leq B \subseteq γ-cl(A) \). Thus B is a fuzzy γ-semi open set.

Theorem 3.3: Let \((X, \tau)\) be a fuzzy topological space. Then a fuzzy subset A of a fuzzy topological space \((X, \tau)\) is fuzzy γ-semi open if and only if \( A \leq γ-cl(γ-int(A)) \).

Proof:
Let A \( \subseteq γ-cl(γ-int(A)) \). Then for \( γ-O = γ-int(A) \), we have \( γ-int(A) \subseteq A \). Therefore \( γ-int(A) \leq A \leq γ-cl(γ-int(A)) \). Conversely, let A be a fuzzy γ-semi open. By Definition 3.1, there exists a fuzzy γ-open set γ-O such that \( γ-O \leq A \leq γ-cl(γ-int(A)) \). But for \( γ-O \leq γ-int(A) \), then \( γ-O \leq γ-int(A) \). Thus \( γ-O \leq γ-cl(γ-int(A)) \). Therefore \( A \leq γ-cl(γ-int(A)) \). Hence \( A \leq γ-cl(γ-int(A)) \).

Remarks 3.4: It is obvious that every fuzzy γ-open is fuzzy γ-semi open and every fuzzy open set is fuzzy γ-semi open but the separate converses may not be true as shown by the following example.

Example 3.5: Let \( X = \{a, b, c\} \) and \( \tau = \{0, 1, \{a_2, b_3, c_3\}, \{a_4, b_7, c_7\}, \{a_5, b_3, c_3\}\} \). Then \((X, \tau)\) is a fuzzy topological space. The family of all fuzzy closed sets of τ is \( τ^c = \{0, 1, \{a_8, b_7, c_7\}, \{a_5, b_3, c_3\}\} \). Let \( A = \{a_4, b_6, c_6\} \). Then \( cl(int(A)) = \{a_4, b_7, c_7\} \) and \( int(cl(A)) = \{a_5, b_3, c_3\} \). Therefore \( int(cl(A)) \lor cl(int(A)) = \{a_5, b_7, c_7\} \). By Definition 2.1(3), A is not fuzzy γ-open. Now let \( γ-int(A) = \{a_2, b_6, c_7\} \). Then \( A \leq cl(γ-int(A)) = \{a_8, b_7, c_7\} \). Thus A is fuzzy γ-semi open.

The next example shows that every fuzzy γ-semi open set need not be fuzzy open.

Example 3.6:
Let \( X = \{a, b, c\} \) and \( \tau = \{0, 1, \{a_1, b_2, c_3\}, \{a_5, b_1, c_4\}\} \). Then \((X, \tau)\) is a fuzzy topological space. The family of all fuzzy closed sets of τ is \( τ^c = \{0, 1, \{a_9, b_8, c_7\}, \{a_5, b_1, c_4\}\} \).
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Let $A = \{a_1, b_2, c_3\}$. Then $\gamma$-int$(A) = \{a_1, b_2, c_3\}$ and $cl(\gamma$-int$(A)) = \{a_1, b_2, c_3\}$. It shows that $A = cl(\gamma$-int$(A))$. By using Theorem 3.3, $A$ is fuzzy $\gamma$-semi open. But $A$ is not a fuzzy open set.

It is clear that every fuzzy semi open is fuzzy $\gamma$-semi open but the converse need not be true as shown by the following example.

**Example 3.7:** Let $X = \{a, b\}$ and $\tau = \{0, 1, \{a, b\}\}$. Then $(X, \tau)$ is a fuzzy topological space. The family of all fuzzy closed sets of $\tau$ is $\tau^c = \{0, 1, \{a, b\}\}$. Let $A = \{a, b\}$. Then $\gamma$-int$(A) = \{a, b\}$ and $cl(\gamma$-int$(A)) = \{a, b\}$. It shows that $A = cl(\gamma$-int$(A))$. By using Theorem 3.3, $A$ is fuzzy $\gamma$-semi open.

**Proposition 3.8:** Let $(X, \tau)$ be a fuzzy topological space. Then the union of any two fuzzy $\gamma$-semi open sets is a fuzzy $\gamma$-semi open set.

**Proof:**

Let $A_1$ and $A_2$ be the two fuzzy $\gamma$-semi open sets. By Theorem 3.3, $A_1 \subseteq cl(\gamma$-int $(A_1))$ and $A_2 \subseteq cl(\gamma$-int $(A_2))$. Therefore $A_1 \cup A_2 \subseteq cl(\gamma$-int $(A_1)) \cup cl(\gamma$-int $(A_2)) = cl(\gamma$-int $(A_1) \cup \gamma$-int $(A_2))$. By using Properties 2.9(6), $A_1 \cup A_2 \subseteq cl(\gamma$-int $(A_1 \cup A_2))$. Hence $A_1 \cup A_2$ is fuzzy $\gamma$-semi open.

The following example shows that the intersection of any two fuzzy $\gamma$-semi open sets need not be fuzzy $\gamma$-semi open set.

**Example 3.9:** Let $X = \{a, b\}$ and $\tau = \{0, 1, \{a, b\}\}$. Then $(X, \tau)$ is a fuzzy topological space. The family of all fuzzy closed sets of $\tau$ is $\tau^c = \{0, 1, \{a, b\}\}$. Let $A = \{a, b\}$ and $\gamma$-int $(A) = \{a, b\}$. Then we get $cl(\gamma$-int $(A)) = \{1\}$. Thus by Theorem 3.3, $A$ is fuzzy $\gamma$-semi open.

Let $B = \{a, b\}$. Then $\gamma$-int $(B) = \{a, b\}$ and we get $cl(\gamma$-int $(B)) = \{1\}$. Thus by Theorem 3.3, $B$ is fuzzy $\gamma$-semi open. Now $A \cap B = \{a, b\}$ and $\gamma$-int $(A \cap B) = \{a, b\}$. Then $cl(\gamma$-int $(A \cap B)) = \{a, b\}$. Thus $A \cap B$ is not less than or equal to $cl(\gamma$-int $(A \cap B))$. Therefore $A \cap B$ is not fuzzy $\gamma$-semi open.

**Theorem 3.10:** Let $(X, \tau)$ be a fuzzy topological space and let $\{A_\alpha\}_{\alpha \in A}$ be a collection of fuzzy $\gamma$-semi open sets in a fuzzy topological space $X$. Then $\bigcap_{\alpha \in A} A_\alpha$ is fuzzy $\gamma$-semi open.

**Proof:**

Let $A$ be a collection of fuzzy $\gamma$-semi open sets of a fuzzy topological space $(X, \tau)$. Then by using Theorem 3.3, for each $\alpha \in A$, $A_\alpha \subseteq cl(\gamma$-int $(A_\alpha))$. Thus $\bigcap_{\alpha \in A} A_\alpha \subseteq \bigcup_{\alpha \in A} cl(\gamma$-int $(A_\alpha))$. Since $\bigcup_{\alpha \in A} cl(\alpha) \subseteq cl(\bigcup_{\alpha \in A} \alpha)$, $\bigcap_{\alpha \in A} A_\alpha \subseteq cl(\bigcup_{\alpha \in A} \gamma$-int $(A_\alpha))$. Thus the arbitrary union of fuzzy $\gamma$-semi open sets is fuzzy $\gamma$-semi open set.

**Theorem 3.11:** Let $(X, \tau)$ and $(Y, \sigma)$ be any two fuzzy topological spaces such that $X$ is product related to $Y$. Then the product $A_1 \times A_2$ of fuzzy $\gamma$-open set $A_1$ of $X$ and a fuzzy $\gamma$-open set $A_2$ of $Y$ is fuzzy $\gamma$-open set of the fuzzy product space $X \times Y$.

**Proof:**

Let $A_1$ be a fuzzy $\gamma$-open subset of $X$ and $A_2$ be a fuzzy $\gamma$-open subset of $Y$. Then by Definition 2.1(3), we have $A_1 \subseteq int(cl(A_1)) \cup cl(int(A_1))$ and $A_2 \subseteq int(cl(A_2)) \cup cl(int(A_2))$. Now $A_1 \times A_2 \subseteq (int(cl(A_1)) \cup cl(int(A_1))) \times (int(cl(A_2)) \cup cl(int(A_2)))$. By using Definition 2.2,

$$
A_1 \times A_2 \subseteq \min \{ int(cl(A_1)) \cup cl(int(A_1)), int(cl(A_2)) \cup cl(int(A_2)) \} = int(cl(A_1)) \cup cl(int(A_1)) \cap (int(cl(A_2)) \cup cl(int(A_2)))
$$

Therefore $A_1 \times A_2$ is fuzzy $\gamma$-open in the fuzzy product space $X \times Y$.

**Theorem 3.12:** Let $(X, \tau)$ and $(Y, \sigma)$ be any two fuzzy topological spaces such that $X$ is product related to $Y$. Then the product $A_1 \times A_2$ of a fuzzy $\gamma$-semi open set $A_1$ of $X$ and a fuzzy $\gamma$-semi open set $A_2$ of $Y$ is fuzzy $\gamma$-semi open set of the fuzzy product space $X \times Y$.

**Proof:**

Let $A_1$ be a fuzzy $\gamma$-semi open subset of $X$ and $A_2$ be a fuzzy $\gamma$-semi open subset of $Y$. Then by using Theorem 3.3, we have $A_1 \subseteq cl(\gamma$-int $(A_1))$ and $A_2 \subseteq cl(\gamma$-int $(A_2))$. This implies that $A_1 \times A_2 \subseteq cl(\gamma$-int $(A_1)) \times cl(\gamma$-int $(A_2))$. By Lemma 2.4(1), $A_1 \times A_2 \subseteq cl(\gamma$-int $(A_1) \times \gamma$-int $(A_2)$).
By Theorem 3.11, \( A_1 \times A_2 \leq \text{cl} (\gamma \text{-int}(A_1 \times A_2)) \). Therefore \( A_1 \times A_2 \) is fuzzy \( \gamma \)-semi open set in the fuzzy product space \( X \times Y \).

### IV. Fuzzy \( \gamma \) – semi closed sets

In this section we introduce the concept of fuzzy \( \gamma \)-semi closed sets in a fuzzy topological space.

**Definition 4.1:** Let \( A \) be a fuzzy subset of a fuzzy topological space \((X, \tau)\). Then \( A \) is called fuzzy \( \gamma \)-semi closed set of \( X \) if there exist a fuzzy \( \gamma \)-closed set \( \gamma-c \) such that \( \text{int} (\gamma-c) \leq A \leq \gamma-c \).

**Theorem 4.2:** Let \( A \) be a fuzzy subset of a fuzzy topological space \((X, \tau)\) and \( \gamma \)-int\(A\) \(\leq B \leq \gamma\text{-cl}(A)\). If \( A \) is a fuzzy \( \gamma \)-semi closed set then so is \( B \).

**Proof:**

Let \( A \) be a fuzzy subset of \( X \) and \( \gamma\text{-int}(A) \leq B \leq \gamma\text{-cl}(A) \). If \( A \) is a fuzzy \( \gamma \)-semi closed set, then by Definition 4.1, there exists a fuzzy \( \gamma \)-closed set \( \gamma-c \) such that \( \text{int}(\gamma-c) \leq A \leq \gamma-c \).

By using Properties 2.

**Proposition 4.4:** Let \((X, \tau)\) be a fuzzy topological space. The family of all fuzzy \( \gamma \)-closed sets of \((X, \tau)\) is fuzzy \( \gamma \)-semi closed if and only if \( A \) is fuzzy \( \gamma \)-semi closed.

**Proof:**

Let \( A \) be a fuzzy \( \gamma \)-semi closed subset of \( X \). Then by Theorem 4.3, \( A \geq \text{int}(\gamma\text{-cl}(A)) \). Taking complement on both sides, we get \( A \leq \text{cl}(\text{int}(\gamma\text{-cl}(A))) \). By using Properties 2., \( A \leq \text{cl}(\text{int}(\gamma\text{-cl}(A))) \).

By Theorem 3.3, we have \( A \) is fuzzy \( \gamma \)-semi open.

Conversely, let \( A \) be fuzzy \( \gamma \)-semi closed. Then by Definition 4.1, there exists a fuzzy \( \gamma \)-closed set \( \gamma-c \) such that \( \text{int}(\gamma-c) \leq A \leq \gamma-c \). But \( \gamma\text{-cl}(A) \leq \gamma-c \) and \( \text{int}(\gamma\text{-cl}(A)) \leq \text{int}(\gamma-c) \), thus \( A \geq \text{int}(\gamma\text{-cl}(A)) \). Hence \( A \) is fuzzy \( \gamma \)-semi closed.

**Remark 4.5:** It is obvious that every fuzzy \( \gamma \)-closed set is fuzzy \( \gamma \)-semi closed and every fuzzy closed set is fuzzy \( \gamma \)-semi closed. But the separate converses may not be true as shown by the following example.

**Example 4.6:** Let \( X = \{a, b, c\} \) and \( \tau = \{0, 1\} \). Let \( A = \{a, b, c\} \). Then \( \text{cl}(A) = \{a, b, c\} \) and \( \text{int}(\gamma\text{-cl}(A)) = \{a, b, c\} \).

**Example 4.7:** Let \( X = \{a, b, c\} \) and \( \tau = \{0, 1\} \). Let \( A = \{a, b, c\} \). Then \( \text{cl}(A) = \{a, b, c\} \) and \( \text{int}(\gamma\text{-cl}(A)) = \{a, b, c\} \).

**Example 4.8:** Let \( X = \{a, b\} \) and \( \tau = \{0, 1\} \). Then \( \text{cl}(A) = \{a, b\} \) and \( \text{int}(\gamma\text{-cl}(A)) = \{a, b\} \).

**Theorem 4.9:** Let \((X, \tau)\) be a fuzzy topological space. Then the intersection of two fuzzy \( \gamma \)-semi closed sets is fuzzy \( \gamma \)-semi closed in the fuzzy topological space \((X, \tau)\).

**Proof:**

Let \( A \) and \( B \) be two fuzzy \( \gamma \)-semi closed sets. By Theorem 4.3, we have \( A \leq \text{int}(\gamma\text{-cl}(A)) \) and \( B \leq \text{int}(\gamma\text{-cl}(B)) \). Therefore \( A \leq \text{int}(\gamma\text{-cl}(A)) \) and \( B \leq \text{int}(\gamma\text{-cl}(B)) \).

By using Properties 2., \( A \leq \text{int}(\gamma\text{-cl}(A)) \) and \( B \leq \text{int}(\gamma\text{-cl}(B)) \). Hence \( A \leq \text{int}(\gamma\text{-cl}(A)) \). Therefore \( A \) is fuzzy \( \gamma \)-semi closed.

The union of two fuzzy \( \gamma \)-semi closed sets is need not be fuzzy \( \gamma \)-semi closed in the fuzzy topological space \( X \) as shown by the following example.

**Example 4.10:** Let \( X = \{a, b, c\} \) and \( \tau = \{0, 1\} \). Let \( A = \{a, b, c\} \) and \( B = \{a, b, c\} \). Then \( \text{cl}(A) = \{a, b, c\} \) and \( \text{int}(\gamma\text{-cl}(A)) = \{a, b, c\} \).

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c, \{a, b, c, \}, \{a, b, c, \}, \{a, b, c, \}, \{a, b, c, \}

Let A = \{a, b, c, \} and γ-cl(A) = \{a, b, c, \}. Then we get int(γ-cl(A)) = \{a, b, c, \}. Thus by Theorem 4.3, A is fuzzy γ-semi closed.

Theorem 4.11: Let (X, τ) be a fuzzy topological space and let \{A_\alpha\}_{\alpha \in \Lambda} be a collection of fuzzy γ-semi closed sets in a fuzzy topological space X. Then \bigcap_{\alpha \in \Lambda} A_\alpha is fuzzy γ-semi closed for each \alpha \in \Lambda.

Proof:
Let \Delta be a collection of fuzzy γ-semi closed sets of a fuzzy topological space (X, τ). Then by Theorem 4.3, for each \alpha \in \Delta, A_\alpha \supseteq int(γ-cl(A_\alpha)). Thus, \bigcap_{\alpha \in \Delta} A_\alpha \supseteq \bigcap_{\alpha \in \Delta}(int(γ-cl(A_\alpha))). Therefore arbitrary intersection of fuzzy γ-semi closed set is fuzzy γ-semi closed.

Theorem 4.12: Let (X, τ) and (Y, σ) be any two fuzzy topological spaces such that X is product related to Y. Then the product A_1 x A_2 of fuzzy γ-closed set A_1 of X and a fuzzy γ-closed set A_2 of Y is fuzzy γ-closed set of the fuzzy product space X x Y.

Proof:
Let A_1 be a fuzzy γ-closed subset of X and A_2 be a fuzzy γ-closed subset of Y. Then by Definition 2.1, we have A_1 \supseteq int(cl(A_1)) \wedge cl(int(A_1)) \wedge cl(int(A_1)) \wedge cl(int(A_1)) \wedge cl(int(A_1)) \wedge cl(int(A_1)). Now A_1 x A_2 \supseteq (int(cl(A_1)) \wedge cl(int(A_1))) \times (int(cl(A_1)) \wedge cl(int(A_1))). By using Lemma 2.5, A_1 x A_2 \supseteq \bigcap (cl(A_1 \times A_2) \wedge cl(int(A_1 \times A_2))). Therefore A_1 x A_2 is fuzzy γ-closed in the fuzzy product space X x Y.

Theorem 4.13: Let (X, τ) and (Y, σ) be any two fuzzy topological spaces such that X is product related to Y. Then the product A_1 x A_2 of fuzzy γ-semi closed set A_1 of X and a fuzzy γ-semi closed set A_2 of Y is fuzzy γ-semi closed set of the fuzzy product space X x Y.

Proof:
Let A_1 be a fuzzy γ-semi closed subset of X and A_2 be a fuzzy γ-semi closed subset of Y. Then by Theorem 4.3, we have A_1 \supseteq int(γ-cl(A_1)) \wedge A_2 \supseteq int(γ-cl(A_2)). Now A_1 x A_2 \supseteq (int(γ-cl(A_1)) \times int(γ-cl(A_2))). By using Lemma 2.4(2), A_1 x A_2 \supseteq int(γ-cl(A_1) \times γ-cl(A_2)). By using the Theorem 4.12, we get A_1 x A_2 \supseteq int(γ-cl(A_1 \times A_2)). Therefore A_1 x A_2 is fuzzy γ-semi closed in the fuzzy product space X x Y.

V. Fuzzy γ-semi interior

In this section we introduce the concept of fuzzy γ-semi interior and their properties in a fuzzy topological space.

Definition 5.1: Let (X, τ) be a fuzzy topological space. Then for a fuzzy subset A of X, the fuzzy γ-semi interior of A (briefly γ-sint(A)) is the union of all fuzzy γ-semi open sets of X contained in A. That is, γ-sint(A) = \bigvee \{B : B \subseteq A, B \text{ is fuzzy γ-semi open in } X\}.

Proposition 5.2: Let (X, τ) be a fuzzy topological space. Then for any fuzzy subsets A and B of a fuzzy topological X we have

(i) γ-sint(A) \subseteq A
(ii) A is fuzzy γ-semi open ⇒ γ-sint(A) = A
(iii) γ-sint(γ-sint(A)) = γ-sint(A)
(iv) if A \subseteq B then γ-sint(A) \subseteq γ-sint(B)

Proof:
(i) follows from Definition 5.1.
(ii) Let A be fuzzy γ-semi open. Then A \subseteq γ-sint(A). By using (i) we get A = γ-sint(A). Conversely assume that A = γ-sint(A). By using Definition 5.1, A is fuzzy γ-semi open. Thus (ii) is proved.
(iii) By using (ii) we get γ-sint(γ-sint(A)) = γ-sint(A). This proves (iii).
(iv) Since A \subseteq B, by using (i) γ-sint(A) \subseteq A \subseteq B. That is γ-sint(A) \subseteq B. By (iii), γ-sint(γ-sint(A)) \subseteq γ-sint(B). Thus γ-sint(A) \subseteq γ-sint(B). This proves (iv).

Theorem 5.3: Let (X, τ) be a fuzzy topological space. Then for any fuzzy subset A and B of a fuzzy topological space, we have

(i) γ-sint(A \wedge B) = (γ-sint(A) \wedge (γ-sint(B)
(ii) $\gamma$-sint (A$\cup$B) $\geq$ ($\gamma$-sint A) $\cup$ ($\gamma$-sint B)

**Proof:**

Since $A\land B \leq A$ and $A\lor B \leq B$, by using Proposition 5.2(iv), we get $\gamma$-sint $(A\land B) \leq \gamma$-sint(A) and $\gamma$-sint $(A\lor B) \leq \gamma$-sint (B). This implies that $\gamma$-sint $(A \land B) \leq (\gamma$-sint A) $\land$ ($\gamma$-sint B) $\leq (\gamma$-sint A) $\lor$ ($\gamma$-sint B) $\leq (\gamma$-sint A) $\land$ (\gamma$-sint B) $\leq (\gamma$-sint A) $\lor$ ($\gamma$-sint B). This implies (i).

By using Proposition 5.2(i), we have $\gamma$-sint(A) $\leq A$ and $\gamma$-sint (B) $\leq B$. This implies that $\gamma$-sint (A) $\land$ $\gamma$-sint (B) $\leq A \land B$. Now applying Proposition 5.2(iv), we get $\gamma$-sint ($\{y$-sint (A) $\land$ $\gamma$-sint (B)$ \leq \gamma$-sint (A$\land$B).

By (i), $\gamma$-sint($\gamma$-sint (A)) $\land$ $\gamma$-sint ($\gamma$-sint (B)) $\leq \gamma$-sint (A $\land$ B). By Proposition 5.2(iii), $\gamma$-sint (A) $\land$ $\gamma$-sint (B) $\leq \gamma$-sint (A $\land$ B) $\leq \gamma$-sint (A $\land$ B) $\leq \gamma$-sint (A) $\land$ $\gamma$-sint (B). This implies (i).

Since $A \leq A \lor B$ and $B \leq A \lor B$, by using Proposition 5.2(iv), we have $\gamma$-sint (A) $\leq \gamma$-sint (A $\lor$ B) and $\gamma$-sint (B) $\leq \gamma$-sint (A $\lor$ B). This implies that $\gamma$-sint (A $\lor$ B) $\leq \gamma$-sint (A $\lor$ B). Hence (ii).

The following example shows that the equality need not hold in Theorem 5.3(ii).

**Example 5.4:** Let $X = \{a, b, c\}$ and $\tau = \{\emptyset, \{a, c\}, \{a, b, c\}, \{a, b\}, \{b\}, \{a\}\}$. Then (X, $\tau$) is a fuzzy topological space. The family of all fuzzy closed sets of $\tau$ is $\tau_0 = \{\emptyset, \{a, b, c\}, \{a, b\}, \{b\}, \{a\}\}$. Then $\gamma$-sint (A) $\leq \gamma$-sint (A $\lor$ B) $\leq \gamma$-sint (A $\land$ B) $\leq \gamma$-sint (A $\lor$ B) $\leq \gamma$-sint (A $\land$ B). This implies (i).

VI. Fuzzy $\gamma$-semi closure

In this section we introduce the concept of fuzzy $\gamma$-semi closure in a fuzzy topological space.

**Definition 6.1:** Let $(X, \tau)$ be a fuzzy topological space. Then for a fuzzy subset A of $X$, the fuzzy $\gamma$-semi closure of A (briefly $\gamma$-scl (A)) is the intersection of all fuzzy $\gamma$-semi closed sets contained in A. That is, $\gamma$-scl (A) = $\cap$ $\{B: B \geq A, B$ is fuzzy $\gamma$-semi closed $\}.$

**Proposition 6.2:** Let $(X, \tau)$ be a fuzzy topological space. Then for any fuzzy subsets A of $X$, we have

i. ($\gamma$-sint (A)$)' = \gamma$-scl (A)$^c$ and

ii. ($\gamma$-scl (A)$)' = \gamma$-sint (A)$^c$

**Proof:**

By using Definition 5.1, $\gamma$-sint (A) $= \{B: B \leq A, B$ is fuzzy $\gamma$-semi open $\}$. Taking complement on both sides, we get $\gamma$-sint (A)$^c$ = $\{B: B \leq A, B$ is fuzzy $\gamma$-semi closed $\}$. Replacing B by A, we get $\gamma$-sint (A)$^c$ = $\{c: c \geq A, c$ is fuzzy $\gamma$-semi closed $\}$. By Definition 6.1, $\gamma$-scl (A)$)' = \gamma$-scl (A)$^c$.$\gamma$-scl (A)$^c = \gamma$-scl (A)$^c$. This proves (i).

By using (i), $\gamma$-scl (A)$)' = \gamma$-scl (A)$^c$ = $\gamma$-scl (A)$^c$. Taking complement on both sides, we set $\gamma$-sint (A)$)' = \gamma$-scl (A)$^c$. Hence proved (ii).

**Proposition 6.3:** Let $(X, \tau)$ be a fuzzy topological space. Then for a fuzzy subset A and B of a fuzzy topological space X, we have

i. A $\leq$ $\gamma$-scl (A).

ii. A is fuzzy $\gamma$-semi closed $\Leftrightarrow$ $\gamma$-scl (A) $= A$.

iii. $\gamma$-scl ($\gamma$-scl (A)) = $\gamma$-scl (A).

iv. if A $\leq$ B then $\gamma$-scl (A) $\leq$ $\gamma$-scl (B).

**Proof:**

i. The proof of (i) follows from the Definition 6.1.

ii. Let A be a fuzzy $\gamma$-semi closed subset in X. By using Proposition 4.4, $A^c$ is fuzzy $\gamma$-semi open. By using Proposition 6.2(ii), $\gamma$-scl(A)$^c$ = $A^c$ $\Leftrightarrow$ $\gamma$-scl (A)$^c$ $= A^c$ $\Leftrightarrow$ $\gamma$-scl (A) $= A$. Thus proved (ii).

iii. By using (ii), $\gamma$-scl($\gamma$-scl (A)) = $\gamma$-scl (A). This proves (iii).

iv. Suppose A $\leq$ B. Then $B^c$ $\leq$ $A^c$. By using Proposition 5.2(iv), $\gamma$-scl (B$^c$) $\leq$ $\gamma$-sint (A$^c$). Taking complement on both sides, we get $\gamma$-scl (B$^c$)$^c$ $\geq$ $\gamma$-sint (A$^c$)$^c$. By Proposition 6.2(ii), $\gamma$-scl (B$^c$)$^c$ $\geq$ $\gamma$-scl (A$^c$)$^c$. This proves (iv).

**Proposition 6.4:** Let A be a fuzzy set in a fuzzy topological space X. Then int(A) $\leq$ sint(A) $\leq$ $\gamma$-int(A) $\leq$ $\gamma$-sint(A) $\leq$ A $\leq$ $\gamma$-cl(A) $\leq$ cl(A).

**Proof:** It follows from the Definitions of corresponding operators.

**Proposition 6.5:** Let $(X, \tau)$ be a fuzzy topological space. Then for a fuzzy subset A and B of a fuzzy topological space X, we have
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(i) $\gamma$-scl $(A \vee B) = \gamma$-scl $(A) \vee \gamma$-scl $(B)$ and

(ii) $\gamma$-scl $(A \wedge B) \leq \gamma$-scl $(A) \wedge \gamma$-scl $(B)$.

**Proof:**

Since $\gamma$-scl $(A \vee B) = \gamma$-scl$[(A \vee B)]^\gamma$, by using Proposition 6.2(i), we have $\gamma$-scl $(A \vee B) = [\gamma$-sint $(A \vee B)]^\gamma = [\gamma$-sint $(A^\gamma \wedge B^\gamma)]^\gamma$. Again using Proposition 5.3(i), we have $\gamma$-scl $(A \vee B) = [\gamma$-sint $(A^\gamma \wedge \gamma$-scl $(B^\gamma))][\gamma$-sint $(B^\gamma)]^\gamma$. By using Proposition 6.2(i), we have $\gamma$-scl $(A \vee B) = \gamma$-scl $(A^\gamma \wedge \gamma$-scl $(B^\gamma))$. That is $A$ is fuzzy $\gamma$-semi closed. Hence proved (i).

Since $A \wedge B \leq A$ and $A \wedge B \leq B$, by using Proposition 6.3(iv), $\gamma$-scl $(A \wedge B) \leq \gamma$-scl $(A)$ and $\gamma$-scl $(A \wedge B) \leq \gamma$-scl $(B)$. This implies that $\gamma$-scl $(A \wedge B) \leq \gamma$-scl $(A) \wedge \gamma$-scl $(B)$. This proves (ii).

The following example shows that $\gamma$-scl $(A \wedge B)$ need not be equal to $\gamma$-scl $(A) \wedge \gamma$-scl $(B)$.

**Example 6.6:** Let $X = \{a, b, c\}$ and $\tau = \{0, 1, \{a, b, c\}, \{a_2, b_1, c_2\}, \{a_1, b_1, c_2\}, \{a_2, b_7, c_4\}\}$. Then $(X, \tau)$ is a fuzzy topological space. The family of all fuzzy closed sets of $\tau$ is $\tau^c = \{0, 1, \{a_9, b_3, c_4\}, \{a_8, b_9, c_4\}, \{a_9, b_9, c_4\}, \{a_9, b_3, c_4\}\}$. Consider $A = \{a_4, b_5, c_3\}$ and $B = \{a_6, b_5, c_3\}$. Then $\gamma$-scl $(A) = \{a_5, b_4, c_4\}$ and $\gamma$-scl $(B) = \{a_6, b_5, c_3\}$. Also $\gamma$-scl $(A) \vee \gamma$-scl $(B) = \{a_6, b_5, c_3\}$. Now $A \wedge B = \{a_4, b_5, c_4\}$ and $\gamma$-scl $(A \wedge B) = \{a_6, b_5, c_4\}$. Thus $\gamma$-scl $(A) \wedge \gamma$-scl $(B) \neq \gamma$-scl $(A \wedge B)$.

**Theorem 6.7:** Let $(X, \tau)$ be a fuzzy topological space. Then for a fuzzy subset $A$ and $B$ of $X$ we have

(i) $\gamma$-scl $(A) \supseteq A \wedge \gamma$-scl $(\gamma$-sint $(A))$.

(ii) $\gamma$-sint $(A) \subseteq A \wedge \gamma$-sint $(\gamma$-scl $(A))$.

(iii) int $(\gamma$-scl $(A)) \subseteq$ int $(\gamma$-scl $(\gamma$-sint $(A)))$.

(iv) int $(\gamma$-scl $(A)) \supseteq$ int $(\gamma$-scl $(\gamma$-sint $(A)))$.

**Proof:**

(i) By Proposition 6.3(i), $A \subseteq \gamma$-scl $(A)$

Again using Proposition 5.2(i), $\gamma$-sint $(A) \subseteq A$.

Then $\gamma$-scl $(\gamma$-sint $(A)) \subseteq \gamma$-scl $(A)$

By (1) & (2) we have $A \wedge \gamma$-scl $(\gamma$-sint $(A)) \subseteq \gamma$-scl $(A)$. This proves (i).

(ii) By Proposition 5.2(i), $\gamma$-scl $(\gamma$-sint $(A)) \subseteq A$

Again using proposition 6.3(i), $A \subseteq \gamma$-scl $(A)$.

Then $\gamma$-sint $(A) \subseteq \gamma$-sint $(\gamma$-scl $(A))$

From (1) & (2), we have $\gamma$-sint $(A) \subseteq A \wedge \gamma$-sint $(\gamma$-scl $(A))$. This proves (ii).

(iii) By Proposition 6.4, $\gamma$-scl $(A) \subseteq cl (A)$.

we get int $(\gamma$-scl $(A)) \subseteq cl (A)$.

(iv) By (i), $\gamma$-scl $(A) \supseteq A \wedge \gamma$-scl $(\gamma$-sint $(A))$. Then we have

int $(\gamma$-scl $(A)) \supseteq int (A \wedge \gamma$-scl $(\gamma$-sint $(A)))$. Since int $(A \wedge B) \supseteq int (A) \vee int (B)$,

int $(\gamma$-scl $(A)) \supseteq int (A) \vee int (\gamma$-scl $(\gamma$-sint $(A)))$

The family of all fuzzy semi open (fuzzy semi closed, fuzzy strongly semi open, fuzzy strongly semi closed, fuzzy $\gamma$-semi open, fuzzy $\gamma$-semi closed, fuzzy $\gamma$-open, fuzzy $\gamma$-closed) sets of an fuzzy topological space $(X, \tau)$ will be denoted by $Fso(\tau)$ ($Fsc(\tau), Fsso(\tau), Fsscl(\tau), Fscl(\tau), Fyo(\tau), Fyos(\tau), Fycl(\tau)$).

**Proposition 6.8:** Let $(X, \tau)$ be a fuzzy topological space. Then

1) $Fsscl(\tau) \wedge Fsc(\tau) \subseteq Fycl(\tau)$.
2) $Fsscl(\tau) \wedge Fso(\tau) \subseteq Fyo(\tau)$.
3) $Fyo(\tau) \wedge Fso(\tau) \subseteq Fyos(\tau)$.
4) $Fycl(\tau) \wedge Fsc(\tau) \subseteq Fycl(\tau)$.

**Proof:**

Let $A$ be a fuzzy subset of $Fsscl(\tau) \wedge Fsc(\tau)$. Then $A \in Fsscl(\tau)$ and $A \in Fsc(\tau)$. By the Definition of fuzzy strongly semi closed, $A \supseteq int (cl (A)) \supseteq int (\gamma$-cl $(A))$. Therefore $A \supseteq int (\gamma$-cl $(A))$. That is $A$ is fuzzy $\gamma$-semi closed. This proves (1).

Let $A \in Fsscl(\tau) \wedge Fso(\tau)$. Then $A \in Fso(\tau)$ and $A \in Fsc(\tau)$. By the Definition of fuzzy strongly semi open, $A \subseteq int (cl (A)) \subseteq int (\gamma$-cl $(A))$. Again using the Definition of fuzzy semi open, $A \subseteq int (A) \subseteq \gamma$-cl $(A)$. Therefore $A$ is fuzzy $\gamma$-semi open. This proves (2).

Let $A \in Fsc(\tau) \wedge Fso(\tau)$. Then $A \in Fso(\tau)$ and $A \in Fsc(\tau)$. By the Definition of fuzzy $\gamma$-open, $A \subseteq cl (int (A))$. That is $A \subseteq cl (int (A)) \subseteq cl (\gamma$-int $(A))$. Again using the Definition of fuzzy semi open, $A \subseteq cl (A)$. This implies that $A \subseteq cl (\gamma$-int $(A))$. Therefore $A$ is fuzzy $\gamma$-semi open. Hence proved (3).

Let $A \in Fycl(\tau) \wedge Fsc(\tau)$. Then $A \in Fycl(\tau)$ and $A \in Fsc(\tau)$. By the Definition of fuzzy $\gamma$-closed, $A \supseteq int (\gamma$-cl $(A)) \wedge int (\gamma$-cl $(A))$. That is $A \supseteq int (\gamma$-cl $(A))$. Again by Theorem 4.3, $A \supseteq int (cl (A))$. Therefore $A$ is fuzzy $\gamma$-semi closed. Hence proved (4).
Definition 6.9: An fuzzy topological space $(X, \tau)$ is fuzzy $\gamma$-SO-extremely disconnected if and only if $\gamma$-scl$(A)$ is a fuzzy $\gamma$-semi open set, for each fuzzy $\gamma$-semi open set $A$ of $(X, \tau)$.

Theorem 6.10: Let $(X, \tau)$ be an fuzzy topological space. Then the following statements are equivalent:

(i) $X$ is $\gamma$-SO-extremely disconnected.
(ii) $\gamma$-rint$(A)$ is a fuzzy $\gamma$-semi closed set, for each fuzzy $\gamma$-semi closed set $A$ of $X$.
(iii) $\gamma$-scl$(\gamma$-scl$(A))^\gamma_\tau = (\gamma$-scl$(A))^\gamma_\tau$, for each fuzzy $\gamma$-semi open set $A$ of $X$.
(iv) $B = (\gamma$-scl$(A))^\gamma_\tau$ implies $\gamma$-scl$(B)=\gamma$-scl$(A)^\gamma_\tau$ for each pair of fuzzy $\gamma$-semi open sets $A$, $B$ of $X$.

Proof:

(i) $\Rightarrow$ (ii) Let $A$ be a fuzzy $\gamma$-semi open set of $X$. Then $A^\gamma_\tau$ is a fuzzy $\gamma$-semi open set. According to the assumption, $\gamma$-scl$(A^\gamma_\tau)$ is fuzzy $\gamma$-semi open set. So $\gamma$-rint $(A)$ is a fuzzy $\gamma$-semi closed set of $X$.

(ii) $\Rightarrow$ (iii) Suppose that $A$ is a fuzzy $\gamma$-semi open set of $X$. Then $\gamma$-scl$(\gamma$-scl$(A))^\gamma_\tau = \gamma$-scl $(\gamma$-rint $(A))^\gamma_\tau$. According to the assumption, $\gamma$-rint $(A^\gamma_\tau)$ is a fuzzy $\gamma$-semi closed set. So $\gamma$-scl $(\gamma$-sint $(A)^\gamma_\tau) = \gamma$-sint $(A) = (\gamma$-scl $(A))^\gamma_\tau$.

(iii) $\Rightarrow$ (iv) Let $A$ and $B$ be a fuzzy $\gamma$-semi open set of $X$ such that $B = (\gamma$-scl $(A))^\gamma_\tau$. From the assumption we have, $\gamma$-scl $B = \gamma$-scl $(\gamma$-scl $(A))^\gamma_\tau = (\gamma$-scl $(A))^\gamma_\tau$. (iv) $\Rightarrow$ (i) Let $A$ be a fuzzy $\gamma$-semi open set of $X$. We put $B = (\gamma$-scl $(A))^\gamma_\tau$. From the assumption, we obtain that $\gamma$-scl $(B) = (\gamma$-scl $(A))^\gamma_\tau$.

Definition 6.11: A fuzzy set $A$ of fuzzy topological space $(X, \tau)$ is said to fuzzy $\gamma$-t-set if $\gamma$-rint $(A) = \gamma$-rint $(\gamma$-cl$(A))$.

Theorem 6.12: Let $(X, \tau)$ be a fuzzy topological space. Then a fuzzy subset $A$ is fuzzy $\gamma$-t-set if and only if $A$ is fuzzy $\gamma$-semi closed.

Proof:

Let $A$ be a fuzzy $\gamma$-t-set. Then by using Definition 6.10, $\gamma$-rint $(A) = \gamma$-rint $(\gamma$-cl$(A))$. Therefore $\gamma$-rint $(\gamma$-cl$(A)) = \gamma$-rint $(\gamma$-cl$(A))$. Hence $A$ is fuzzy $\gamma$-semi closed. Conversely, $A$ is fuzzy $\gamma$-semi closed. Then by using Definition 2.1, $\gamma$-rint $(\gamma$-cl$(A)) \subseteq \gamma$-rint $(A)$. Also $A \subseteq \gamma$-cl$(A)$. This implies that $\gamma$-rint $(A) \subseteq \gamma$-rint $(\gamma$-cl$(A))$. Hence $\gamma$-rint $(A) = \gamma$-rint $(\gamma$-cl$(A))$. Thus $A$ is fuzzy $\gamma$-t-set.

Theorem 6.13: Let $(X, \tau)$ be an fuzzy topological space. If $A$ is fuzzy $\gamma$-closed, then it is fuzzy $\gamma$-t-set.

Proof:

Let $A$ be fuzzy $\gamma$-closed. Then by Proposition 2.10, $A = \gamma$-cl$(A)$ and $\gamma$-rint $(A) = \gamma$-rint $(\gamma$-cl$(A))$. Therefore $A$ is fuzzy $\gamma$-t-set.

Theorem 6.14: Let $(X, \tau)$ be an fuzzy topological space. Then the intersection of any two fuzzy $\gamma$-t-set is fuzzy $\gamma$-t-set.

Proof:

Let $A$ and $B$ be fuzzy $\gamma$-t-set. Then by Definition 6.10, $\gamma$-rint $(A) = \gamma$-rint $(\gamma$-cl$(A))$ and $\gamma$-rint $(B) = \gamma$-rint $(\gamma$-cl$(B))$. Therefore $\gamma$-rint $(A) \land \gamma$-rint $(B) = \gamma$-rint $(\gamma$-cl$(A) \land \gamma$-cl$(B))$. By Remark 2.6, $\gamma$-rint $(A \land B) = \gamma$-rint $(\gamma$-cl$(A \land B))$.

The following example shows that union of two fuzzy $\gamma$-t-set need not be fuzzy $\gamma$-t-set.

Example 6.15: Let $X = \{a, b\}$ and $\tau = \{\emptyset, \{a\}, \{b\}, \{a, b\}\}$. Then $(X, \tau)$ is a fuzzy topological space. The family of all fuzzy closed sets of $\tau$ is $\tau^\gamma_\tau = \{\emptyset, \{a\}, \{b\}, \{a, b\}\}$. Consider $A = \{a, b\}$ and $B = \{a, b\}$. Then $\gamma$-rint $(A) = \{a, b\}$ and $\gamma$-rint $(B) = \{a, b\}$. It follows that $\gamma$-rint $(A) = \gamma$-rint $(B)$ and $\gamma$-scl $(A \lor B) = \gamma$-scl $(A \land B)$.

Therefore by Definition 6.10, $A$ and $B$ are fuzzy $\gamma$-t-set. Now $\gamma$-scl $(A \lor B) = \gamma$-scl $(A \land B)$, but $\gamma$-rint $(A \lor B) = \gamma$-rint $(A \land B)$. It shows that $A \lor B$ is not an fuzzy $\gamma$-t-set.

References