

$\approx g_\alpha$ -CLOSED SETS IN TOPOLOGICAL SPACES

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ABSTRACT

In this paper, we introduce a new class of sets called $\approx g_\alpha$ -closed sets in topological spaces. We prove that this class lies between α -closed sets and α g-closed sets and discuss some basic properties of $\approx g_\alpha$ -closed sets.

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1. INTRODUCTION

The concept of generalized closed sets plays a significant role in topology. There are many research papers which deals with different types of generalized closed sets. Bhattacharya and Lahiri [4] introduced sg-closed sets in topological spaces. Arya and Nour [3] introduced gs-closed sets in topological spaces. Sheik John [17] introduced ω -closed sets in topological spaces. Ravi and Ganesan [15] introduced \ddot{g} -closed sets in topological spaces. Quite Recently, Ravi et. al. [16] have introduced $\approx g$ -closed sets in topological spaces. In this paper we introduce a new class of sets namely $\approx g_\alpha$ -closed sets in topological spaces and study their basic properties.

2. PRELIMINARIES

Throughout this paper (X, τ) (or X) represents topological space on which no separation axioms are assumed unless otherwise mentioned. For a subset A of a space (X, τ) , $\text{cl}(A)$, $\text{int}(A)$ and A^c or $X - A$ denote the closure of A , the interior of A and the complement of A respectively.

We recall the following definitions which are useful in the sequel.

Definition: 2.1 A subset A of a space (X, τ) is called

- (i) Semi-open set [9] if $A \subseteq \text{cl}(\text{int}(A))$;
- (ii) preopen set [12] if $A \subseteq \text{int}(\text{cl}(A))$;
- (iii) α -open set [13] if $A \subseteq \text{int}(\text{cl}(\text{int}(A)))$;
- (iv) semi-preopen set [1] if $A \subseteq \text{cl}(\text{int}(\text{cl}(A)))$.

The complements of the above mentioned open sets are called their respective closed sets.

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The preclosure [14] (resp. semi-closure [6], α -closure [13], semi-pre-closure [1]) of a subset A of X, denoted by $\text{pcl}(A)$ (resp. $\text{scl}(A)$, $\alpha \text{cl}(A)$, $\text{spcl}(A)$), is defined to be the intersection of all preclosed (resp. semi-closed, α -closed, semi-preclosed) sets of (X, τ) containing A. It is known that $\text{pcl}(A)$ (resp. $\text{scl}(A)$, $\alpha \text{cl}(A)$, $\text{spcl}(A)$) is a preclosed (resp. semi-closed, α -closed, semi-preclosed) set.

Definition: 2.2 A subset A of a space (X, τ) is called

(i) a generalized closed (briefly g-closed) set [8] if $\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is open in (X, τ) . The complement of g-closed set is called g-open set;

(ii) a semi-generalized closed (briefly sg-closed) set [4] if $\text{scl}(A) \subseteq U$ whenever $A \subseteq U$ and U is semi-open in (X, τ) . The complement of sg-closed set is called sg-open set;

(iii) a generalized semi-closed (briefly gs-closed) set [3] if $\text{scl}(A) \subseteq U$ whenever $A \subseteq U$ and U is open in (X, τ) . The complement of gs-closed set is called gs-open set;

(iv) an α -generalized closed (briefly α g-closed) set [11] if $\alpha \text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is open in (X, τ) . The complement of α g-closed set is called α g-open set;

(v) a generalized semi-preclosed (briefly gsp-closed) set [7] if $\text{spcl}(A) \subseteq U$ whenever $A \subseteq U$ and U is open in (X, τ) . The complement of gsp-closed set is called gsp-open set;

(vi) a generalized preclosed (briefly gp-closed) set [14] if $\text{pcl}(A) \subseteq U$ whenever $A \subseteq U$ and U is open in (X, τ) . The complement of gp-closed set is called gp-open set;

(vii) a \ddot{g} -closed set [15] if $\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is sg-open in (X, τ) . The complement of \ddot{g} -closed set is called \ddot{g} -open set;

(viii) a A-closed set [16] if $\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is \ddot{g} -open in (X, τ) . The complement of A-closed set is called A-open set;

(ix) a B-closed set [16] if $\text{scl}(A) \subseteq U$ whenever $A \subseteq U$ and U is A-open in (X, τ) . The complement of B-closed set is called B-open set;

(x) a $\approx \mathbf{g}$ -closed set [16] if $\text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is B-open in (X, τ) . The complement of $\approx \mathbf{g}$ -closed set is called $\approx \mathbf{g}$ -open set.

The collection of all $\approx \mathbf{g}$ -closed (resp. g-closed, gs-closed, gsp-closed, α g-closed, sg-closed, gp-closed, α -closed, semi-closed) sets in (X, τ) is denoted by $\approx \mathbf{G}C(X)$ (resp. $\mathbf{G}C(X)$, $\mathbf{GS}C(X)$, $\mathbf{GSP}C(X)$, $\alpha \mathbf{G}C(X)$, $\mathbf{SG}C(X)$, $\mathbf{GP}C(X)$, $\alpha C(X)$, $\mathbf{S}C(X)$).

We denote the power set of X by P(X).

Remark: 2.3 [16] For a topological space (X, τ) , the following hold.

- (1) Every semi-open set is B-open but not conversely.
- (2) Every open set is B-open but not conversely.
- (3) Every open set is A-open but not conversely.
- (4) Every closed set is $\approx \mathbf{g}$ -closed but not conversely.

3. $\approx \mathbf{g}_\alpha$ - CLOSED SETS

We introduce the following definition.

Definition: 3.1 A subset A of a space (X, τ) is called an $\approx \mathbf{g}_\alpha$ -closed set if $\alpha \text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is B-open in (X, τ) .

The complement of $\approx \mathbf{g}_\alpha$ -closed set is called $\approx \mathbf{g}_\alpha$ -open set.

The collection of all $\approx \mathbf{g}_\alpha$ -closed (resp. $\approx \mathbf{g}_\alpha$ -open) sets in (X, τ) is denoted by $\approx \mathbf{G}_\alpha C(X)$ (resp. $\approx \mathbf{G}_\alpha O(X)$).

Proposition: 3.2 Every α -closed set is $\approx g_\alpha$ -closed.

Proof: Let A be an α -closed set and G be any B-open set containing A. Since A is α -closed, we have $\alpha \text{ cl}(A) = A \subseteq G$. Hence A is $\approx g_\alpha$ -closed.

The converse of Proposition 3.2 need not be true as seen from the following example.

Example: 3.3 Let $X = \{a, b, c\}$ with $\tau = \{\emptyset, \{a, b\}, X\}$. Then $\approx G_\alpha C(X) = \{\emptyset, \{c\}, \{a, c\}, \{b, c\}, X\}$ and $\alpha C(X) = \{\emptyset, \{c\}, X\}$. We have $A = \{a, c\}$ is $\approx g_\alpha$ -closed set but not α -closed.

Proposition: 3.4 Every $\approx g$ -closed set is $\approx g_\alpha$ -closed.

Proof: Let A be a $\approx g$ -closed set and G be any B-open set containing A. Since A is $\approx g$ -closed, we have $G \supseteq \text{cl}(A) \supseteq \alpha \text{ cl}(A)$. Hence A is $\approx g_\alpha$ -closed.

The converse of Proposition 3.4 need not be true as seen from the following example.

Example: 3.5 Let $X = \{a, b, c\}$ with $\tau = \{\emptyset, \{b\}, X\}$. Then $\approx GC(X) = \{\emptyset, \{a, c\}, X\}$ and $\approx G_\alpha C(X) = \{\emptyset, \{a\}, \{c\}, \{a, c\}, X\}$. We have $A = \{a\}$ is $\approx g_\alpha$ -closed set but not $\approx g$ -closed.

Proposition: 3.6 Every $\approx g_\alpha$ -closed set is αg -closed.

Proof: Let A be an $\approx g_\alpha$ -closed set and G be any open set containing A. Since any open set is B-open, we have $\alpha \text{ cl}(A) \subseteq G$. Hence A is αg -closed.

The converse of Proposition 3.6 need not be true as seen from the following example.

Example: 3.7 Let $X = \{a, b, c\}$ with $\tau = \{\emptyset, \{c\}, X\}$. Then $\approx G_\alpha C(X) = \{\emptyset, \{a\}, \{b\}, \{a, b\}, X\}$ and $\alpha G C(X) = \{\emptyset, \{a\}, \{b\}, \{a, b\}, \{a, c\}, \{b, c\}, X\}$. We have $A = \{a, c\}$ is αg -closed set but not $\approx g_\alpha$ -closed.

Proposition: 3.8 Every $\approx g_\alpha$ -closed set is g s-closed (sg-closed).

Proof: Let A be an $\approx g_\alpha$ -closed set and G be any open set (semi-open set) containing A. Since any open (semi-open) set is B-open, we have $\text{scl}(A) \subseteq \alpha \text{ cl}(A) \subseteq G$. Hence A is g s-closed (sg-closed).

The converse of Proposition 3.8 need not be true as seen from the following example.

Example: 3.9 Let $X = \{a, b, c\}$ with $\tau = \{\emptyset, \{a\}, \{b\}, \{a, b\}, X\}$. Then $\approx G_\alpha C(X) = \{\emptyset, \{c\}, \{a, c\}, \{b, c\}, X\}$ and $SG C(X) = GS C(X) = \{\emptyset, \{a\}, \{b\}, \{c\}, \{a, c\}, \{b, c\}, X\}$. We have $A = \{a\}$ is both g s-closed set and g -closed set but not $\approx g_\alpha$ -closed.

Proposition: 3.10 Every $\approx g_\alpha$ -closed set is g sp-closed.

Proof: Let A be an $\approx g_\alpha$ -closed set and G be any open set containing A. Since any open set is B-open, we have $\text{spl}(A) \subseteq \alpha \text{ cl}(A) \subseteq G$. Hence A is g sp-closed.

The converse of Proposition 3.10 need not be true as seen from the following example.

Example: 3.11 Let X and τ be as in Example 3.5. Then $GSP C(X) = \{\emptyset, \{a\}, \{c\}, \{a, b\}, \{a, c\}, \{b, c\}, X\}$. We have $A = \{a, b\}$ is g sp-closed set but not $\approx g_\alpha$ -closed.

Proposition: 3.12 Every $\approx g_\alpha$ -closed set is g p-closed.

Proof: Let A be an $\approx g_\alpha$ -closed set and G be any open set containing A. Since any open set is B-open, we have $\text{pcl}(A) \subseteq \alpha \text{cl}(A) \subseteq G$. Hence A is gp-closed.

The converse of Proposition 3.12 need not be true as seen from the following example.

Example: 3.13 Let $X = \{a, b, c\}$ with $\tau = \{\emptyset, \{a\}, X\}$. Then $\approx G_\alpha C(X) = \{\emptyset, \{b\}, \{c\}, \{b, c\}, X\}$ and $GPC(X) = \{\emptyset, \{b\}, \{c\}, \{a, b\}, \{a, c\}, \{b, c\}, X\}$. We have $A = \{a, b\}$ is gp-closed set but not $\approx g_\alpha$ -closed.

Proposition: 3.14 Every $\approx g$ -closed set is g-closed.

Proof: Let A be a $\approx g$ -closed set and G be any open set containing A. Since any open set is B-open, we have $G \supseteq \text{cl}(A)$. Hence A is g-closed.

The converse of Proposition 3.14 need not be true as seen from the following example.

Example: 3.15 Let X and τ be as in Example 3.13. Then $GC(X) = \{\emptyset, \{b\}, \{c\}, \{a, b\}, \{a, c\}, \{b, c\}, X\}$ and $\approx GC(X) = \{\emptyset, \{b, c\}, X\}$. We have $A = \{a, b\}$ is g-closed set but not $\approx g$ -closed.

Remark: 3.16 The following examples show that $\approx g_\alpha$ -closedness is independent of semi-closedness and g-closedness.

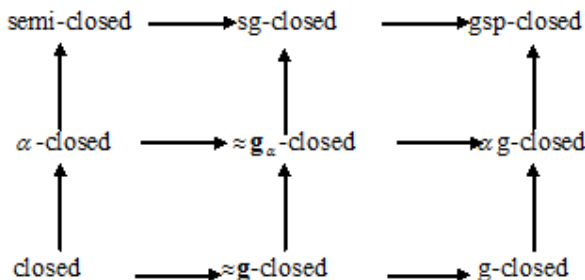
Example: 3.17 Let X and τ be as in Example 3.9. Then $SC(X) = \{\emptyset, \{a\}, \{b\}, \{c\}, \{a, c\}, \{b, c\}, X\}$. We have $A = \{b\}$ is semi-closed set but not $\approx g_\alpha$ -closed.

Example: 3.18 Let X and τ be as in Example 3.3. Then $SC(X) = \{\emptyset, \{c\}, X\}$. We have $A = \{b, c\}$ is $\approx g_\alpha$ -closed set but not semi-closed.

Example: 3.19 Let $X = \{a, b, c\}$ with $\tau = \{\emptyset, \{a\}, \{a, b\}, X\}$. Then $\approx G_\alpha C(X) = \{\emptyset, \{b\}, \{c\}, \{b, c\}, X\}$ and $GC(X) = \{\emptyset, \{c\}, \{a, c\}, \{b, c\}, X\}$. We have

- (i) $A = \{b\}$ is $\approx g_\alpha$ -closed set but not g-closed.
- (ii) $B = \{a, c\}$ is g-closed set but not $\approx g_\alpha$ -closed.

Remark: 3.20 From the above discussions and the known results in [7, 14, 16, 18], we obtain the following diagram, where $A \rightarrow B$ represents A implies B but not conversely.



None of the above implications is reversible as shown in the above examples and in the related papers [7, 14, 16, 18].

4. PROPERTIES OF $\approx g_\alpha$ -CLOSED SETS

In this section, we discuss some basic properties of $\approx g_\alpha$ -closed sets.

Definition: 4.1 [16] The intersection of all B-open subsets in (X, τ) containing A is called the B-kernel of A and denoted by $B\text{-ker}(A)$.

Lemma: 4.2 A subset A of (X, τ) is $\approx g_\alpha$ -closed if and only if $\alpha \text{cl}(A) \subseteq B\text{-ker}(A)$.

Proof: Suppose that A is $\approx g_\alpha$ -closed. Then $\alpha \text{ cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is B-open. Let $x \in \alpha \text{ cl}(A)$. If $x \notin B\text{-ker}(A)$, then there is a B-open set U containing A such that $x \notin U$. Since U is a B-open set containing A, we have $x \notin \alpha \text{ cl}(A)$ and this is a contradiction.

Conversely, let $\alpha \text{ cl}(A) \subseteq B\text{-ker}(A)$. If U is any B-open set containing A, then $\alpha \text{ cl}(A) \subseteq B\text{-ker}(A) \subseteq U$. Therefore, A is $\approx g_\alpha$ -closed.

Proposition: 4.3 If A and B are $\approx g_\alpha$ -closed sets in (X, τ) , then $A \cup B$ is $\approx g_\alpha$ -closed in (X, τ) .

Proof If $A \cup B \subseteq G$ and G is B-open, then $A \subseteq G$ and $B \subseteq G$. Since A and B are $\approx g_\alpha$ -closed, $G \supseteq \alpha \text{ cl}(A)$ and $G \supseteq \alpha \text{ cl}(B)$ and hence $G \supseteq \alpha \text{ cl}(A) \cup \alpha \text{ cl}(B) = \alpha \text{ cl}(A \cup B)$. Thus $A \cup B$ is $\approx g_\alpha$ -closed in (X, τ) .

Proposition: 4.4 If a set A is $\approx g_\alpha$ -closed in (X, τ) and $A \subseteq B \subseteq \alpha \text{ cl}(A)$, then B is $\approx g_\alpha$ -closed in (X, τ) .

Proof: Let G be a B-open set in (X, τ) such that $B \subseteq G$. Then $A \subseteq G$. Since A is an $\approx g_\alpha$ -closed set, $\alpha \text{ cl}(A) \subseteq G$. Also $\alpha \text{ cl}(B) = \alpha \text{ cl}(A) \subseteq G$. Hence B is also an $\approx g_\alpha$ -closed in (X, τ) .

Proposition: 4.5 If A is B-open and $\approx g_\alpha$ -closed in (X, τ) , then A is α -closed in (X, τ) .

Proof: Since A is B-open and $\approx g_\alpha$ -closed, $\alpha \text{ cl}(A) \subseteq A$ and hence A is α -closed in (X, τ) .

Proposition: 4.6 For each $x \in X$, either $\{x\}$ is B-closed or $\{x\}^c$ is $\approx g_\alpha$ -closed in (X, τ) .

Proof Suppose that $\{x\}$ is not B-closed in (X, τ) . Then $\{x\}^c$ is not B-open and the only B-open set containing $\{x\}^c$ is the space X itself. Therefore $\alpha \text{ cl}(\{x\}^c) \subseteq X$ and so $\{x\}^c$ is $\approx g_\alpha$ -closed in (X, τ) .

Definition: 4.7 A subset A of a space (X, τ) is called Λ_B -set if $A = B\text{-ker}(A)$.

Definition: 4.8 A subset A of a space (X, τ) is called λ_B -closed if $A = L \cap F$ where L is a Λ_B -set and F is α -closed.

The complement of λ_B -closed set is called λ_B -open set.

The collection of all λ_B -closed (resp. λ_B -open) sets in (X, τ) is denoted by $\lambda_B C(X)$ (resp. $\lambda_B O(X)$).

Lemma: 4.9 For a subset A of a topological space (X, τ) , the following conditions are equivalent.

- (i) A is λ_B -closed.
- (ii) $A = L \cap \alpha \text{ cl}(A)$ where L is a Λ_B -set.
- (iii) $A = B\text{-ker}(A) \cap \alpha \text{ cl}(A)$.

Lemma: 4.10

- (i) Every α -closed set is λ_B -closed but not conversely.
- (ii) Every Λ_B -set is λ_B -closed but not conversely.

The separate converses of Lemma 4.10 need not be true as seen from the following examples.

Example: 4.11 Let X and τ be as in Example 3.13. Then $\alpha C(X) = \{\phi, \{b\}, \{c\}, \{b, c\}, X\}$ and $\lambda_B C(X) = P(X)$. We have $A = \{a\}$ is λ_B -closed set but not α -closed.

Example: 4.12 Let X and τ be as in Example 3.13. Then Λ_B -sets are $\phi, \{a\}, \{a, b\}, \{a, c\}$ and X; and $\lambda_B C(X) = P(X)$. We have $A = \{b\}$ is λ_B -closed set but not Λ_B -set.

Theorem: 4.13 For a subset A of a topological space (X, τ) , the following conditions are equivalent.

- (i) A is α -closed.
- (ii) A is $\approx g_\alpha$ -closed and λ_B -closed.

Proof: (i) \Rightarrow (ii). Obvious.

(ii) \Rightarrow (i). Since A is $\approx g_\alpha$ -closed, so by Lemma 4.2, $\alpha cl(A) \subseteq B\text{-ker}(A)$. Since A is λ_B -closed, so by Lemma 4.9, $A = B\text{-ker}(A) \cap \alpha cl(A) = \alpha cl(A)$. Hence A is α -closed.

Remark: 4.14 The following examples show that the concepts of $\approx g_\alpha$ -closed sets and λ_B -closed sets are independent of each other.

Example: 4.15 Let X and τ be as in Example 3.13. Then $\approx G_\alpha C(X) = \{\phi, \{b\}, \{c\}, \{b, c\}, X\}$ and $\lambda_B C(X) = P(X)$. We have $A = \{a\}$ is λ_B -closed set but not $\approx g_\alpha$ -closed.

Example: 4.16 Let X and τ be as in Example 3.3. Then $\approx G_\alpha C(X) = \{\phi, \{c\}, \{a, c\}, \{b, c\}, X\}$ and $\lambda_B C(X) = \{\phi, \{a\}, \{b\}, \{c\}, \{a, b\}, X\}$. We have $A = \{a\}$ is λ_B -closed set but not $\approx g_\alpha$ -closed.

5. PROPERTIES OF $\approx g_\alpha$ lc* -SETS

Definition: 5.1 Let (X, τ) be a topological space. A subset A of X is called $\approx g_\alpha$ lc* -set if $A = M \cap N$ where M is B-open and N is α -closed in (X, τ) .

Example: 5.2 Let X and τ be as in Example 3.3. Then $A = \{a\}$ is an $\approx g_\alpha$ lc* -set.

Proposition: 5.3 Every B-open set is $\approx g_\alpha$ lc* -set but not conversely.

Example: 5.4 Let X and τ be as in Example 3.3. Then $\approx g_\alpha$ lc* -sets are $\phi, \{a\}, \{b\}, \{c\}, \{a, b\}$ and X; and B-open sets are $\phi, \{a\}, \{b\}, \{a, b\}$ and X. We have $A = \{c\}$ is $\approx g_\alpha$ lc* -set but not B-open.

Proposition: 5.5 Every α -closed set is $\approx g_\alpha$ lc* -set but not conversely.

Example: 5.6 Let X and τ be as in Example 3.3. Then $\approx g_\alpha$ lc* -sets are $\phi, \{a\}, \{b\}, \{c\}, \{a, b\}$ and X; and $\alpha C(X) = \{\phi, \{c\}, X\}$. We have $A = \{a\}$ is $\approx g_\alpha$ lc* -set but not α -closed.

Theorem: 5.7 Let (X, τ) be a topological space and A a subset of X. Then, A is α -closed if and only if it is $\approx g_\alpha$ -closed and $\approx g_\alpha$ lc* -set.

Proof: Let A be an α -closed. By Propositions 3.2 and 5.5, A is $\approx g_\alpha$ -closed and $\approx g_\alpha$ lc* -set.

Conversely, let $A = M \cap N$. Then M is B-open and N is α -closed. Since A is $\approx g_\alpha$ -closed, $\alpha cl(A) \subseteq M$. Also $\alpha cl(A) \subseteq \alpha cl(N) = N$. We have $\alpha cl(A) \subseteq M \cap N = A$. Hence A is α -closed.

Remark: 5.8 The following example shows that the concepts of $\approx g_\alpha$ -closed sets and $\approx g_\alpha$ lc* -sets are independent of each other.

Example: 5.9 Let X and τ be as in Example 3.3. Then $\approx g_\alpha$ lc* -sets are $\phi, \{a\}, \{b\}, \{c\}, \{a, b\}$ and X; and $\approx G_\alpha C(X) = \{\phi, \{c\}, \{a, c\}, \{b, c\}, X\}$. We have

- (i) $A = \{a\}$ is $\approx g_\alpha$ lc* -set but not $\approx g_\alpha$ -closed.
- (ii) $A = \{a, c\}$ is $\approx g_\alpha$ -closed set but not $\approx g_\alpha$ lc* -set.

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