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(gsp)** - CLOSED SETS IN TOPOLOGICAL SPACES

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ABSTRACT

*In this paper we introduce a new class of sets called (gsp)**-closed sets in topological spaceswhich is properly placed in between the class of closed sets and gsp-closed sets. As an application, we introduce two new spaces namely, T_{gsp}^{**} space, ${}_{\alpha}T_{gsp}^{**}$ space. Further, (gsp)**-continuous, (gsp)**-irresolute mappings are also introduced and investigated.*

Key words: *(gsp)**closed set, (gsp)**-continuous map, (gsp)**-irresolute map,T_{gsp}^{**}, ${}_{\alpha}T_{gsp}^{**}$ -spaces.*

1. INTRODUCTION

Levine [11] introduced the class of g-closed sets in 1970. Arya and Tour [3] defined gs-closed sets in 1990. Dontchev [9], Gnanambal [10] Palaniappan and Rao [17] introduced gsp-closed sets, gpr-closed sets and rg-closed sets respectively. Veerakumar [18] introduced g*-closed sets in 1991. Dontchev [8] introduced gsp-closed sets in 1995. Levine [11] Devi [6,8] introduced $T_{1/2}$-spaces, T_b spaces and ${}_{\alpha}T_b$ spaces respectively. PaulineMHelen[20] introduced (gsp)* sets. The purpose of this paper is to introduce the concepts of (gsp)**-closed set, (gsp)**-continuous map, (gsp)**-irresolute maps. T_{gsp}^{**}-space, ${}_{\alpha}T_{gsp}^{**}$-space are introduced and investigated.

2. PRILIMINARIES

Throughout this paper (X,τ), (Y,σ) represent non-empty topological spaces of which no separation axioms are assumed unless otherwise stated. For a subset A of a space (X,τ), cl(A) and int(A) denote the closure and the interior of A respectively. The class of all closed subsets of a space (X,τ) is denoted by C(X,τ).The smallest semi-closed (resp.pre-closed and α-closed) set containing a subset A of (X, τ) is called the semi-closure (resp.pre-closure and α-closure) of A and is denoted by scl(A)(resp.pcl(A) and αcl(A)).

Definition 2.1: A subset A of a topological space (X, τ) is called
(1) a pre-open set [14] if A ⊆ int(cl(A) and a pre-closed set if cl(int(A))⊆ A.
(2) a semi-open set [12] if A ⊆ cl(int(A)) and a semi-closed set if int(cl(A)) ⊆ A.
(3) a semi-preopen set [1] if A ⊆ cl(int(cl(A)) and a semi-preclosed set [1] if int(cl(int(A))) ⊆ A.
(4) an α-open set [16] if A ⊆ int(cl(int(A))) and an α-closed set [16] if cl(int(cl(A)) ⊆ A.
(5) a regular-open set [14] if int(cl(A) = A and regular-closed set [14] if A = int(cl(A).

Definition 2.2: A subset A of topological space (X,τ) is called
(1) a generalized closed set (briefly g-closed) [1] if cl(A) ⊆ U whenever A ⊆ U and U is open in (X,τ).
(2) generalized semi-closed set (briefly gs-closed) [3] if scl(A) ⊆ U whenever A ⊆ U and U is open in (X,τ).
(3) an α-generalized closed set (briefly αg-closed) [19] if αcl (A) ⊆ U whenever A ⊆ U and U is open in (X,τ).
(4) a generalized semi pre-closed set (briefly gsp-closed) [9] if sp cl(A) ⊆ U whenever A ⊆ U and U is open in (X,τ).
(5) a regular generalized closed set (briefly rg-closed) [17] if cl(A) ⊆ U whenever A ⊆ U and U is regular open in (X,τ).

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(6) a generalized pre-closed set (briefly gp-closed) [13] if p cl (A) ⊆ U whenever A ⊆ U and U is open in (X,τ).
(7) a generalized pre regular-closed set (briefly gpr-closed)[10] if p cl(A) ⊆ U whenever A ⊆ U and U is regular open in (X,τ).
(8) a g*-closed set [18]if cl(A) ⊆ U whenever A ⊆ U and U is g-open in (X,τ).
(9) a wg-closed set [16]if cl(int(A) whenever A ⊆ U and U is open in (X,τ).
(10) a (gsp)*-closed set [20]if cl(A) ⊆ U whenever A ⊆ U and U is gsp-open in (X,τ).

Definition 2.3: A function f: (X,τ) →(Y, σ) is called
(1) g-continuous [4] iff^{-1}(V) is a g-closed set of (X,τ) for every closed set V of (Y, σ).
(2) αg-continuous [10] iff^{-1}(V) is an αg-closed set of (X,τ) for every closed set V of (Y, σ).
(3) gs-continuous [7] iff^{-1}(V) is a gs-closed set of (X,τ) for every closed set V of (Y, σ).
(4) gsp-continuous [9] if f^{-1}(V) is a gsp-closed set of (X,τ) for every closed set V of (Y, σ).
(5) rg-continuous [17] if f^{-1}(V) is a rg-closed set of (X,τ) for every closed set V of (Y, σ).
(6) gp-continuous [2] if f^{-1}(V) is a gp-closed set of (X,τ) for every closed set V of (Y, σ).
(7) gpr-continuous [10] if f^{-1}(V) is a gpr-closed set of (X,τ) for every closed set V of (Y, σ).
(8) g*-continuous [18] if f^{-1}(V) is a g-closed set of (X,τ) for every closed set V of (Y, σ).
(9) wg-continuous [16] if f^{-1}(V) is a wg-closed set of (X,τ) for every closed set V of (Y, σ).
(10) (gsp)*-continuous[20] if f^{-1}(V) is an (gsp)*-closed set of (X,τ) for every closed set V of (Y, σ).

Definition 2.4: A topological space (X,τ) is said to be
(1) a $T_{1/2}$-space [11] if every g-closed set in it is closed.
(2) a T_b space [6] if every gs-closed set in it is closed.
(3) a ${}_{\alpha}T_b$ -space [8] if every αg-closed set in it is closed.
(4) a $T^*_{1/2}$-space [18] if every g*-closed set in it is closed.
(5) a T^*_{gsp} -space [20] if every (gsp)*-closed set is closed.
(6) a gT^*_{gsp} -space [20] if every g-closed set is (gsp)* closed.

3. Basic properties of (gsp)- closed sets**

We introduce the following definition

Definition 3.1: A subset A of (X,τ) is said to be a (gsp)**-closed set if cl(A) ⊆ U whenever A ⊆ U and U is (gsp)*-open in X.

Proposition 3.2: Every closed set is (gsp)**-closed.

Proof: Let A be closed set, Then cl(A) = A.

Let A ⊆ U and U be (gsp)*-open.

Then cl(A) ⊆ U whenever A ⊆ U and U is (gsp)*-open.

Therefore A is (gsp)**-closed.

Proposition 3.3: Every (gsp)**-closed set is gs-closed.

Proof: Let A be a (gsp)**-closed set. Let A ⊆ U and U be open. Then cl(A) ⊆ U since U is (gsp)*-open and A is (gsp)**-closed. scl(A) ⊆ cl(A) ⊆ U . Hence A is gs-closed.

The converse of the above proposition need not be true in general as seen in the following example.

Example 3.4: Let X = {a, b, c}, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$. Then A = $\{b\}$ is gs-closed but not (gsp)**-closed in (X,τ).

Proposition 3.5: Every (gsp)**-closed set is αg-closed, but not conversely.

Proof: Let A be a (gsp)**-closed set. cl(A) ⊆ U since U is (gsp)*-open and A is (gsp)**-closed. But αcl(A) ⊆ cl(A) ⊆ U . Hence A is αg-closed.

Example 3.6: Let X = {a, b, c}, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$. Then A = $\{b\}$ is αg-closed but not (gsp)**-closed in (X,τ).

Proposition 3.7: Every (gsp)**-closed set is gsp-closed, but not conversely.

Proof: Let A be a (gsp)**-closed set. Let A ⊆ U and U be open. Then cl(A) ⊆ U since U is (gsp)*-open and A is (gsp)**-closed. spcl(A) ⊆ cl(A) ⊆ U . Hence A is gsp-closed.

Example 3.8: Let X = {a, b, c}, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$. Then A = $\{b\}$ is gsp-closed but not (gsp)**-closed in (X,τ).

Proposition 3.9: Every (gsp)**-closed set is rg-closed.

Proof: Let A be a (gsp)**-closed set. Let A ⊆ U and U be regular open. Then A ⊆ U and U is (gsp)*-open and cl(A) ⊆ U, since A is (gsp)**-closed. Hence A is rg-closed.

The converse of the above proposition need not be true in general as seen in the following example.

Example 3.10: Let X = {a, b, c}, $\tau = \{\varphi, X, \{b\}, \{a, b\}\}$. Then A = $\{a\}$ is rg-closed but not (gsp)**-closed in (X,τ).

Proposition 3.11: Every (gsp)**-closed set is gp-closed, but not conversely.

Proof: Let A be a (gsp)**-closed set. Let A ⊆ U and U be open. Then cl(A) ⊆ U since U is (gsp)*-open and A is (gsp)**-closed. pcl(A) ⊆ cl(A) ⊆ U . Hence A is gp-closed.

The converse of the above proposition need not be true in general as seen in the following example.

Example 3.12: Let X = {a, b, c}, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$. Then A = $\{b\}$ is gp-closed but not (gsp)**-closed in (X,τ).

Proposition 3.13: Every (gsp)**-closed set is gpr-closed, but not conversely.

Proof: Let A be a (gsp)**-closed set. Let A ⊆ U and U be regular open. Then A ⊆ U and U is (gsp)*-open and cl(A) ⊆ U, since A is (gsp)**-closed. Then pcl(A) ⊆ cl(A) ⊆ U . Hence A is gpr-closed.

Example 3.14: Let X = {a, b, c}, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$. Then A = $\{a\}$ is gpr-closed but not (gsp)**-closed in (X,τ).

Proposition 3.15: Every (gsp)**-closed set is wg-closed, but not conversely.

Proof: Let A be a (gsp)**-closed set. Let A ⊆ U and U be open. Then U is (gsp)*-open and cl(A) ⊆ U, since A is (gsp)**-closed. cl(int(A)) ⊆ cl(A) ⊆ U . Hence A is wg-closed.

Example 3.16: Let X = {a, b, c}, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$. Then A = $\{b\}$ is wg-closed but not (gsp)**-closed in (X,τ).

Proposition 3.17: If A and B are (gsp)**-closed sets then A∪B is also (gsp)**-closed.

Proof: follows from the fact that cl(A∪B) = cl(A) ∪ cl(B).

Proposition 3.18: If A is (gsp)**-closed set of (X,τ) such that A ⊆ B ⊆ cl(A), then B is also a (gsp)**-closed set of (X,τ).

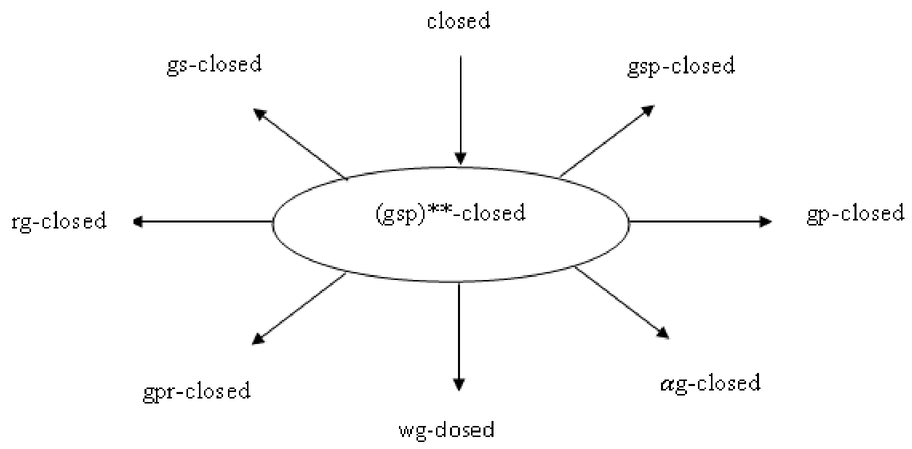
Proof: Let U be the (gsp)*-open set of (X,τ) such that B ⊆ U. Then A ⊆ U where U is (gsp)*-open. Since A is (gsp)**-closed, cl(A) ⊆ U. Then cl(B) ⊆ U, Hence B is (gsp)**-closed.

Proposition 3.19: If A is (gsp)**-closed set of (X,τ), then cl(A) \ A does not contain any non-empty (gsp)*-closed set.

Proof: Let F be (gsp)*-closed set of (X,τ) such that F ⊆ cl(A) \ A. Then A ⊆ X \ F. Since A is (gsp)**-closed cl(A) ⊆ X \ F.This implies F ⊆ X \ cl(A). Hence F ⊆ (X \ cl(A)) ∩ (cl(A) \ A)= ϕ. Hence cl(A) \ A does not contain any non-empty (gsp)*-closed set.

Proposition 3.20: If A is both (gsp)*-open and (gsp)**-closed then A is closed.

The above results can be represented in the following figure.



Where A→ B represents A implies B and B need not imply A.

4. (gsp)-continuous and (gsp)**-irresolute maps**

We introduce the following definitions:

Definition 4.1: A function f: (X,τ) → (Y,σ) is called (gsp)**-continuous if $f^{-1}(V)$ is a (gsp)**-closed set in (X,τ) for every closed set V of (Y,σ).

Definition 4.2: A function f: (X,τ) → (Y,σ) is called (gsp)**-irresolute if $f^{-1}(V)$ is a (gsp)**-closed set in (X,τ) for every (gsp)**-closed set V of (Y,σ).

Theorem 4.3: Every continuous map is (gsp)**-continuous.

Proof: Let f: (X,τ) → (Y,σ) be a continuous map. Let F be a closed set in (Y,σ) since f is continuous $f^{-1}(F)$ is closed in (X,τ) and hence $f^{-1}(F)$ is (gsp)**-closed. Therefore f is (gsp)**-continuous.

Theorem 4.4: Every (gsp)**-continuous map is (1) gs-continuous (2) αg-continuous (3) gsp-continuous (4) rg-continuous (5) gp-continuous (6) gpr-continuous and (7) wg-continuous but not conversely.

Proof: Let f: (X,τ) → (Y,σ) be (gsp)**-continuous and let F be a closed set of (Y,σ). Since f is (gsp)**-continuous $f^{-1}(F)$ is (gsp)**-closed in (X,τ), Then $f^{-1}(F)$ is gs- closed, αg- closed, gsp- closed, rg- closed, gp- closed, gpr-closed and wg- closed. Hence f is gs-continuous, αg-continuous, gsp-continuous, rg-continuous, gp-continuous, gpr-continuous and wg-continuous.

Example 4.5: Let X = {a, b, c}= Y, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$, σ = $\{\varphi, Y, \{a, c\}\}$ Let f: (X,τ) → (Y,σ) be the identity map. The closed sets of Y are $\varphi, Y, \{b\}. f^{-1}(b) = b$ is not (gsp)**-closed in (X,τ). Hence f is not (gsp)**-continuous. $f^{-1}(b) = b$ is gs- closed, αg- closed, gsp- closed, gp- closed and wg-closed. Hence f is gs-continuous, αg-continuous, gsp-continuous, gp-continuous and wg-continuous.

Example 4.6: Let X = {a, b, c}= Y, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$, σ = $\{\varphi, Y, \{b\}\}$ Let f: (X,τ) → (Y,σ) be defined as f(a) = c, f(b) = a, f(c) = b. $f^{-1}\{a, c\} = \{a, b\}$ is gpr- closed in (X,τ), but not (gsp)**-closed in (X,τ). Hence f is gpr-continuous but not (gsp)**-continuous.

Example 4.7: Let X = {a, b, c}= Y, $\tau = \{\varphi, X, \{b\}, \{a, b\}\}$, σ = $\{\varphi, Y, \{c\}\}$ Let f: (X,τ) → (Y,σ) be the identity map. The closed sets of Y are φ, Y and $\{a, b\}$. $f^{-1}\{a, b\} = \{a, b\}$ is rg- closed but not (gsp)**-closed and hence f is rg-continuous but not (gsp)**- continuous.

Theorem 4.8: Every (gsp)**-irresolute is (gsp)**- continuous.

Proof: Let f: (X,τ) → (Y,σ) be a (gsp)**- irresolute. Let V be a closed set of (Y,σ). Then V is (gsp)**-closed and $f^{-1}(V)$ is (gsp)**-closed since f is a (gsp)**-irresolute. Hence f is (gsp)**-continuous.

Theorem 4.9: Let f: (X,τ) → (Y,σ) be a (gsp)**-irresolute then f is
(1) gs-continuous
(2) αg-continuous
(3) gsp- continuous
(4) rg-continuous
(5) gp-continuous
(6) gpr-continuous and
(7) wg-continuous but not conversely.

Proof: Since every (gsp)**-irresolute is (gsp)**- continuous, f is (gsp)**- continuous. Then by theorem 4.4 the result follows.

Example 4.10: Let X = {a, b, c}= Y, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$, $\sigma = \{\varphi, Y, \{a, b\}\}$ Let f: (X,τ) → (Y,σ) be defined as f(a) = a, f(b) = c, f(c) = b. $f^{-1}\{c\} = \{b\}$ is gs- closed in (X,τ) and hence f is gs- continuous. (gsp)**-closed sets of (Y,σ) are $\varphi, Y, \{c\}, \{a, c\} and\ \{b, c\}$. $f^{-1}\{c\} = \{b\}$ is not (gsp)**-closed set in (X,τ). Hence f is not a (gsp)**-irresolute.

Example 4.11: Let X = {a, b, c}= Y, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$, $\sigma = \{\varphi, Y, \{a, b\}\}$ Let f: (X,τ) → (Y,σ) be defined as f(a) = a, f(b) = c, f(c) = b. $f^{-1}\{c\} = \{b\}$ is gp- closed in (X,τ) and hence f is gp- continuous. (gsp)**-closed sets of (Y,σ) are $\varphi, Y, \{c\}, \{a, c\} and\ \{b, c\}$. $f^{-1}\{c\} = \{b\}$ is not (gsp)**-closed set in (X,τ). Hence f is not a (gsp)**-irresolute.

Example 4.12: Let X = {a, b, c}= Y, $\tau = \{\varphi, X, \{b\}, \{a, b\}\}$, $\sigma = \{\varphi, Y, \{a, b\}\}$ Let f: (X,τ) → (Y,σ) be defined by f(a) = b, f(b) = c, f(c) = a. $f^{-1}\{c\} = \{b\}$ is rg- closed in (X,τ) and hence f is rg- continuous. (gsp)**-closed sets of (Y,σ) are $\varphi, Y, \{c\}, \{a, c\} and\ \{b, c\}$. $f^{-1}\{c\} = \{b\}$ is not (gsp)**-closed set in (X,τ). Hence f is not a (gsp)**-irresolute.

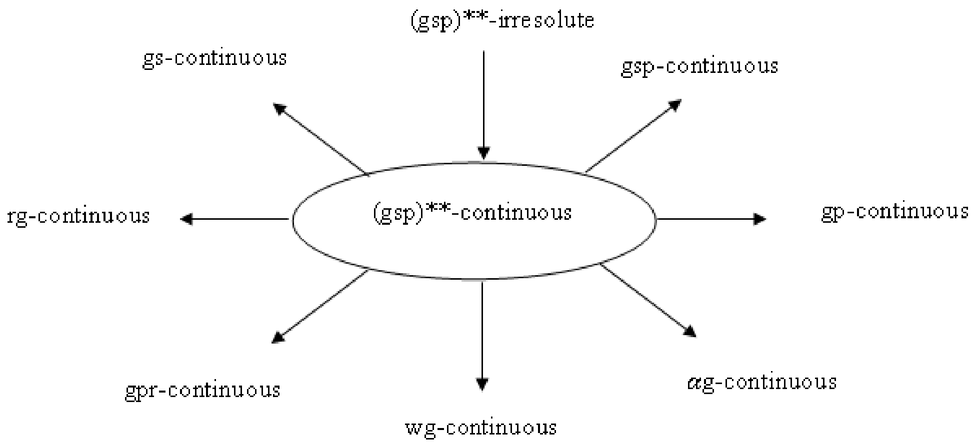
Example 4.13: Let X = {a, b, c}= Y, $\tau = \{\varphi, X, \{b, c\}\}$, $\sigma = \{\varphi, Y, \{a, b\}\}$ Let f: (X,τ) → (Y,σ) be the identity map. $f^{-1}\{c\} == \{c\}$ is gsp- closed in (X, τ) and hence f is gsp- continuous. (gsp)**-closed sets of (Y, σ) are $\varphi, Y, \{c\}, \{a, c\} and\ \{b, c\}$. $f^{-1}\{c\} = \{c\}$ is not (gsp)**-closed set in (X,τ). Hence f is not a (gsp)**-irresolute.

Example 4.14: Let X = {a, b, c}= Y, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$, $\sigma = \{\varphi, Y, \{a, b\}\}$ Let f: (X,τ) → (Y,σ) be defined as f(a) = a, f(b) = c, f(c) = b. $f^{-1}\{c\} = \{b\}$ is wg- closed in (X,τ) and hence f is wg- continuous. (gsp)**-closed sets of (Y,σ) are $\varphi, Y, \{c\}, \{a, c\} and\ \{b, c\}$. $f^{-1}\{c\} = \{b\}$ is not (gsp)**-closed set in (X,τ). Hence f is not a (gsp)**-irresolute.

Example 4.15: Let X = {a, b, c}= Y, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$, $\sigma = \{\varphi, Y, \{a, b\}\}$ Let f: (X,τ) → (Y,σ) be defined as f(a) = b, f(b) = c, f(c) = a. $f^{-1}\{c\} = \{b\}$ is αg-closed in (X,τ) and hence f is αg- continuous. (gsp)**-closed sets of (Y,σ) are $\varphi, Y, \{c\}, \{a, c\} and\ \{b, c\}$. $f^{-1}\{c\} = \{b\}$ is not (gsp)**-closed set in (X,τ). Hence f is not a (gsp)**-irresolute.

Example 4.16: Let X = {a, b, c}= Y, $\tau = \{\varphi, X, \{a\}, \{a, b\}\}$, $\sigma = \{\varphi, Y, \{a, b\}\}$ Let f: (X,τ) → (Y,σ) be defined as f(a) = b, f(b) = c, f(c) = a. $f^{-1}\{c\} = \{b\}$ is gpr- closed in (X,τ) and hence f is gpr- continuous. (gsp)**-closed sets of (Y,σ) are$\varphi, Y, \{c\}, \{a, c\} and\ \{b, c\}$. $f^{-1}\{c\} = \{b\}$ is not (gsp)**-closed set in (X,τ). Hence f is not a (gsp)**-irresolute.

The above results can be represented in the following figure.



Where A→ B represents A implies B and B need not imply A.

5. APPLICATIONS OF (gsp)**-CLOSED SETS

Definition 5.1: A space (X,τ) is called a T_{gsp}^{**}-space if every (gsp)**-closed set is closed.

Definition 5.2: A space (X,τ) is called a ${}_{\alpha}T_{gsp}^{**}$-space if every αg -closed set is (gsp)**-closed.

Theorem 5.3: Every T_b-space is T_{gsp}^{**}-space but not conversely.

Proof: Let (X,τ) be a T_b-space. Let A be a (gsp)**-closed set. Since every (gsp)**-closed set is gs-closed and hence A is gs-closed. Since (X,τ) is a T_b-space, A is closed. Hence (X,τ) is aT_{gsp}^{**}-space.

Example 5.4: Let X = {a, b, c} and $\tau = \{\varphi, X, \{a\}, \{b\}, \{a, b\}\}$. (X,$\tau$) is a T_{gsp}^{**}-space A = $\{a\}$ is gs-closed, but it is not closed, and hence it is not a T_b-space. Hence a T_{gsp}^{**}-space need not be a T_b-space.

Theorem 5.5: Every T_b -space is a ${}_{\alpha}T_{gsp}^{**}$- space.

Proof: Let (X,τ) be a T_b -space. Let A be αg –closed. Then A is gs-closed. Since the space is T_b –space, A is closed and hence A is (gsp)**-closed. Therefore the space (X,τ) is a ${}_{\alpha}T_{gsp}^{**}$- space.

Example 5.6: Let X = {a, b, c} and $\tau = \{\varphi, X, \{a\}, \{b\}, \{a, b\}\}$. Here (gsp)**-closed sets are $\{\varphi, X, \{c\}, \{b, c\}, \{a, c\}\}$, αg –closed sets are $\{\varphi, X, \{c\}, \{b, c\}, \{a, c\}\}$ and the gs-closed sets are $\{\varphi, X, \{a\}, \{b\}, \{c\}, \{b, c\}, \{a, c\}\}$. Since every αg -closed set is (gsp)**-closed the space (X,τ) is a ${}_{\alpha}T_{gsp}^{**}$-space. A = $\{a\}$ is gs-closed, but it is not closed, and hence it is not a T_b-space.

Theorem 5.7: Let f: (X,τ) → (Y,σ) be (gsp)**-continuous map and let (X,τ) be aT_{gsp}^{**}-space then f is continuous.

Proof: Let f: (X,τ) → (Y,σ) be (gsp)**-continuous map. Let F be a closed set of (Y,σ). Since f is (gsp)**-continuous, $f^{-1}(F)$ is (gsp)**-closed set in (X,τ). Since (X,τ) is a T_{gsp}^{**}-space, $f^{-1}(F)$ is closed in (X,τ). Therefore f is continuous.

Theorem 5.8: Let f: (X,τ) → (Y,σ) be αg -continuous map where (X,τ) is a ${}_{\alpha}T_{gsp}^{**}$- space. Then f is (gsp)**-continuous.

Proof: Let f: (X,τ) → (Y,σ) be a αg -continuous map. Let F be a closed set of (Y,σ). Since f is αg -continuous, $f^{-1}(F)$ is αg -closed set in (X,τ). Since (X,τ) is a ${}_{\alpha}T_{gsp}^{**}$-space, $f^{-1}(F)$ is (gsp)**-closed in (X,τ). Therefore f is (gsp)**-continuous.

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