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On πgθ-Closed sets in Topological spaces

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ABSTRACT

In this paper a new class of sets called πgθ -closed is introduced and its properties are studied. Further the notion of πgθ-$T_{½}$ space and πgθ -continuity are introduced.

***Mathematics Subject Classification**: 54A05.*

***Key words:** πgθ -closed set, πgθ -open set, πgθ -continuity and πgθ-$T_{½}$ space.*

1. INTRODUCTION

Velicko[23] introduced the notions of θ-open subsets, θ-closed subsets and θ-closure, for the sake of studying the important class of H-closed spaces in terms of arbitrary filterbases. Dontchev and Maki [2] alone have explored the concept of θ-generalized closed sets. The finite union of regular open set is π-open and subsequently the complement of π-open set is said to be π-closed, which has been highlighted by Zaitsev [23]. Dontchev and Noiri have explored the concept of quasi normal spaces and πg-closed sets. The studies of πgα-closed set [11], πgp-closed set [19], πgb-closed set[20], πgs-closed set[4] were introduced later.

The prime objective of this study is to explore the idea of πgθ -closed sets, its properties, characterization and its functions.

2. PRELIMINARIES

Throughout this paper (X, τ) and (Y, σ) represents non-empty topological spaces on which no separation axioms are assumed unless otherwise mentioned . For a subset A of a space (X, τ), cl(A) and int(A) denote the closure of A and the interior of A respectively. (X, τ) will be replaced by X if there is no chance of confusion.

Let us recall the following definitions which we shall require later.

Definition 2.1: A subset A of space (X, τ) is called
(1) a pre open set[16] if A $\subset$ int(cl(A)) and a pre closed set if cl(int(A)) $\subset$ A;
(2) a semi-open set[3] if A $\subset$ cl(int(A)) and semi-closed if int(cl(A)) $\subset$ A;
(3) a α-open set [17] if A $\subset$ int(cl(int(A))) and α-closed set if cl(int(cl(A))) $\subset$ A;
(4) a semi- pre open set[2] if A $\subset$ cl(int(cl(A)) and semi-pre closed set if int(cl(int(A))) $\subset$ A;
(5) a regular open set [21] if A= int (cl(A)) and a regular closed set if A = cl(int(A)).

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

(1) a generalized closed (briefly g-closed) set [13] if cl(A) $\subset$ U whenever A $\subset$ U and U is open.
(2) a semi-generalized closed (briefly sg-closed)set [5] if scl(A) $\subset$ U whenever A $\subset$ U and U is semi-open.
(3) a generalized semi-closed (briefly gs-closed)set [3] if scl(A) $\subset$ U whenever A $\subset$ U and U is open.
(4) a α-generalized closed (briefly αg-closed) set [15] if αcl(A) $\subset$ U whenever A $\subset$ U and U is open in (X,τ).
(5) a generalized α-closed (briefly gα-closed) set[14] if αcl(A) $\subset$ U whenever A $\subset$ U and U is α-open in (X,τ).
(6) a θ-generalized closed (briefly, θg-closed) set [7] if $cl_\theta(A)$ $\subset$ U whenever A $\subset$ U and U is open in (X,τ).
(7) πg -closed set [8]if cl(A) $\subset$ U, whenever A $\subset$ U and U is π-open.
(8) πgα-closed set [11] if αcl(A) $\subset$ U, whenever A $\subset$ U and U is π-open.
(9 πgs-closed set [4] if scl(A) $\subset$ U, whenever A $\subset$ U and U is π-open.
(10) πgb -closed set [20] if bcl(A) $\subset$ U, whenever A $\subset$ U and U is π-open.
(11) πgp -closed set [19] if pcl(A) $\subset$ U, whenever A $\subset$ U and U is π-open.

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The compliment of g-closed (resp. sg-closed, gs-closed, αg-closed, gα-closed, θg-closed, πg –closed, πgα-closed, πgs-closed, πgθ -closed, πgp-closed) is g-open (resp. sg- open, gs- open, αg- open, gα- open, θg- open, πg – open, πgα-open, πgs- open, πgθ - open, πgp- open)

Definition 2.3: Let (X, τ) be a topological space. A point x ε X is said to be in the θ-closure of a subset $A \subseteq X$ if for each open neighbourhood U of x we have cl(U)∩A≠Φ. We shall denote the θ-closure of A by $cl_\theta(A)$. A subset $A \subseteq X$ is called θ- closed if A = $cl_\theta(A)$. The compliment of θ- closed is θ- open.

Definition 2.4: A function f: (X, τ) →(Y, σ) is called
(1) π-open map [23] if f(F) is π-open in Y for every π-open in X.
(2) π-irresolute [23] if $f^{-1}(V)$ is π-closed in (X,τ) for every π-closed of (Y,σ);
(3) θ-irresolute [18] if for each θ-open set V in Y, $f^{-1}(V)$ is θ-open in X;
(4) θ-continuous [18] if for each open set V in Y, $f^{-1}(V)$ is θ-open in X.

3. πgθ-CLOSED SETS
We introduce the following definition.
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Definition 3.1: A subset A of (X, τ) is called πgθ -Closed set (briefly πgθ -closed) if $cl_\theta(A) \subset U$ whenever $A \subset U$ and U is π-open. By πGθC (τ) we mean the family of all πgθ -closed subsets of the space (X, τ). The compliment of πgθ-closed is πgθ -open.

Theorem 3.2:
1. Every θ- closed set is πgθ-closed.
2. Every θg-closed set is πgθ -closed.
3. Every πgθ -closed set is πg-closed.
4. Every πgθ -closed set is πgα -closed.
5. Every πgθ -closed set is πgs -closed.
6. Every πgθ -closed set is πgb-closed.
7. Every πgθ -closed set is πgp-closed.

Proof: Straight forward.

Converse of the above need not be true as seen in the following examples.

Example 3.3: Let X = {a, b, c},τ = { Φ,{a},{c},{a, c},{b, c},X}. Let A = {b}. Then A is πgθ -closed but not θ-closed

Example 3.4: Let X = {a, b, c, d}, τ = {Φ, {b}, {d}, {b, d}, {a, b, d}, {b, c, d}, X}. Let A = {a, d}. Then A is πgθ -closed but not θg-closed.

Example 3.5: Let X = {a, b, c, d, e}, τ = {Φ, {a, b}, {c, d}, {a, b, c, d}, X}. Let A = {a, e}. Then A is πg-closed but not πgθ –closed.

Example 3.6: Let X = {a, b, c, d}, τ = {Φ, {a}, {d}, {a, d}, {c, d}, {a, c, d}, X}, Let A = {c}. Then A is πgα -closed but not πgθ -closed.

Example 3.7: Let X = {a, b, c, d}, τ = {Φ, {a}, {b}, {a, b}, {a, b, d}, X}, Let A = {a}. Then A is πgs-closed but not πgθ -closed.

Example 3.8: Let X = {a, b, c, d}, τ = {Φ, {a}, {d}, {a, d}, {c, d}, {a, c, d}, X}. Let A = {a, c}. Then A is πgb-closed but not πgθ- closed.

Example 3.9: Let X = {a, b, c, d}, τ = { ϕ,{a},{d},{a, d},{c, d}, {a, c, d}, X}. Let A = {c}. Then A is πgp-closed but not πgθ -closed. πgθ -closed is independent of closedness, α- closedness, semi –closedness, sg-closedness, gs-closedness, g- closedness, αg- closedness and gα- closedness, as seen in the following examples.

Example 3.10: Let X = {a, b, c, d}, τ = {Φ,{a},{b},{a, b}, {a, b, d}, X}.(i) Let A = {d}. Then A is πgθ -closed but not g-closed.

Example 3.11: Let X = {a, b, c, d, e}, τ = {Φ,{a, b},{c, d}, {a, b, c, d}, X}. Let A = {e}. Then A is g-closed but not πgθ -closed.

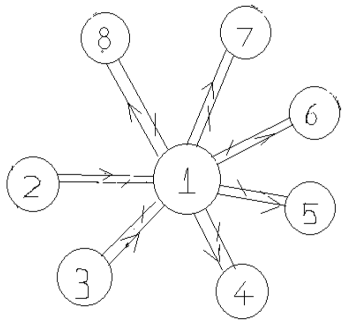
Example 3.12: Let $X = \{a, b, c,\}$, $\tau = \{\Phi, \{a\}, \{b\},\{a, b\},\{b, c\}, X\}$. Let $A= \{b\}$. Then A is $\pi g\theta$ -closed but not closed, α- closed, semi –closed.

Example 3.13: Let $X = \{a, b, c\}$, $\tau = \{\Phi, \{a\}, \{b\},\{a, b\},\{b, c\}, X \}$. Let $A = \{a\}$. Then A is closed, α- closed, semi –closed but not $\pi g\theta$ -closed.

Example 3.14: Let $X = \{a, b, c, d\}$, $\tau = \{\Phi, \{a\}, \{b\}, \{a, b\}, \{a, b, c\}, \{a, b, d\}, X\}$.
(i) Let $A = \{a, b, c\}$. Then A is $\pi g\theta$ -closed but neither sg-closed nor gs-closed.
(ii) Let $A = \{a\}$. Then A is sg-closed, gs-closed but not $\pi g\theta$ -closed.

Example 3.15: Let $X = \{a, b, c, d\}$, $\tau= \{\Phi, \{a\}, \{d\}, \{a, d\}, \{c, d\}, \{a, c, d\}, X\}$.
(i) Let $A = \{b, d\}$. Then A is $\pi g\theta$ -closed but neither αg- closed nor gα- closed.
(ii) Let $A = \{c\}$. Then A is αg- closed, gα- closed but not $\pi g\theta$ -closed.

Remark 3.16: The above discussion are summarized in the following diagram.



1 = $\pi g\theta$ -closed, 2 = θ-closed, 3 = θg-closed, 4 = πg-closed, 5 = πgα-closed, 6 = πgs -closed, 7 = πgb-closed, 8 = πgp-closed.

Theorem 3.17: If A is regular open and $\pi g\theta$ -closed, then A is θ-closed.

Proof: Let A be regular open and $\pi g\theta$ -closed. Since every regular open is π-open and since A is $\pi g\theta$ -closed, $cl_\theta(A) \subset A$. Then $A = cl_\theta(A)$. Hence A is θ-closed.

Theorem 3.18: Let A be $\pi g\theta$ -closed in (X, τ). Then $cl_\theta(A) - A$ does not contain any non-empty π-closed set.

Proof: Let F be a non-empty π-closed set such that $F\subset cl_\theta(A) - A$. Since A is $\pi g\theta$-closed, $A \subset X - F$ where $X - F$ is π-open implies $cl_\theta(A) \subset X - F$. Hence $F\subset X- cl_\theta(A)$. Now, $F\subset cl_\theta(A) \cap X- cl_\theta(A)$ implies $F =\phi$ which is a contradiction. Therefore $cl_\theta(A) -A$ does contain any non-empty π-closed set.

Corollary 3.19: Let A be $\pi g\theta$ -closed in (X, τ). Then A is θ-closed if and only if $cl_\theta(A)-A$ is π-closed.

Proof: Let A be θ-closed. Then $cl_\theta(A) = A$ implies $cl_\theta(A) - A = \phi$ which is π-closed. Assume $cl_\theta(A) - A = \phi$ is π-closed. Then $cl_\theta(A) - A = \phi$. Hence $cl_\theta(A) = A$.

Theorem 3.20*:* If A is $\pi g\theta$-closed set and B is any set such that $A \subset B\subset cl_\theta(A)$, then B is $\pi g\theta$ -closed set.

Proof*: Let B* $\subset$ U and U be π-open. Given $A \subset B$. Then $A\subset U$. Since A is $\pi g\theta$–closed, $A\subset U$ implies $cl_\theta(A) \subset U$. By assumption it follows that $cl_\theta(B)\subset cl_\theta(A) \subset U$. Then B is $\pi g\theta$ - closed.

Theorem 3.21: A finite union of $\pi g\theta$ -closed sets is always a $\pi g\theta$-closed.

Proof: Let $A, B \in \pi G\theta C(X)$. Let U be any π-open set such that $(A\cup B) \subseteq U$. Since $cl_\theta(A\cup B) = cl_\theta(A) \cup cl_\theta(B)\subseteq U\cup U=U$. This implies $cl_\theta(A\cup B) \subseteq U$. Hence $A\cup B$ is also a $\pi g\theta$ -closed set.

Remark 3.22: Finite intersection of $\pi g\theta$ -closed sets need not be $\pi g\theta$-closed.

Example 3.23: Let $X = \{a, b, c, d\}$ and $\tau = \{\Phi, \{a\}, \{b\}, \{a, b\}, \{a, b, d\}, X\}$. Let $A= \{a, b, c\}$ and $B = \{a, b, d\}$.Clearly A and B are $\pi g\theta$ -closed sets. But $A\cap B = \{a, b\}$is not a $\pi g\theta$ -closed set.

4. $\pi g\theta$ -OPEN SETS

Definition 4.1: A set $A \subset X$ is called $\pi g\theta$ -open if and only if its complement is $\pi g\theta$ -closed.

Remark 4.2: $cl_\theta(X-A) = X - int_\theta(A)$. By $\pi G\theta O(\tau)$ we mean the family of all $\pi g\theta$ -open subsets of the space (X, τ).

Theorem 4.3: If $A \subset X$ is $\pi g\theta$ -open if and only if $F \subset int_\theta(A)$ whenever F is π-closed and $F \subset A$.

Proof: Necessity: Let A be $\pi g\theta$ -open Let F be π-closed and $F \subset A$. Then $X-A \subset X-F$ where X-F is π-open. By assumption, $cl_\theta(X-A) \subset X-F$. By remark 4.2, $X- int_\theta(A) \subset (X-F)$. Thus $F \subset int_\theta(A)$.

Sufficiency: Suppose F is π-closed and $F \subset A$ such that $F \subset int_\theta(A)$. Let $X-A \subset U$ where U is π-open. Then $X-U \subset A$ where X-U is π-closed. By hypothesis, $X-U \subset int_\theta(A)$ which implies $cl_\theta(X-A) \subset X- int_\theta(A) \subset U$. Thus X-A is $\pi g\theta$ -closed and A is $\pi g\theta$ -open.

Theorem 4.4: If $int_\theta(A) \subset B \subset A$ and A is $\pi g\theta$-open, then B is also $\pi g\theta$ -open.

Proof: Let $int\theta(A) \subset B \subset A$. Thus $X-A \subset X-B \subset cl_\theta(X-A)$. Since $X – A$ is $\pi g\theta$ - closed, by theorem 3.20, $X-A \subset X-B \subset cl_\theta(X-A)$ implies X-B is $\pi g\theta$– closed.

Remark 4.5: For any $A \subset X$, $int_\theta(cl_\theta(A)-A) = \Phi$.

Theorem 4.6: If $A \subset X$ is $\pi g\theta$ -closed , then $cl_\theta(A) -A$ is $\pi g\theta$– open.

Proof: Let A be $\pi g\theta$-closed. Let F be π-closed. $F \subset cl_\theta(A) –A$.By theorem3.18, $F = \Phi$. By remark 4.5, $int_\theta(cl_\theta(A)-A) = \Phi$. Thus $F \subset int_\theta(cl_\theta(A)-A) = \Phi$. Thus $cl_\theta(A) -A$ is $\pi g\theta$– open.

Definition 4.7: A space (X, τ) is called a $\pi g\theta$-$T_{1/2}$ space if every $\pi g\theta$ –closed set is θ-closed.

Theorem 4.8:
(i)$\theta O(\tau) \subset \pi G\theta O(\tau)$.(ii) A space (X, τ) is $\pi g\theta$-$T_{1/2}$ space iff $\theta O(\tau) =\pi G\theta O(\tau)$.

Proof: Let A be θ–open, then X-A is θ –closed. So X-A is of $\pi g\theta$–closed. Then A is of $\pi g\theta$–open. Hence $\theta O(\tau) \subset \pi G\theta O(\tau)$.

(ii)Necessity: Let (X,τ) be $\pi g\theta$-$T_{1/2}$ space. Let $A \in \pi G\theta O(\tau)$. Then X-A is $\pi g\theta$ -closed. By hypothesis, $X – A$ is θ-closed, thus $A \in \theta O(\tau)$. Thus $\pi G\theta O(\tau) = \theta O(\tau)$.

Sufficiency: Let $\theta O(\tau) = \pi G\theta O(\tau)$. Let A be of $\pi g\theta$–closed. Then X-A is $\pi g\theta$ –open. $X-A \in \pi G\theta O(\tau)$.This implies $X-A \in \theta O(\tau)$. Hence A is θ–closed. This implies(X, τ) is a $\pi g\theta$-$T_{1/2}$ space.

Theorem 4.9: For a topological space(X, τ) the following are equivalent .
(i)X is a $\pi g\theta$-$T_{1/2}$ spa ce. (ii)Every singleton set is π–closed or θ-open.

Proof: (i) $\Rightarrow$ (ii): Let X be a $\pi g\theta$-$T_{1/2}$ space. Let $x \in X$ and assuming that $\{x\}$ is not π–closed. Then clearly $X –\{x\}$is trivially $\pi g\theta$–closed in X. Since X is $\pi g\theta$-$T_{1/2}$ space, $X-\{x\}$ is θ-closed. Therefore $\{x\}$ is θ-open.

(ii)$\Rightarrow$(i) Assume every singleton of X is either π–closed or θ-open. Let A be $\pi g\theta$-closed set. Let $\{x\} \in cl_\theta(A)$.

Case (i): Let $\{x\}$ be π-closed. Suppose$\{x\} \notin cl_\theta(A)$.Then$\{x\} \in cl_\theta(A)-A$. By theorem.3.18, $\{x\} \in A$. Hence $cl_\theta(A) \subset A$.

Case (ii) : Let $\{x\}$ be θ-open. Since$\{x\} \in cl_\theta(A)$, we have $\{x\} \cap A \neq \Phi$ implies $\{x\} \in A$. Therefore $cl_\theta(A) \subset A$. Hence A is θ-closed.

5. $\pi g\theta$ -continuous and $\pi g\theta$–irresolute functions

Definition 5.1.: A function $f: (X, \tau) \to (Y, \sigma)$ is called $\pi g\theta$–continuous if every $f^{-1}(V)$ is $\pi g\theta$ –closed in(X, τ) for every closed set V of (Y, σ).

Definition 5.2: A function $f: (X, \tau) \to (Y, \sigma)$ is called $\pi g\theta$–irresolute if $f^{-1}(V)$ is $\pi g\theta$ –closed in (X, τ) for every $\pi g\theta$-closed set V in (Y, σ).

Remark 5.3: **1.** $\pi g\theta$–irresolute function is independent of **θ**–irresoluteness, as seen in the following examples.

Example 5.4:(a). Let X=Y= {a, b, c, d}, τ ={Φ,{a},{d},{a, d},{a, b, d},{a, c, d},X },σ = {Φ,{a}, {d},{a, d},{c, d},{a, c, d},X}. Let f: (X, τ)→ (Y, σ) be an identity function. Then f is θ-irresolute but not πgθ–irresolute, since f^{-1}{b, c, d} = {b, c, d} is not πgθ–closed in (X, τ).

Example 5.4: (b). Let X=Y={a, b, c, d}, τ ={Φ,{a},{d},{a, d},{a, b, d},{a, c, d},X },σ = {Φ,{a}, {c},{d}, {a, d},{a, c},{c, d},{a, c, d},{a, b, d},X}. Let f: (X, τ)→ (Y, σ) be an identity function. Then f is πgθ-irresolute but not θ–irresolute, since f^{-1}{a, b, d}={a, b, d} is not θ–closed in (X, τ).

Remark 5.3:2. Every θ-continuous is πgθ–continuous The converse of the above need not be true as seen in the following examples.

Example 5.5: Let X=Y={a, b, c, d, e }, τ ={ Φ,{a, b},{c},{a, b, c},X }, σ = { Φ, {a, b},{c, d}, {a, b, c, d}, X }. Let f: (X, τ) → (Y, σ) be an identity function. Then f is πgθ-continuous but not θ–continuous, since f^{-1}{c, d, e}={c, d, e} is not θ–closed in (X, τ).

Remark 5.6: Composition of two πgθ–continuous function need not be πgθ–continuous.

Example 5.7: Let X=Y=Z ={a, b, c, d, e},τ ={Φ,{a, b},{c, d},{a, b, c, d},X},σ ={Φ, {a, b}, {c}, {a, b, c},X },η = {Φ,{e},{a, b, c, d}, X }. Let f: (X, τ)→ (Y, σ) be an identity function. Let g: (Y,σ) → (Z,η) be an identity function. Both f and g are πgθ-continuous but gof is not πgθ –continuous, since $(gof)^{-1}${a, b, c, d} = {a, b, c, d) is not πgθ-closed in (X, τ).

Definition 5.8: A function f: X→Y is said to be pre-θ-closed if f(U) is θ–closed in Y for each θ–closed set in X.

Preposition 5.9: Let f: (X, τ)→ (Y, σ) be π- irresolute and pre-θ- closed map. Then f(A) is πgθ –closed in Y for every πgθ–closed set A of X.

Proof: Let A be any πgθ-closed set of X and U be any π- open set of Y containing f(A). Since f is π-irresolute, $f^{-1}(U)$ is π-open in X and $A \subseteq f^{-1}(U)$. Therefore we have $cl_\theta(A) \subseteq f^{-1}(U)$ and hence $f(cl_\theta(A)) \subseteq U$.

Since f is pre- θ-closed, $cl_\theta(f(A)) \subseteq cl_\theta(f(cl_\theta(A))) = f(cl_\theta(A)) \subseteq U$. Hence f(A) is πgθ–closed in Y.

Theorem 5.10: Let f: (X, τ)→ (Y, σ) be a function.
(i) If f is πgθ–irresolute and X is πgθ-$T_{½}$ space, then f is θ–irresolute.
(ii) If f is πgθ–continuous and X is πgθ-$T_{½}$ space then f is θ–continuous.

Proof:
(i) Let V be θ **-** closed in Y. Since f is πgθ–irresolute, $f^{-1}(V)$ is πgθ–closed in X.

Since X is πgθ-$T_{½}$ space, $f^{-1}(V)$ is θ -closed in X. Hence f is θ –irresolute.

(ii)Let V be closed in Y. Since f is πgθ –continuous, $f^{-1}(V)$ is πgθ–closed in X.

By assumption, it is θ –closed. Therefore f is θ –continuous.

Theorem 5.11: If the bijective f: (X, τ) → (Y, σ) is θ –irresolute and π-open map then f is πgθ–irresolute.

Proof: Let V be πgθ-closed in Y. Let $f^{-1}(V) \subset U$ where U is π-open in X. Then $V \subset f(U)$ and f(U) is π–open implies $cl_\theta(V) \subset f(U)$. This implies $f^{-1}(cl_\theta(V)) \subset U$. Since f is θ-irresolute, $f^{-1}(cl_\theta(V))$ is θ –closed. Hence $cl_\theta(f^{-1}(V)) \subset cl_\theta(f^{-1}(cl_\theta(V))) = f^{-1}(cl_\theta(V)) \subset U$. Therefore f is πgθ –irresolute.

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