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Between Closed Sets and $g\omega$-Closed Sets

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Abstract: *Levine [7] introduced the notion of g-closed sets and further proper ties of g-closed sets are investigated. In 1982, the notions of ω-open and ω-closed sets were introduced and studied by Hdeib [5]. Khalid Y. Al-Zoubi [6] introduced the notion of gω-closed sets and further properties of gω-closed sets are investigated. In this paper, we introduce the notion of mgω-closed sets and obtain the unified characterizations for certain families of subsets between closed sets and gω-closed sets.*
Key words and phrases:*gω-closed set, m-structure, m-space, mgω -closed set.*

I. Introduction

In 1970, Levine [7] introduced the notion of generalized closed (g-closed) sets in topological spaces. In 1982, Hdeib [5] introduced the notion of ω-closed sets in topo-logical spaces. Recently, many variations of g-closed sets are introduced and inves-tigated. One among them is $g\,\omega$-closed sets which were introduced by Khalid Y. Al-Zoubi [6]. In 2006, Noiri and Popa [11] introduced the notion of $mg^{\star}$-closed sets and studied the basic properties, characterizations and preservation properties. Also, they de fined several subsets which lie between closed sets and g-closed sets.In this paper, we introduce the notion of $mg\omega$-closed sets and obtain the basic properties, characterizations and preservation properties. In the last section, we define several new subsets which lie between closed sets and $g\omega$-closed sets.

II. Preliminaries

Let (X,τ) be a topological space and A a subset of X. The closure of A and the interior of A are denoted by cl(A) and int(A), respectively. A subset A is said to be regular open if int(cl(A))=A. The finite union of regular open sets is said to beπ-open.

Definition 2.1:*A subset A of a topological space (X,τ) is said to beα-openifA $\subset$int(cl(int(A))). The complement of an α-open set is said to be α-closed.*

Note: The family of all α-open (resp. regular open, π--open) sets in X is denoted byτ^{α}(resp. RO(X), $\pi O(X)$).

Definition 2.2:*A subset A of a topological space (X,τ) is said to be g-closed* [7]*(resp. $g^{\star}$-closed* [20] *or strongly g-closed* [18], *πg-closed* [4], *rg-closed* [14]*)if cl(A)$\subset$U whenever A $\subset$U and U is open (resp. g-open, π-open, regular open) in (X,τ). The complements of the above closed sets are called their respective open sets.*

The family of all g-open sets in (X,τ) is denoted by gO(X). The g-closure (resp.α-closure) of a subset A of X, denoted by $g$cl(A) (resp.αcl(A)), is defined to be theintersection of all g-closed sets (resp. α-closed sets) containing A.

Definition 2.3:*A subset A of a topological space (X,τ) is said to beαg-closed* [8]*(resp. $g^{\#}\alpha$-closed* [13], *$\pi g\alpha$-closed* [2], *$r\alpha g$-closed* [10]*) if αcl(A) $\subset$ U whenever A $\subset$U and U is open (resp. g-open, π-open, regular open) in (X,τ).*

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

Definition 2.4[21]:*LetHbe a subset of a space (X,τ), a point p inXis called acondensation point of H if for each open set U containing p, U$\cap$ H is uncountable.*

Definition 2.5[5]:*A subsetHof a space (X,τ) is calledω-closed if it contains allits condensation points.The complement of an ω-closed set is called ω-open.*It is well known that a subset W of a space (X,τ) is ω-open if and only if for each$x \in W$, there exists $U \in\tau$such that $x \in U$ and $U-W$ is countable.The familyofall ω-open sets, denoted by ω, is a topology on X, which is finer than τ. The interior and closure operator in (X, ω) are denoted by int_{ω} and cl_{ω}respectively.

Lemma 2.1 [5]: *LetHbe a subset of a space (X,τ). Then*

(1) *H is ω-closed in X if and only if H =$cl_\omega(H)$.*
(2) $cl_\omega(X \backslash H) = X \backslash int_\omega(H)$.
(3) $cl_\omega(H)$ *is ω-closed in X.*
(4) $x \in cl_\omega(H)$ *if and only if* $H \cap G \neq \emptyset$ *for each ω-open set G containing x.*
(5) $cl_\omega(H) \subset cl(H)$.
(6) $int(H) \subset int_\omega(H)$.

Definition 2.6:*LetAbe a subset of a space (X,τ). ThenAis said to be*
(1) *g⋆ω-closed* [17] *if* $cl_\omega(A) \subset U$ *whenever* $A \subset U$ *and U is g-open in (X,τ).*
(2) *gω-closed* [6] *if* $cl_\omega(A) \subset U$ *whenever* $A \subset U$ *and U is open in (X, τ).*
(3) *πgω-closed* [3] *if* $cl_\omega(A) \subset U$ *whenever* $A \subset U$ *and U is π-open in (X,τ).*
(4) *rω-closed* [1] *if* $cl_\omega(A) \subset U$ *whenever* $A \subset U$ *and U is regular open in (X, τ).*

Remark 2.1 [17]:*For a subset of a topological space, we obtain the following implications:*

closed	→	*g⋆-closed*	→	*g-closed*
↓		↓		↓
ω-closed	→	*g⋆ ω-closed*	→	*g ω-closed*

None of the above implications is reversible.
Lemma 2.2 [6]:*The open image of anω-open set isω-open.*
Throughout the present paper, (X, τ) and (Y, σ) always denote topological spaces andf : (X, τ) → (Y, σ) presents a function.

III. m-Structures

Definition 3.1:*A subfamily* m_X*of the power set℘(X) of a nonempty set X is calleda Minimal Structure (briefly m-Structure)* [15] *on X if* $\emptyset \in m_X$ *and* $X \in m_X$.
By (X, m_X), we denote a nonempty set X with a minimal structure m_X on X and call it an m-space. Each member of m_X is said to be m_X -open (or briefly m-open) and the complement of an m_X -open set is said to be m_X -closed (or briefly m-closed).
Remark 3.1: *Let (X, τ) be a topological space. Then the families,*τ_ω, τ^α,τ, *RO(X),πO(X) and gO(X) are all m-structures on X.*
Definition 3.2:*Let (X,* m_X*) be an m-space. For a subset A of X, the* m_X*-closureof A and the* m_X *-interior of A are defined in* [9] *as follows:*
(1) m_X *-cl(A) =* $\cap \{F : A \subset F, X-F \in m_X \}$,
(2) m_X *-int(A) =* $\cup\{U : U \subset A, U \in m_X \}$.
Remark 3.2: *Let (X, τ) be a topological space and A a subset of X. If* m_X*=τ(resp.*τ_ω,τ^α*, gO(X)), then we have* m_X *-cl(A)=cl(A) (resp.* $cl_\omega(A)$*, αcl(A), gcl(A)).*
Lemma 3.1 [15]: *Let (X,* m_X*) be an m-space and A a subset of X. Then x∈*m_X*-cl(A)if and only if* $U \cap A \neq \emptyset$ *for every* $U \in m_X$ *containing x.*
Definition 3.3[9]: *An m-structure* m_X*on a nonempty set X is said to have property(B) if the union of any family of subsets belonging to* m_X *belongs to* m_X *.*
Remark 3.3: *Let (X, τ) be a topological space. Then the familiesτω,*τ^α*,τandπO(X) are all m-structures with property (B).*
Lemma 3.2 [16]:*Let X be a nonempty set and* m_X*an m-structure on X satisfyingproperty (B). For a subset A of X, the following properties hold:*
(1) $A \in m_X$ *if and only if* m_X *-int(A)=A,*
(2) *A is m-closed if and only if* m_X *-cl(A)=A,*
(3) m_X *-int(A)* $\in m_X$ *and* m_X *-cl(A) is m-closed.*

Definition 3.4 [11]: *Let (X, τ) be a topological space and* m_X*an m-structure on X.A subset A of X is said to be*

(1) *$mg^{\star}$-closed if cl(A) ⊂ U whenever A ⊂U and U is m_X -open,*

(2) *$mg^{\star}$-open if its complement is $mg^{\star}$-closed.*

Proposition 3.1 [11]: *Let$\tau \subset m_X$. Then the following implications hold:*

closed → $mg^{\star}$-closed → g-closed

Proposition 3.2:*Let$\tau \subset m_X$. Then the following implications hold:*

closed → $mg^{\star}$-closed → g-closed → gω-closed

Proof: It follows from Remark 2.1.

Theorem 3.1 [11]: *Let$\tau \subset m_X$and $m_X$have property (B). A subset A of X is$mg^{\star}$-closed if and only if cl(A)−A does not contain any nonempty m-closed set.*

Theorem 3.2 [11]:*Let$m_X$have property (B). A subset A of X is$mg^{\star}$-closed ifand only if m_X -cl({x}∩ A ≠ϕ for each x ∈ cl(A).*

IV. mgω-Closed Sets

In this section, let (X, τ) be a topological space and m_X an m-structure on X. We obtain several basic properties of *mg*ω-closed sets.

Definition 4.1:*Let (X, τ) be a topological space and $m_X$an m-structure on X. Asubset A of X is said to be*

(1) *mgω-closed if cl**ω**(A) ⊂ U whenever A ⊂U and U is m_X -open,*

(2) *mgω-open if its complement is mgω-closed.*

Remark 4.1: *Let (X, τ) be a topological space and A a subset of X. If m_X=gO(X)(resp. τ, πO(X), RO(X)) and A is mgω-closed, then A is $g^{\star}\omega$-closed(resp.gω-closed,πgω-closed, rgω-closed).*

Proposition 4.1: *Let$\tau \subset m_X$. Then the following implications hold:closed→ ω-closed → mgω-closed → gω-closed*

Proof:It is obvious that every closed set isω-closed [1,5] and everyω-closed set is *mgω*-closed by Lemma 2.1(1). Suppose that A is an *mgω*-closed set. Let A⊂Uand

U∈τ. Since $\tau \subset m_X$, cl_{ω}(A) ⊂U and hence A is *gω*-closed.

Proposition 4.2:
Let$m_X$be anm-structure onXin the topological space (X, τ). IfA and B are mgω-closed, then A∪B is mgω-closed.

Proof:Let A∪B⊂U and U∈m_X.Then A⊂U and B⊂U. Since A and Bare *mgω*-closed, we have cl_{ω}(A∪B)=cl_{ω}(A) ∪ cl_{ω}(B) ⊂U. Therefore, A∪B is *mgω*-closed.

Proposition 4.3:*Let$m_X$be anm-structure onXin the topological space (X, τ). IfA is mgω-closed and m-open, then A is ω-closed.*

Proof:This is obvious.

Proposition 4.4:*Let (X, m_X) be an m-space andA⊆X. If A ismgω-closed andA ⊂B ⊂ cl_{ω}(A), then B is mgω-closed.*

Proof:Let B⊂U and U∈m_X. Then A⊂U and A is *mgω*-closed. Hence cl_{ω}(B) =cl_{ω}(A) ⊂ U and B is *mgω*-closed.

Definition 4.2: [12] *Let (X, m_X) be an m-space and A a subset of X. The m_X-frontier of A, m_X -Fr(A), is defined as follows:*

m_X -Fr(A) = m_X -cl(A) ∩ m_X -cl(X−A).

Proposition 4.5:*If A is amgω-closed subset of X and A⊂U∈m_X, then m_X-Fr(U)⊂ int_{ω}(X−A).*

Proof*:*

Let A be *mgω*-closed and A⊂U∈m_X. Then cl_{ω}(A)⊂U.

Suppose that x∈ m_X -Fr(U).

Since U ∈m_X , m_X -Fr(U)= m_X -cl(U)∩ m_X -cl(X−U)
= m_X -cl(U) ∩ (X−U)
= m_X -cl(U)-U.
Therefore, x∉U and x ∉ cl_{ω}(A).

This shows that x ∈int_{ω}(X−A) and hence m_X -Fr(U) ⊂ int_{ω}(X−A).

Proposition 4.6:*In the m-space (X, m_X), a subset A of X ismgω-open if and onlyif $F \subset int_\omega(A)$ whenever $F \subset A$ and F is m-closed.*

Proof:

Suppose that A is $mg\omega$-open. Let F⊂A and F be m-closed.

Then $X-A \subset X-F \in m_X$ and X−A is $mg\omega$-closed.

Therefore, we have $X-int_\omega(A) = cl_\omega(X-A) \subset X-F$and hence $F \subset int_\omega(A)$.

Conversely, let $X-A \subset G$ and $G \in m_X$.

Then X−G ⊂ A and X−G is m-closed.

By the hypothesis, we have $X-G \subset int_\omega(A)$ and hence $cl_\omega(X-A) = X-int_\omega(A) \subset G$. Therefore, X−A is $mg\omega$-closed and A is $mg\omega$-open.

Corollary 4.1:*Let$\tau \subset m_X$. Then the following properties hold:*

(1) *Every open set is mgω-open and every mgω-open set is gω-open,*

(2) *If A and B are mgω-open, then A ∩ B is mgω-open,*

(3) *If A is mgω-open and m-closed, then A is ω-open,*

(4) *If A is mgω-open and intω(A) ⊂B ⊂ A, then B is mgω-open.*

Proof:This follows from Propositions 4.1, 4.2, 4.3 and 4.4.

Proposition 4.7:*Everymg⋆-closed set ismgω-closed.*

Proof:It follows from Lemma 2.1(5).

Proposition 4.8:*Let$\tau \subset m_X$. Then everymg⋆-closed set isgω-closed.*

Proof:It follows from Propositions 4.1 and 4.7.

Proposition 4.9: *Let$\tau \subset m_X$. Then the following implications hold:*

closed→ mg⋆-closed → mgω-closed → gω-closed

Proof:It follows from Propositions 3.2, 4.1 and 4.7.

V. Characterizations Of mgω-Closed Sets

In this section, let (X, τ) be a topological space and m_X an m-structure on X. We obtain some characterizations of $mg\omega$-closed sets.

Theorem 5.1: *A subset A of X ismgω-closed if and only if $cl_\omega(A) \cap F = \emptyset$wheneverA $\cap F = \emptyset$ and F is m-closed.*

Proof:Suppose that A is $mg\omega$-closed. Let $A \cap F = \emptyset$and F be m-closed. Then

$A \subset X-F \in m_X$and$cl_\omega(A) \subset X-F$.

Therefore, we have $cl_\omega(A) \cap F = \emptyset$.

Conversely, let $A \subset U$ and $U \in m_X$. Then

$A \cap (X-U) = \emptyset$ and X−U is m-closed.

By the hypothesis, $cl_\omega(A) \cap (X-U) = \emptyset$ and hence $cl_\omega(A) \subset U$.

Therefore, A is $mg\omega$-closed.

Theorem 5.2:*Let$\tau_\omega \subset m_X$and $m_X$have property (B). A subset A of X ismgω-closed if and only if $cl_\omega(A)-A$ does not contain any nonempty m-closed set.*

Proof:Suppose that A is $mg\omega$-closed. Let $F \subset cl_\omega(A)-A$ and F be m-closed. Then

$F \subset cl_\omega(A)$ and $A \subset X-F \in m_X$.

Hence$cl_\omega(A) \subset X-F$.

Therefore, we have $F \subset X-cl_\omega(A)$.

Hence $F \subset cl_\omega(A) \cap (X-cl_\omega(A)) = \emptyset$.

Conversely, suppose that A is not $mg\omega$-closed. Then

$\emptyset \neq cl_\omega(A)-U$ for some $U \in m_X$ containing A.

Since $\tau_\omega \subset m_X$ and m_X has property (*B*), $cl_\omega(A)-U$ is m-closed.

Moreover, $cl_\omega(A)-U \subset cl_\omega(A)-A$.

Thus $cl_\omega(A)-A$ contains a nonempty m-closed set which is a contradiction.

Hence A is $mg\omega$-closed.

Theorem 5.3:*Let$\tau_\omega \subset m_X$and $m_X$have property (B). A subset A of X ismgω-closed if and only if $cl_\omega(A)-A$ is mgω-open.*

Proof: Suppose that A is $mg\omega$-closed. Let F⊂ cl_ω(A)−A and F be m-closed.
ByTheorem 5.2, we have F = ∅and F ⊂int $\omega(cl_\omega$(A)−A).
It follows from Proposition 4.6, cl_ω(A)−A is $mg\omega$-open.
Conversely, let A⊂U and U ∈m_X .
Then cl_ω(A) ∩ (X−U) ⊂ cl_ω(A)−A and cl_ω(A)−A is $mg\omega$-open.
Since $\tau_\omega \subset m_X$ and $m_X$has property (*B*), cl_ω(A) ∩ (X−U) is m-closed and by Proposition 4.6, cl_ω(A) ∩ (X−U) ⊂$int_\omega(cl_\omega$(A)−A).
Now,$int_\omega(cl_\omega$(A)−A) = $int_\omega(cl_\omega$(A)) ∩ intω(X−A)
⊂ cl_ω(A) ∩ int_ω(X−A)
= cl_ω(A) ∩ (X−cl_ω(A)) = ∅.
Thus cl_ω(A) ∩ (X−U) =∅ and hence cl_ω(A) ⊂U.
This shows that A is $mg\omega$-closed.

Theorem 5.4:*Let $m_X$have property (B). A subset A of X ismgω-closed if andonly if m_X -cl({x} ∩ A ≠ ∅ for each x ∈ cl_ω(A).*

Proof:Suppose m_X-cl({x}) ∩ A =∅for some x∈clω(A).
By Lemma 3.2, m_X-cl({x})is m-closed and A ⊂X−(m_X -cl({x})) ∈ m_X .
If$cl_\omega(A)$ ⊂X− (m_X -cl({x})) then
x∈ cl_ω(A) ⊂X−(m_X -cl({x}))⊂X−{x} is a contradiction.
Thuscl_ω(A) ⊈ X−(m_X- cl({x}) and hence *A* in not $mg\omega$-closed.
Conversely, suppose that A is not $mg\omega$-closed.
Then there exists U ∈m_X such that A ⊂ U, but cl_ω(A) ⊈ U.
So there exists x ∈ cl_ω(A) but x ∉U. Then x ∈ U^c which is m_X -closed.
Thus m_X -cl({x}) ⊂m_X -cl(U^c) = U^c.
This implies m_X -cl({x})∩ U = ∅.
Hence m_X -cl({x})∩A ⊂ m_X -cl({x}) ∩ U = ∅.
Thus there exists x ∈ cl_ω (A) such that m_X -cl({x})∩ A = ∅. This proves the converse.

Corollary 5.1: *Letτ_ω ⊂$m_X$and $m_X$have property (B). For a subset A of X, thefollowing properties are equivalent:*
(1) *A is mg ω-open,*
(2) *A−int_ω(A) does not contain any nonempty m-closed set,*
(3) *A−int_ω(A) is mg ω-open,*
(4) *m_X-cl({x}∩(X−A) ≠∅for each x∈X−int_ω(A).*

Proof:This follows from Proposition 4.6 and Theorems 5.2, 5.3 and 5.4.

VI. Preservation Theorems

Definition 6.1 [11]:*A function f : (X, m_X)→(Y, m_Y) is said to be*
(1) *M-continuous if for each x∈ X and each V∈ m_Y containing f(x), there existsU∈ $m_X$containing x such that f(U) ⊂ V.*
(2) *M-closed if for each m-closed set F of (X, m_X), f(F) is m-closed in (Y, m_Y).*

Theorem 6.1[15]: *Let $m_X$be an m-structure on X with property (B) and $m_Y$bea minimal structure on Y. Let f :(X, m_X) → (Y, m_Y) be a function. Then the following are equivalent:*
(1) *f is M-continuous,*
(2) *f^{-1}(V)∈ m_X for every V ∈ m_Y .*

Lemma 6.1[11]: *A function f : (X, m_X)→(Y, m_Y) is M-closed if and only if foreach subset B of Y and each U ∈ m_X containing f^{-1}(B), there exists V ∈ m_Y such that B ⊂ V and f^{-1}(V) ⊂ U.*

Theorem 6.2: *If f : (X,τ)→(Y,σ) is closed and f : (X, m_X)→(Y, m_Y) is M-continuous, where m_X has property (B), then f(A) is mgω-closed in (Y, m_Y) for each mgω-closed set A of (X, m_X).*

Proof:Let A be any $mg\omega$-closed set of (X, m_X) and f(A)⊂V∈m_Y.
Since $m_X$has property (*B*), A ⊂f^{-1}(V) ∈ m_X by Theorem 6.1.
Since A is $mg\omega$-closed, cl_ω(A)⊂f^{-1}(V) and f(cl_ω(A))⊂V.
Since f is closed, by Lemma 2.2, cl_ω(f(A))⊂ f(cl_ω(A))⊂ V.
Hence f(A) is $mg\omega$-closed in (Y, m_Y).

Definition 6.2 [6]: *A function $f : (X, \tau)\to(Y,\sigma)$ is calledω-irresolute if $f^{-1}(B)$ isω-open in (X, τ) for every ω-open set B of (Y,σ).*
Theorem 6.3:*If $f : (X, \tau)\to(Y,\sigma)$ isω-irresolute and $f : (X, m_X)\to(Y, m_Y)$ isM-closed, then $f^{-1}(B)$ is mgω-closed in (X, m_X) for each mgω-closed set B of (Y, m_Y).*

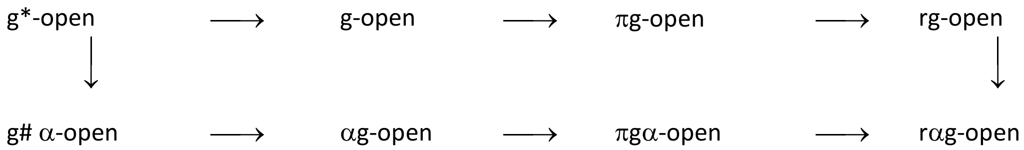
Proof:Let B be any *mgω*-closed set of (Y, m_Y) and $f^{-1}(B)\subset U\in m_X$.

Since f isM-closed, by Lemma 6.1, there exists $V \in m_Y$such that
$B \subset V$ and $f^{-1}(V) \subset U$.
Since B is *mgω*-closed in Y, $cl_\omega(B) \subset V$ and
since f is *ω*-irresolute, $cl_\omega(f^{-1}(B)) \subset f^{-1}(cl_\omega(B)) \subset f^{-1}(V) \subset U$.
Hence $f^{-1}(B)$ is *mgω*-closed in (X, m_X).

VII. New Forms Of mgω-Closed Sets

In a topological space (X, τ), from the definitions, we obtain the following diagram.

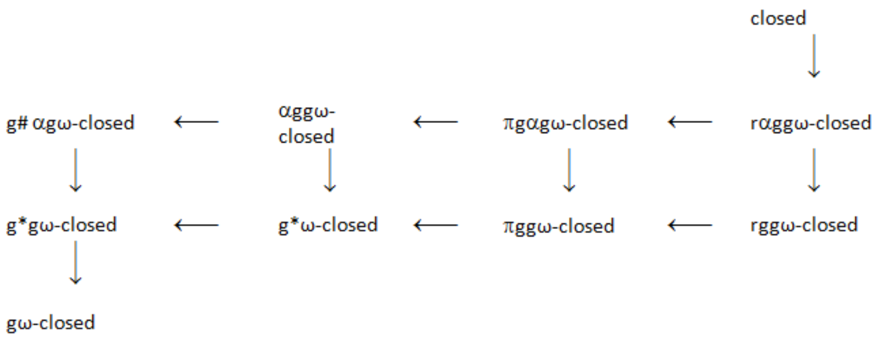
Diagram – I



In (X, τ) we denote the collection of all *g*-open (resp. $g^\star$-open, *πg*-open, r*g*-open, $g^{\#}\alpha$-open, *αg*-open, $\pi g\alpha$-open, r$g\alpha$-open) sets by *g*O(X) (resp. $g^\star$O(X), πgO(X), r*g*O(X), $g^{\#}\alpha$O(X), αgO(X), $\pi g\alpha$O(X), r$g\alpha$O(X)). These collections of are all m-structure onX. Using these m-structures *g*O(X) $g^\star$O(X), *πg*O(X), r*g*O(X), $g^{\#}\alpha$O(X), *αg*O(X),
$\pi g\alpha$O(X), r$g\alpha$O(X)) for a subset A, we define new types of *gω*-closed sets as follows.

Dfinition 7.1:*A subset A of a topological space (X, τ) is said to be$g^\star g\omega$-closed(resp. $g^\star\omega$-closed* [18], *πggω-closed, rggω-closed, $g^{\#}\alpha g\omega$-closed, αggω-closed, πgαgω-closed, rαggω-closed) if clω(A) ⊂ U whenever A ⊂ U and U is $g^\star$-open (resp. g-open,*
πg-open, rg-open, $g^{\#}\alpha$-open, αg-open, πgα-open, rαg-open) in (X, τ). By Diagram I and Definition 7.1, we have the following diagram:

Diagram - II



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