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SOME BITOPOLOGICAL SEPARATION AXIOMS USING Q*- OPEN SETS

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Abstract. In this paper , we introduce pairwise Q^* - H_i - spaces , $(i = 0, 1, 2)$ and pairwise Q^* - U_i - Spaces $(i = 0, 1)$ in topological spaces and study its properties .

1. Introduction

Separation axioms are properties by which the topology on a space X separates points from points, points from closed sets and closed sets from each other. The various separation axioms give rise to a sequence of successively stronger requirements, which are put upon the topology of a space to separate varying types of subsets.

In 1963, Levine [12] introduced the concept of semi - open sets. Since then , a considerable number of papers discussing separation axioms, essentially by replacing open sets by semi-open sets, have appeared in the literature. For instance, Maheshwari and Prasad introduced semi-T_0, semi-T_1, semi-T_2, s - normality and s - regularity as a generalization of T_0, T_1, T_2 , regularity and normality axioms respectively, and investigated their properties . The notion of semi-open sets was used by Maheshwari and Prasad to introduce pairwise semi-T_0, pairwise semi-T_1, pairwise semi-T_2, pairwise s - regular and pairwise s-normal spaces .Moreover , s - normal (resp. semi normal) spaces were introduced and studied by Maheshwari and Prasad [14] (resp. Dorsett [9]). The notion of Q^* - open sets in a topological space was introduced by Murugalingam and Lalitha[19, 20].

Throughout this paper X and Y always represent nonempty bitopological spaces (X, τ_1, τ_2) and (Y, σ_1, σ_2). In this paper , we introduce pairwise Q^* - H_i - spaces , (i = 0, 1, 2) and pairwise Q^* - U_i - Spaces (i = 0, 1) in bitopological spaces and study its properties.

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2. Preliminaries

A topological space (X , τ) is a hyperconnected space if X cannot be written as the union of two proper closed sets. Moreover, for a topological space X the following conditions are equivalent: i) No two nonempty open sets are disjoint. ii) X cannot be written as the union of two proper closed sets. i.e) X is hyperconnected. iii) Every nonempty open set is dense in X. iv) The interior of every proper closed set is empty.

A subset A of a space X is said to be bi - Q* open [23] if it is both τ_i - Q* open and τ_j - Q* open, where i, j = 1, 2 and $i \neq j$. A subset A of a bitopological spaces X is called [19] $\tau_1\tau_2$ - Q* - closed if i) τ_1- int (A) = ϕ and A is τ_2- closed . ii) $\tau_1\tau_2$ - Q* - open if X − A is $\tau_1\tau_2$- Q* - closed in X . The set of all Q* - closed sets [19] with X is a topology . It is denoted by $\tau_{Q^*} = \sigma^*$. A bitopological space X is said to be pairwise semi - H_0 [26] if for every pair of points x and y such that x $\notin \tau_i$ -scl{ y } there exists a τ_i - semi - open set U and a τ_j- semi - open set V such that x ∈U, y ∈V, U ∩ V = ϕ , i $\neq$ j , i, j = 1 , 2. A bitopological space X is said to be pairwise semi - H_1 [26] if for every pair of points x and y such that τ_i -scl { x } ∩ τ_j -scl{ y } = ϕ , there exists a τ_i - semi - open set U and a τ_j-semi - open set V such that x ∈U, y ∈V, U ∩ V = ϕ , i $\neq$ j , i, j = 1, 2 . A bitopological space X is said to be pairwise semi- H_2[26] if for every τ_j-semi - closed set A and a point x such that τ_i - scl { x } n A =ϕ , there exists a τ_i-semi - open set U and a τ_j - semi- open set V such that x ∈U, A ⊆V, U ∩ V = ϕ , i $\neq$ j , i, j = 1 , 2. A bitopological space X is called pairwise Q^*T_0 [23] if for any pair of distinct points x , y of X , there exists a set which is either τ_i - Q^* open or τ_j - Q^* open containing one of the points but not the other , where i, j = 1, 2 and $i \neq j$ .A bitopological space X is called pairwise Q^*T_1 [23] if for every distinct points x , y of X , there is a τ_i - Q^* open set U and a $\tau_j - Q^*$ open set V such that $x \in U$, $y \notin U$ and $y \in V$, $x \notin V$, where i, j = 1, 2 and $i \neq j$. A bitopological space X is called pairwise Q^*T_2 [23] or pairwise Q^* Hausdorff if given distinct points x, y of X , there is a $\tau_i - Q^*$ open set U and a $\tau_j - Q^*$ open set V such that $x \in U$, $y \in V$,$U \cap V = \phi$ where i, j = 1, 2 and $i \neq j$.

3. Pairwise Q*- H_i -Spaces (i = 0, 1, 2) and pairwise Q*- U_i - Spaces (i = 0, 1)

Here we introduce the bitopological analogues of Q* - H_i - spaces, (i = 0, 1, 2) and Q* - U_i - Spaces (i = 0, 1).

Definition 3.1. A bitopological space X is said to be pairwise Q*- H_0 if for every pair of points x and y such that x $\notin \sigma_i^*$ - cl { y } there exists a τ_i - Q* - open set U and a τ_j - Q* - open set V such that x ∈U, y ∈V, U ∩ V = ϕ , i $\neq$ j , i , j = 1 , 2 .

Example 3.2. Let X = { a, b, c } , τ_1 = { ϕ, X, { a } }, τ_2 = { ϕ, X, { b }, { a, b } }. Let a, b ∈ X such that { a } $\notin \sigma_i^*$ - cl ({ b }), there exists a τ_i - Q* - open set U = { a } and a τ_j - Q* - open set V = { b } such that a ∈U, b ∈V, U ∩ V = ϕ. Therefore, X is pairwise Q* - H_0.

Definition 3.3. A bitopological space X is said to be pairwise Q*- H_1 if for every pair of points x and y such that σ_i^* - cl { x } ∩ σ_j^*- cl{ y } = ϕ, there exists a τ_i - Q* - open set U and a τ_j - Q* - open set V such that x ∈U, y ∈ V, U ∩ V = ϕ, i $\neq$ j, i, j = 1, 2.

Example 3.4. Let X = { a, b, c, d }, τ_1 = { ϕ, X, { a, b }, { b, c, d } }, τ_2= { ϕ, X, { c, d }, { b, c, d }, { a, b, d } }. Let a, c$\in$ X such that σ_i^* - cl { a }$\cap$ σ_j^* - cl { c } = { a } $\cap$ { c } = ϕ , there exists a τ_i - Q* - open set U = { a , b} and a τ_j - Q* - open set V = { c, d } such that x $\in$ U, y $\in$ V, { a, b } $\cap${ c, d } = ϕ. Therefore, X is called pairwise Q* H_1.

Definition 3.5. A bitopologicalspace X is said to be pairwise Q*- H_2 if for every τ_j - Q* - closed set A and a point x such that σ_i^* - cl { x } $\cap$ A =ϕ , there exists a τ_i - Q*- open set U and a τ_j - Q*- open set V such that x $\in$U, A $\subseteq$V, U $\cap$ V = ϕ, i $\neq$ j , i , j = 1 , 2.

Example 3.6. Let X = { a , b , c , d } , τ_1 = { ϕ , X , { a , b } , { b , d } } , τ_2= { ϕ , X , { c , d } , { a , c } , { a , b, c } , { a , b, d } , { a , c, d } } . Let a, b $\in$ X such that σ_i^* - cl ({ a }) $\cap$ { d } = { a , c } $\cap$ { d } = ϕ . Then there is a τ_1 - Q* open set U = {a,b} & τ_2 - Q* open set V = { c , d }such that a $\in$ U, { d } $\subseteq$ { c , d } and U $\cap$ V = ϕ . Therefore, X is called pairwise Q* H_2.

Definition 3.7. A bitopological space X is said to be pairwise Q*- U_0 if for every pair of points x and y such that x $\notin\sigma_i^*$ - cl {y}, there exists a τ_i - Q* - open set U and a τ_j - Q* - open set V such that x $\in$ U, y $\in$V, σ_j^*- cl (U) $\cap$ σ_i^* - cl (V) = ϕ , i $\neq$ j , i , j = 1 , 2.

Example 3.8. Let X = { a , b , c , d } , τ_1 = { ϕ , X , { a } , { a , c, d } } , τ_2= { ϕ , X , { b } , { a , b, c } , { a , b, d } , { b , c , d } } . Let a, b $\in$ X such that { a } $\notin\sigma_i^*$ - cl ({ b }) . Then there is a τ_1 - Q* open set U = { a } & τ_2 - Q* open set V = { b }such that σ_j^*- cl ({ a }) $\cap$ σ_i^*-cl ({ b }) = { a } $\cap$ { b } =ϕ . Therefore, X is called pairwise Q* U_0 .

Example 3.9. A bitopological space X is said to be pairwise Q*- U_1 if for every pair of points x and y such thatσ_i^* - cl {x} n σ_j^* - cl { y } = ϕ , there exists a τ_i - Q* - open set U and a τ_j - Q* - open set V such that x $\in$V, y $\in$U, σ_j^* - cl (U) $\cap\sigma_i^*$- cl (V) = ϕ, i , j = 1 , 2.

Example 3.10. Let X = { a , b , c , d } , τ_1 = { ϕ , X , { b , c, d } } , τ_2= { ϕ , X , { a } , { a , b , c } , { b , c , d } , { a , c , d } } . Let a , b $\in$ X such that σ_i^* - cl { a } $\cap$ σ_j^* - cl { b } = ϕ , there exists a τ_i - Q* - open set U = { b, c, d } and a τ_j - Q* - open set V = { a } such that x $\in$V, y $\in$U , σ_j^* - cl ({ b , c, d }) $\cap\sigma_i^*$ - cl ({ a }) = { b, c , d } $\cap$ { a } = ϕ . Therefore , X is called pairwise Q* U_1 .

Theorem 3.11. *Every pairwise Q* normal space is pairwise Q* - H_2 .*

Proof. Let X is pairwise Q* normal space. Let x $\in$X and let A be a τ_j - Q* - closed set such that σ_i^*- cl { x } $\cap$A = ϕ. By pairwise Q*- normality of X , there exists a τ_i - Q*- open set U and a τ_j - Q*- open set V such that σ_i^*- cl { x } $\subseteq$V, A $\subseteq$U, U $\cap$ V = ϕ. Hence x $\in$V, A $\subseteq$U, U $\cap$ V = ϕ. Hence, X is pairwise Q*- H_2. □

Theorem 3.12. *Every pairwise Q* normal space is pairwise H_2 .*

Proof. Straight forward. □

Theorem 3.13. *Every pairwise Q* normal space is pairwise semi- H_2 .*

Proof. Straight forward. □

Theorem 3.14. *Every pairwise Q^*- H_2space is pairwise Q^*- H_1.*

Proof. Let X is Q^*- H_2 space . Let x and y be two distinct points of X such that σ_i^* - cl {x} $\cap$ σ_j^* - cl{y} = ϕ . Since X is pairwise Q^*- H_2 , therefore there exists a τ_i - Q^*- open set U and a τ_j - Q^*- open set V such that x $\in$V, σ_j^*- cl {y} $\subseteq$U, U $\cap$ V = ϕ. Thus x $\in$V, y $\in$U , U $\cap$ V = ϕ. Hence, X is pairwise Q^*- H_1. □

Theorem 3.15. *Every pairwise Q^*- H_0 space is pairwise Q^*- H_1.*

Proof. Let X is pairwise Q^*- H_0 space. Let x and y be two distinct points of X such that σ_i^* - cl {x} $\cap\sigma_j^*$ - cl {y} = ϕ. Hence x $\notin\sigma_j^*$- cl {y}. Since X is pairwise Q^*- H_2,therefore there exists a τ_i - Q^*- open set U and a τ_j - Q^*- open set V such that x $\in$ V, y $\in$ U, U $\cap$ V = ϕ. Hence, X is pairwise Q^*- H_1. □

Definition 3.16 (22)**.** A bitopological space X is pairwise $Q^* - R_0$ if for each $\tau_i - Q^*$ open set G , $x \in G$ implies σ_j^* - cl (x) $\subset$ G , where i , j = 1 , 2 and $i \neq j$.

Definition 3.17 (22)**.** A bitopological space X is pairwise $Q^* - R_1$ if for each $x, y \in X$,σ_i^* - cl (x) $\neq$ σ_j^* - cl (y) , there exist disjoint sets $U \in Q^*O(X, \tau_j)$ and $V \in Q^*O(X, \tau_i)$ such that σ_j^* - cl(x) $\subset U$ and σ_i^* - cl (y) $\subset V$ where i , j = 1 , 2 and $i \neq j$.

Theorem 3.18. *Every pairwise Q^*- R_1 space is pairwise Q^*- H_0.*

Proof. Let X is pairwise Q^*- R_1 space. Let x $\notin\sigma_i^*$ - cl {y}. Then σ_j^* - cl {x} $\neq\sigma_i^*$- cl {y}. Thus there exists a τ_i - Q^*- open set U and a τ_j - Q^*- open set V such that x $\in$U, y $\in$V, U $\cap$ V = ϕ. Hence, X is pairwise Q^*- H_0. □

Theorem 3.19. *Every pairwise Q^*- R_1 space is pairwise Q^*- H_1.*

Proof. Follows in view of Theorem 3.18 and 3.15. □

Definition 3.20. A space X is said to be pairwise strongly Q^*- regular if for each τ_j - Q^*- closed subset A of X and x $\notin$ A , there exist disjoint τ_i - Q^*- open set U and τ_j - Q^*- open set V such that x $\in$U and A $\subseteq$V.

Theorem 3.21. *Every pairwise Q^*- H_0 space is pairwise Q^*- R_0.*

Proof. Let X is pairwise Q^*- H_0 space. Let x $\in$G $\in Q^*$O (τ_i) and let y $\in$X − G. Then x $\notin\sigma_i^*$ - cl {y}. Since X is pairwise Q^*- H_0 , there exists a τ_i - Q^*- open set U and a τ_j - Q^*- open set V such that x $\in$U, y $\in$V, U $\cap$ V = ϕ. Thus {x} $\cap$ V = ϕ so that y $\notin\sigma_j^*$ - cl {x}. Hence X − G $\subseteq$X − σ_j^* - cl {x} or σ_j^* - cl {x} $\subseteq$G. Thus X is pairwise Q^*- R_0. □

Theorem 3.22. *Every pairwise strongly Q^*- regular space is pairwise Q^*- H_2.*

Proof. Let X is pairwise strongly Q^*- regular space. Let x $\in$X and let A be a τ_j - Q^*- closed subset of X such that σ_i^*- cl {x} $\cap$ A= ϕ. Then x $\notin$A . By pairwise strongly Q^*- regularity of X , there exists a τ_i - Q^*-open set U and a τ_j - Q^*- open set V such that x $\in$V, A $\subseteq$U, U $\cap$ V = ϕ . Hence, X is pairwise Q^*- H_2. □

Theorem 3.23. *A space is pairwise Q^*- T_2 if and only if it is pairwise Q^*-T_0 and pairwise Q^*-H_0.*

Proof. Let X is pairwise Q*-T$_2$ space. Clearly, X is Q*-T$_0$. Let x, y $\in$X such that x $\notin\sigma_i^*$ - cl {y}. Then x $\neq$y , since X is pairwise Q*- T$_2$, there exists a τ_i - Q*- open set U and a τ_j - Q*- open set V, such that x $\in$ U, y $\in$V, U $\cap$ V = ϕ . Hence X is pairwise Q*-H$_0$. Conversely, let X is pairwise Q*- T$_0$ and pairwise Q*- H$_0$. Let x, y be two distinct points of X. Since X is pairwise Q*- T$_0$, there exists aτ_i - Q*- open set U or a τ_j - Q*- open set V such that x $\in$ U, y $\notin$V or x $\notin$U, y $\in$V. Thus x $\notin\sigma_i^*$ - cl {y} or y $\notin\sigma_j^*$ - cl {x}.Let x $\notin\sigma_i^*$- cl {y}. Since the space is pairwise Q*- H$_0$, there exists a τ_i - Q*- open set P and a τ_j - Q*- open set Q such that x $\in$P, y $\in$Q, P $\cap$ Q = ϕ. The result follows similarly in case y $\notin\sigma_j^*$- cl {x}. Hence X is pairwise Q*- T$_2$. □

Theorem 3.24. *A space is pairwise Q*- T_2 if and only if it is pairwise Q*- T_1 and pairwise Q*- H_1.*

Proof. Let X is pairwise Q*-T$_2$ space. Clearly, X is pairwise Q*- T$_1$. Let x, y $\in$X such that σ_i^* - cl {x} $\cap$ σ_j^*- cl {y} = ϕ . Then x, y are distinct points of X so that there exists a τ_i - Q*- open set U and a τ_j - Q*- open set V, such that x $\in$ U, y $\in$V, U $\cap$ V = ϕ . Hence, X is pairwise Q*- H$_1$.
Conversely, let X is pairwise Q*- T$_1$ and pairwise Q*- H$_1$. Let x, y be two distinct points of X . Since X is pairwise Q*- T$_1$, therefore {x} and {y} are bi - Q*- closed sets. Hence σ_j^* - cl {x} $\cap$ σ_i^*- cl {y} = {x} $\cap$ {y} = ϕ. Since X is pairwise Q*- H$_1$, there exists a τ_i - Q*- open set U and a τ_j - Q*- open set V such that x $\in$ U, y $\in$V, U $\cap$ V = ϕ . Hence X is pairwise Q*- T$_2$. □

Theorem 3.25. *Every pairwise strongly Q*- regular space is pairwise Q*- U_0.*

Proof. Let X is pairwise strongly Q*- regular space. Let x, y $\in$X such that x $\notin\sigma_i^*$- cl {y}. Since the space is pairwise strongly Q*- regular, there exists a τ_i- Q*- open set U and a τ_j- Q*- open set V such that x $\in$U, σ_i^* - cl {y} $\subseteq$V, σ_j^* - cl (U) $\cap$ σ_i^* - cl(V) = ϕ . Hence x $\in$U,y $\in$ V, U $\cap$ V = ϕ and thus X is pairwise Q*- U$_0$. □

Theorem 3.26. *Every pairwise Q*-U_0 space is pairwise Q*-H_0.*

Proof. Let X is pairwise Q*-U$_0$ space. Let x, y $\in$ X such that x $\notin\sigma_i^*$ - cl {y}. Since X is pairwise Q*- U$_0$, there exists a τ_i- Q*- open set U and a τ_j- Q*- open set V such that x $\in$ U, y $\in$V, σ_j^* - cl (U) $\cap$ σ_i^*- cl (V) = ϕ . Hence x $\in$ U, y $\in$V, U $\cap$ V = ϕ and thus X is pairwise Q*- H$_0$. □

Theorem 3.27. *Every pairwise Q*-U_0 space is pairwise H_0.*

Proof. Straight forward. □

Theorem 3.28. *Every pairwise Q*-U_0 space is pairwise semi - H_0.*

Proof. Straight forward. □

Theorem 3.29. *Every pairwise Q*- U_1 space is pairwise Q*-H_1.*

Proof. Let X is pairwise Q*-U$_1$ space. Let x, y $\in$X such that σ_i^*- cl {x} $\cap$ σ_j^*- cl {y} = ϕ. Since X is pairwise Q*-U$_1$, there exists a τ_i- Q*-open set U and a τ_j- Q*-open set V such that x $\in$ U, y $\in$V, σ_j^*- cl (U)$\cap$ σ_i^*- cl (V) = ϕ. Hence x $\in$ V, y $\in$U, U $\cap$ V = ϕ and thus X is pairwise Q*-H$_1$. □

Theorem 3.30. *Every pairwise Q*- U_1 space is pairwise semi -H_1.*

Proof. Straight forward. □

Theorem 3.31. *Every pairwise Q^* normal space is pairwise semi- U_1.*

Proof. Straight forward. □

Remark 3.32. The above relation between pairwise Q^*- H_i axioms, i ∈ { 0, 1, 2 } and pairwise Q^*- U_i axioms, i ∈ { 0, 1, 2} can be summarized in the following diagram:

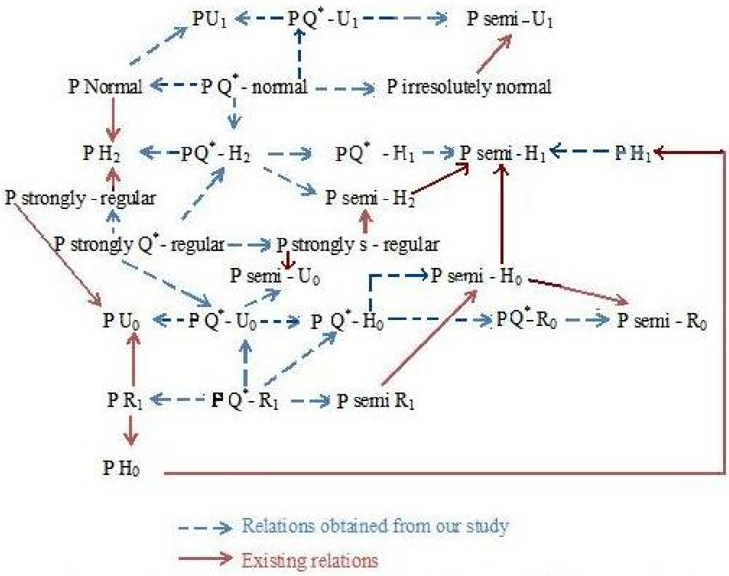

Fig 3.1 Relations between existing P - H_0 and P Q^*- H_0

Pairwise Q^*-T_2 ⇒ Pairwise Q^*- T_0 + Pairwise Q^*- H_0
Pairwise Q^*-T_2 ⇒ Pairwise Q^*-T_1 + Pairwise Q^*- H_1
Pairwise semi -T_2 ⇒ Pairwise semi- T_0 + Pairwise semi- H_0
Pairwise semi-T_2 ⇒ Pairwise semi -T_1 + Pairwise semi- H_1
Pairwise semi -T_2 ⇒ Pairwise Q^*- T_0 + Pairwise Q^*- H_0
Pairwise semi-T_2 ⇒ Pairwise Q^*-T_1 + Pairwise Q^*- H_1

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