

$(\tau_1, \tau_2)^*$ - Q^* CLOSED SETS IN BITOPOLOGICAL SPACES

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ABSTRACT

In the present paper, we introduced $(\tau_1, \tau_2)^*$ - Q^* closed sets in bitopological spaces and studied its some of their bitopological properties. Also some relations are established with known generalized closed sets.

Keywords : $(\tau_1, \tau_2)^*$ - Q^* closed sets, $(\tau_1, \tau_2)^*$ - Q^* open sets .

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1. Introduction

A triple (X, τ_1, τ_2) where X is a non-empty set and τ_1, τ_2 are topologies on X is called a bitopological space and Kelly initiated the study of such spaces. Maheswari and Prasad introduced semi open sets in bitopological spaces in 1977.

Levine [8] introduced the concept of generalized closed sets in topological spaces. Also he introduced the notion of semi open sets in topological spaces. Bhattacharyya and Lahiri [1] introduced a class of sets called semi generalized closed sets by means of semi open sets of Levine and obtained various topological properties.

In 1985, Fukutake [5] introduced the concepts of g -closed sets in bitopological spaces and after that several authors turned their attention towards generalizations of various concepts of topology by considering bitopological spaces.

The notion of Q^* - closed sets in a topological space was introduced by Murugalingam and Lalitha [9] in 2010.

Recently, P. Padma and S. Udayakumar [11] introduced the concept of $\tau_1\tau_2 - Q^*$ continuous maps in bitopological spaces.

In the present paper, we introduced $(\tau_1, \tau_2)^* - Q^*$ closed sets in bitopological spaces and studied its some of their bitopological properties. Also some relations are established with known generalized closed sets.

2.1 PRELIMINARIES

Throughout this paper X and Y always represent nonempty bitopological spaces (X, τ_1, τ_2) and (Y, σ_1, σ_2) . For a subset A of X , $\tau_1 - cl(A)$, $\tau_1 - Q^*cl(A)$ (resp. $\tau_1 - int(A)$, $\tau_1 - Q^*int(A)$) represents closure of A and Q^* closure of A (resp. interior of A , Q^* - interior of A) with respect to the topology τ_1 . We shall now require the following known definitions.

Definition 2.1: A subset S of X is called $\tau_1\tau_2 - open$ if $S \in \tau_1 \cup \tau_2$ and the complement of $\tau_1\tau_2 - open$ set is $\tau_1\tau_2 - closed$.

Example 2.1: Let $X = \{a, b, c\}$, $\tau_1 = \{\phi, X, \{a\}, \{a, b\}\}$ and $\tau_2 = \{\phi, X, \{b\}\}$. Then $\tau_1 - open$ sets on X are $\phi, X, \{a\}, \{a, b\}$ and $\tau_2 - open$ sets on X are $\phi, X, \{b\}$. Therefore, $\tau_1\tau_2 - open$ sets on X are $\phi, X, \{a\}, \{b\}, \{a, b\}$ and $\tau_1\tau_2 - closed$ sets are $X, \phi, \{b, c\}, \{c, a\}, \{c\}$.

Definition 2.2: A set A of a bitopological space (X, τ_1, τ_2) is called

- a) $\tau_1\tau_2 - semi\ open$ if there exists an $\tau_1 - open$ set U such that $U \subseteq A \subseteq \tau_2 - cl(A)$. Equivalently, a set A is $\tau_1\tau_2 - semi\ open$ if $A \subseteq \tau_2 - cl(\tau_1 - int(A))$.

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- b) $\tau_1 \tau_2$ - semi closed if $X - A$ is $\tau_1 \tau_2$ - semi open.
- c) $\tau_1 \tau_2$ - generalized open ($\tau_1 \tau_2$ - g open) if $X - A$ is $\tau_1 \tau_2$ - generalized closed.
- d) $\tau_1 \tau_2$ - generalized closed ($\tau_1 \tau_2$ - g closed) if $\tau_2 - \text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is τ_1 - open in X .
- e) $\tau_1 \tau_2$ - generalized open ($\tau_1 \tau_2$ - g open) if $X - A$ is $\tau_1 \tau_2$ - g closed.
- f) $\tau_1 \tau_2$ - semi generalized closed ($\tau_1 \tau_2$ - sg closed) if $\tau_2 - \text{scl}(A) \subseteq U$ whenever $A \subseteq U$ and U is τ_1 - semi open in X .
- g) $\tau_1 \tau_2$ - semi generalized open ($\tau_1 \tau_2$ - sg open) if $X - A$ is $\tau_1 \tau_2$ - sg closed.
- h) $\tau_1 \tau_2$ - generalized semi closed ($\tau_1 \tau_2$ - gs closed) if $\tau_2 - \text{cl}(A) \subseteq U$ whenever $A \subseteq U$ and U is τ_1 - open in X .
- i) $\tau_1 \tau_2$ - generalized semi open ($\tau_1 \tau_2$ - gs open) if $X - A$ is $\tau_1 \tau_2$ - gs closed.
- j) $\tau_1 \tau_2$ - regular open if $A = \tau_1 - \text{int}[\tau_2 - \text{cl}(A)]$.
- k) $\tau_1 \tau_2$ - regular closed if $A = \tau_1 - \text{cl}[\tau_2 - \text{int}(A)]$.

Definition 2.3: A subset A of a bitopological space (X, τ_1, τ_2) is called $(\tau_1, \tau_2)^*$ -semi generalized closed (briefly $(\tau_1, \tau_2)^*$ -sg closed) set if and only if $\tau_1 \tau_2 - \text{scl}(S) \subseteq F$ whenever $S \subseteq F$ and F is $\tau_1 \tau_2$ -semi open set. The complement of $(\tau_1, \tau_2)^*$ - semi generalized closed set is $\tau_1 \tau_2$ - semi generalized open.

Definition 2.4: A subset A of a bitopological space (X, τ_1, τ_2) is called $(\tau_1, \tau_2)^*$ -generalized closed (briefly $(\tau_1, \tau_2)^*$ -g closed) set if and only if $\tau_1 \tau_2 - \text{cl}(S) \subseteq F$ whenever $S \subseteq F$ and F is $\tau_1 \tau_2$ -open set. The complement of $(\tau_1, \tau_2)^*$ -generalized closed set is $(\tau_1, \tau_2)^*$ - generalized open.

3. $(\tau_1, \tau_2)^* - Q^*$ - CLOSED SETS

The family of all $(\tau_1, \tau_2)^* - Q^*$ closed subsets of a bitopological space (X, τ_1, τ_2) is denoted by $(\tau_1, \tau_2)^* - Q^*$.

Definition 3.1: A subset A of a bitopological spaces (X, τ_1, τ_2) is called

- i) $(\tau_1, \tau_2)^* - Q^*$ closed if $\tau_1 \tau_2 - \text{int}(A) = \phi$ and A is $\tau_1 \tau_2$ - closed.
- ii) $(\tau_1, \tau_2)^* - Q^*$ - open if $X - A$ is $(\tau_1, \tau_2)^* - Q^*$ closed in X .

Example 3.1: Let $X = \{a, b, c\}$, $\tau_1 = \{\phi, X, \{c\}\}$, $\tau_2 = \{\phi, X, \{b, c\}, \{c\}\}$. Then $\tau_1 \tau_2$ - open sets on X are $\phi, X, \{b, c\}, \{c\}$ and $\tau_1 \tau_2$ - closed sets on X are $\phi, X, \{a\}, \{a, b\}$. Clearly $\phi, \{a, b\}$ and $\{a\}$ are $(\tau_1, \tau_2)^* - Q^*$ closed.

Remark 3.1: Since every $(\tau_1, \tau_2)^* - Q^*$ closed is $\tau_1 \tau_2$ - closed and $\tau_1 \tau_2$ - closed set is $(\tau_1, \tau_2)^* - g$ closed, $(\tau_1, \tau_2)^* - sg$ closed, we have $(\tau_1, \tau_2)^* - Q^*$ closed is $(\tau_1, \tau_2)^* - g$ closed, $(\tau_1, \tau_2)^* - sg$ closed. But the converse is not true in general.

The following example supports our claim.

Example 3.2: Let $X = \{a, b, c\}$, $\tau_1 = \{\phi, X, \{a\}, \{b\}, \{a, b\}\}$, $\tau_2 = \{\phi, X\}$. Then $\tau_1 \tau_2$ - open sets on X are $\phi, X, \{a\}, \{b\}, \{a, b\}$ and $\tau_1 \tau_2$ - closed sets on X are $\phi, X, \{b, c\}, \{c, a\}, \{c\}$. Clearly $\{b, c\}$ is $(\tau_1, \tau_2)^* - sg$ closed but it is not $(\tau_1, \tau_2)^* - Q^*$ closed since $\tau_1 \tau_2 - \text{int}(\{b, c\}) = b \neq \phi$.

Example 3.3: Let $X = \{a, b, c\}$, $\tau_1 = \{\phi, X, \{a\}\}$, $\tau_2 = \{\phi, X\}$. Then $\tau_1 \tau_2$ - open sets on X are $\phi, X, \{a\}$ and $\tau_1 \tau_2$ - closed sets on X are $\phi, X, \{b, c\}$. Clearly $\{c\}$ is $(\tau_1, \tau_2)^* - g$ closed but not $(\tau_1, \tau_2)^* - Q^*$ closed.

Remark 3.2: Since every $(\tau_1, \tau_2)^* - Q^*$ closed is τ_2 - closed and τ_2 - closed set is $\tau_1 \tau_2$ - g closed, $\tau_1 \tau_2$ - gs closed $\tau_1 \tau_2$ - sg closed, s^*g closed, we have every $(\tau_1, \tau_2)^* - Q^*$ closed is $\tau_1 \tau_2$ - g closed, $\tau_1 \tau_2$ - gs closed $\tau_1 \tau_2$ - sg closed $\tau_1 \tau_2$ - s^*g closed. But the converse is not true in general. The following example supports our claim.

Example 3.4: In example 3.1, $\{c\}$ $\tau_1 \tau_2$ - g closed, $\tau_1 \tau_2$ - sg closed and $\tau_1 \tau_2$ - gs closed but not $(\tau_1, \tau_2)^* - Q^*$ closed.

Remark 3.3: Since every $(\tau_1, \tau_2)^* - Q^*$ closed set is $\tau_1 \tau_2 - Q^*$ closed. But the converse is not true in general. The following example supports our claim.

Example 3.5: Let $X = \{a, b, c\}$, $\tau_1 = \{\phi, X, \{a\}\}$, $\tau_2 = \{\phi, X, \{a\}, \{b, c\}\}$. Then $\phi, X, \{a\}, \{b, c\}$ are $\tau_1 \tau_2$ - open and $X, \phi, \{b, c\}, \{a\}$ are $\tau_1 \tau_2$ - closed. Clearly $\{b, c\}$ is $\tau_1 \tau_2 - Q^*$ closed but it is not $(\tau_1, \tau_2)^* - Q^*$ closed since $\tau_1 \tau_2 - \text{int}(\{b, c\}) = \{b, c\} \neq \phi$.

Remark 3.4: Every $(\tau_1, \tau_2)^* - Q^*$ closed set is $(\tau_1, \tau_2)^* -$ semi closed. But the converse need not be true. The following example supports our claim.

Example 3.5: In example 3.2, $\{a\}$ is $(\tau_1, \tau_2)^* -$ semi closed but not $(\tau_1, \tau_2)^* - Q^*$ closed.

Proposition 3.1: If $A, B \in (\tau_1, \tau_2)^* - Q^*$ then $A \cup B \in (\tau_1, \tau_2)^* - Q^*$.

Proof: Let A and B be $(\tau_1, \tau_2)^* - Q^*$ closed sets in (X, τ_1, τ_2) .

Claim: $A \cup B$ be a $(\tau_1, \tau_2)^* - Q^*$ closed sets in (X, τ_1, τ_2) .

i.e) to prove $\tau_1 \tau_2 - \text{int}(A \cup B) = \phi$ and A is $\tau_1 \tau_2$ - closed.

Since, A and B be $(\tau_1, \tau_2)^* - Q^*$ closed sets in (X, τ_1, τ_2) we have

$\tau_1 \tau_2 - \text{int}(A) = \phi$ and A is $\tau_1 \tau_2$ - closed and $\tau_1 \tau_2 - \text{int}(B) = \phi$ and B is $\tau_1 \tau_2$ - closed.

Since (X, τ_1, τ_2) be a bitopological space, we have finite union of $\tau_1 \tau_2$ - closed sets are $\tau_1 \tau_2$ - closed.

$\Rightarrow \tau_1 \tau_2 - \text{int}(A \cup B) = \phi$ and A is $\tau_1 \tau_2$ - closed .

$\Rightarrow A \cup B$ is $(\tau_1, \tau_2)^* - Q^*$ closed sets in (X, τ_1, τ_2) .

$\Rightarrow A \cup B \in (\tau_1, \tau_2)^* - Q^*$.

Proposition 3.2: Every $(\tau_1, \tau_2)^* - Q^*$ closed set is τ_2 - closed.

Proof: Let A be a $(\tau_1, \tau_2)^* - Q^*$ closed set in X .

Then $X - A$ is $(\tau_1, \tau_2)^* - Q^*$ - open.

We have to show that

A is $(\tau_1, \tau_2)^* - Q^*$ closed.

Since every $(\tau_1, \tau_2)^* - Q^*$ open set is τ_2 - open, we have $X - A$ is τ_2 - open.

Thus,

A is τ_2 - closed.

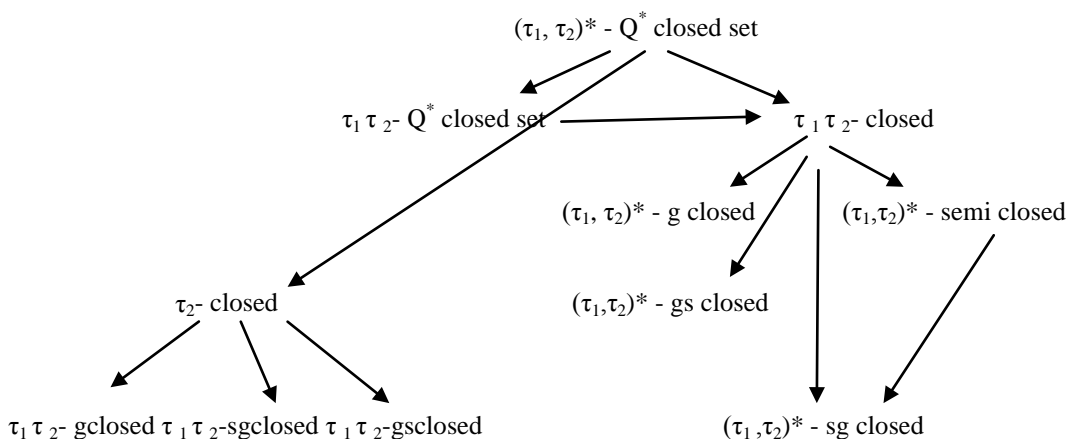
Remark 3.5: The converse of the above proposition is not true in general i.e) τ_2 - closed is not A is $(\tau_1, \tau_2)^* - Q^*$ closed. The next example supports our claim.

Example 3.7: In example 3.1, X is not A is $(\tau_1, \tau_2)^* - Q^*$ closed.

Remark 3.6: $\tau_1 \tau_2$ - regular closed sets and $(\tau_1, \tau_2)^* - Q^*$ closed sets are independent of each other in general. It is proved in the following example.

Example 3.8: $X = \{a, b, c\}$, $\tau_1 = \{\phi, X, \{b, c\}\}$, $\tau_2 = \{\phi, X, \{a\}, \{b, c\}\}$. Then $\{a\}$ is $\tau_1 \tau_2$ - regular closed but not $(\tau_1, \tau_2)^* - Q^*$ closed set.

Result 3.1: From the above results we conclude the following



Theorem 3.1: If A is $(\tau_1, \tau_2)^* - Q^*$ closed then A is nowhere dense.

Proof: Since A is $(\tau_1, \tau_2)^* - Q^*$ closed, we have $\tau_1\tau_2 - \text{int} (A) = \phi$ and A is $\tau_1\tau_2$ - closed.

Therefore,

$$\tau_1\tau_2 - \text{cl} [\tau_1\tau_2 - \text{int} (A)] = \phi .$$

Hence A is nowhere dense.

Theorem 3.2: Every $(\tau_1, \tau_2)^* - Q^*$ closed set is $(\tau_1, \tau_2)^* - \delta$ set.

Proof: Let A be $(\tau_1, \tau_2)^* - Q^*$ closed.

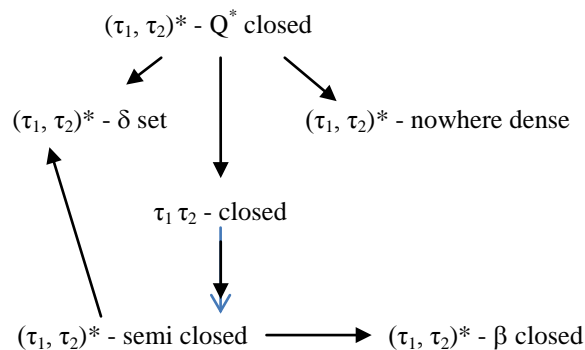
Then $\tau_1\tau_2 - \text{int} (A) = \phi$ and A is $\tau_1\tau_2$ - closed.

Consequently,

$$\begin{aligned} \tau_1\tau_2 - \text{int} \{ \tau_1\tau_2 - \text{cl} [\tau_1\tau_2 - \text{int} (A)] \} &= \tau_1\tau_2 - \text{int} \{ \tau_1\tau_2 - \text{cl} (\phi) \} \\ &= \tau_1\tau_2 - \text{int} (\phi) \\ &= \phi . \end{aligned}$$

Therefore, A is $(\tau_1, \tau_2)^* - \delta$ set .

Result 3.2: The relationship between $(\tau_1, \tau_2)^* - Q^*$ closed sets and other generalizations is given by the following figure



4. $(\tau_1, \tau_2)^* - Q^*$ OPEN SETS

Definition 4.1: A subset A of a bitopological spaces (X, τ_1, τ_2) is called $(\tau_1, \tau_2)^* - Q^*$ open if $X - A$ is $(\tau_1, \tau_2)^* - Q^*$ closed in X .

Example 4.1: In example 3.1, X, {c}, {b, c} are $(\tau_1, \tau_2)^* - Q^*$ open.

Remark 4.1: Since every $(\tau_1, \tau_2)^* - Q^*$ open set is τ_2 - open and every τ_2 - open set is $\tau_1\tau_2$ -g open, $\tau_1\tau_2$ - sg open, $\tau_1\tau_2$ - gs we have every $(\tau_1, \tau_2)^* - Q^*$ open set is $\tau_1\tau_2$ - g open, $\tau_1\tau_2$ - sg open and $\tau_1\tau_2$ - gs open . But the converse need not be true in general. The following example supports our claim.

Example 4.2: In example 3.1, {a, b} $\tau_1\tau_2$ - is g open, $\tau_1\tau_2$ - sg open and $\tau_1\tau_2$ -gs open but not $(\tau_1, \tau_2)^* - Q^*$ open.

Remark 4.2: Since every $(\tau_1, \tau_2)^* - Q^*$ open is $\tau_1\tau_2$ - open and $\tau_1\tau_2$ - open set is $(\tau_1, \tau_2)^* - \text{gopen}$, $(\tau_1, \tau_2)^* - \text{s g open}$, we have $(\tau_1, \tau_2)^* - Q^*$ open is $(\tau_1, \tau_2)^* - \text{gopen}$, $(\tau_1, \tau_2)^* - \text{s g open}$. But the converse is not true in general. The following example supports our claim.

Example 4.3: In example 3.2, {a} is $(\tau_1, \tau_2)^* - \text{sg open}$ but not $(\tau_1, \tau_2)^* - Q^*$ open.

Example 4.4: In example 3.3, {a, b} is $(\tau_1, \tau_2)^* - \text{g open}$ but not $(\tau_1, \tau_2)^* - Q^*$ open.

Theorem 4.1: A set A of a bitopological space (X, τ_1, τ_2) is $(\tau_1, \tau_2)^* - Q^*$ open if and only if $\tau_1\tau_2 - \text{cl} (A) = X$ and A is $\tau_1\tau_2$ - open .

Proof: Necessity: Suppose that A is $(\tau_1, \tau_2)^* - Q^*$ open.

Then A^c is $(\tau_1, \tau_2)^* - Q^*$ closed.

Therefore,

$$\tau_1\tau_2 - \text{int} (A^c) = [\tau_1\tau_2 - \text{cl} (A)]^c = \phi \text{ and } A^c \text{ is } \tau_1\tau_2\text{- closed.}$$

Consequently,

$$\tau_1\tau_2 - \text{cl} (A) = X \text{ and } A \text{ is } \tau_1\tau_2\text{- open.}$$

Sufficiency: Suppose that $\tau_1\tau_2 - \text{cl} (A) = X$ and A is $\tau_1\tau_2$ - open.

$$\text{Then } [\tau_1\tau_2 - \text{cl} (A)]^c = \tau_1\tau_2 - \text{int} (A^c) = \phi \text{ and } A^c \text{ is } \tau_1\tau_2\text{- closed.}$$

Consequently,

$$A^c \text{ is } (\tau_1, \tau_2)^* - Q^* \text{ closed.}$$

This completes the proof.

Corollary 4.1: A set A of a bitopological space (X, τ_1, τ_2) is $(\tau_1, \tau_2)^* - Q^*$ open if and only if A is $\tau_1\tau_2$ - dense and $\tau_1\tau_2$ - open.

Theorem 4.2: If A and B are $(\tau_1, \tau_2)^* - Q^*$ open sets then so is $A \cap B$.

Proof: Suppose that A and B are $(\tau_1, \tau_2)^* - Q^*$ open sets.

Then A^c and B^c are $(\tau_1, \tau_2)^* - Q^*$ closed sets.

Therefore,

$$A^c \cup B^c \text{ is } (\tau_1, \tau_2)^* - Q^* \text{ closed sets.}$$

$$\text{But } A^c \cup B^c = (A \cap B)^c .$$

Hence $A \cap B$ $(\tau_1, \tau_2)^* - Q^*$ open.

Theorem 4.3:

- i) X is not $(\tau_1, \tau_2)^* - Q^*$ - closed.
- ii) ϕ is $(\tau_1, \tau_2)^* - Q^*$ - closed.
- iii) X is $(\tau_1, \tau_2)^* - Q^*$ - open
- iv) X is not $(\tau_1, \tau_2)^* - Q^*$ - open.

Remark 4.3: It is obvious that every $(\tau_1, \tau_2)^* - Q^*$ - open set is τ_2 - open, but the converse is not true in general. The following example supports our claim.

Example 4.5: In example 3.1, ϕ is τ_2 - open but not $(\tau_1, \tau_2)^* - Q^*$ - open set.

Remark 4.4: Every $(\tau_1, \tau_2)^* - Q^*$ open is $(\tau_1, \tau_2)^* -$ semi open. But the converse need not be true.

The following example supports our claim.

Example 4.6: In example 3.2, $\{b, c\}$ is $(\tau_1, \tau_2)^* -$ semi open but not $(\tau_1, \tau_2)^* - Q^*$ open.

Theorem 4.4:- If $B \subset A \subset X$, where A is $(\tau_1, \tau_2)^* - Q^*$ open and B is $(\tau_1, \tau_2)^* - Q^*$ open in A then B is $(\tau_1, \tau_2)^* - Q^*$ open in X .

Proof: Since B is $\tau_1\tau_2$ - open in A , A is $\tau_1\tau_2$ - open in X and B is $\tau_1\tau_2$ - open in X .

We claim that $\tau_1\tau_2 - \text{cl} (B) = X$.

Let U be any $\tau_1\tau_2$ - open set.

Since $\tau_1\tau_2$ -cl (B) is A, $(U \cap A) \cap B \neq \phi$.

Then

$$(U \cap A) \cap B \neq \phi .$$

Hence

$$\tau_1\tau_2$$
-cl (B) = X.

Therefore,

$$B \text{ is } (\tau_1, \tau_2)^* - Q^* \text{ open in } X .$$

Theorem 4.5: If A and B are $\tau_1\tau_2$ -open sets with $A \cap B = \phi$ then A and B are not $(\tau_1, \tau_2)^* - Q^*$ open.

Proof: Since $A \cap B = \phi$, the points of B cannot be limit points of A.

Then $\tau_1\tau_2$ -cl (A) \neq X.

Hence A is not $(\tau_1, \tau_2)^* - Q^*$ open.

Similarly,

B is not $(\tau_1, \tau_2)^* - Q^*$ open.

Theorem 4.6 - Let (X, τ_1, τ_2) be a hyper connected bitopological space. Let $A \subset X$. If A is $\tau_1\tau_2$ -open then A is $(\tau_1, \tau_2)^* - Q^*$ open in X.

Proof: It is enough to prove that A is $\tau_1\tau_2$ -dense.

Suppose that $\tau_1\tau_2$ -cl (A) \neq X.

Then $[\tau_1\tau_2$ -cl (A)]^c $\neq \phi$.

Consequently,

$$A \cap [\tau_1\tau_2$$
-cl (A)]^c $\neq \phi$.

This is a contradiction to the fact that (X, τ_1, τ_2) is a hyper connected bitopological space.

Hence A is $\tau_1\tau_2$ -dense.

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