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Regular Sets in Generalised Topological Space

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ABSTRACT: We define and study regular and locally closed sets in generalized topological spaces.

KEYWORDS: Generalized topological spaces, Strong space, Regular set, extremely disconnected space.

I. INTRODUCTION

In 1975, A. Csaszar defined and studied regular sets in generalized topological spaces. In Section 2, we define various kinds of regular sets and discuss their properties. Section 3 is devoted to the study of locally closed sets in generalized topological spaces.

II. PRELIMINARIES

We recall some notion of the essential concepts needed in the following. A nonempty family λ of subsets of a set X is said to be a generalized topology [3] if $\emptyset \in \lambda$ and an arbitrary union of elements of λ is again in λ . The pair (X, λ) is called a generalized topological space and elements of λ are called λ -open sets. $A \subset X$ is λ -closed if $X - A$ is λ -open. By a space (X, λ) , we always mean a generalized topological space. If $X \in \lambda$, (X, λ) is called a strong generalized topological space. In a space (X, λ) , if λ is closed under finite intersection, (X, λ) is called a quasi-topological space [4]. Clearly, every strong quasi topological space is a topological space. For $A \subset X$, $C_\lambda(A)$ is the smallest λ -closed set containing A and $i_\lambda(A)$ is the largest λ -open set contained in A . Moreover, $X - C_\lambda(A) = i_\lambda(X - A)$ or every subset A of X .

Lemma 2.1. If (X, λ) is a quasi-topological space, then the following hold. (a) If A and B are λ -open sets, then $A \cap B$ is a λ -open set [7, Theorem 3.1].

(b) $i_\lambda(A \cap B) = i_\lambda(A) \cap i_\lambda(B)$ for every subsets A and B of X [5, Theorem 3.2].

(c) $C_\lambda(A \cup B) = C_\lambda(A) \cup C_\lambda(B)$ for every subsets A and B of X [7, Theorem 3.3(b)].

Lemma 2.2. If (X, λ) is a quasi-topological space, then the following hold. (a) $i_\lambda(A \cup F) \subset i_\lambda(A) \cup F$ where F is λ -closed [8, Theorem 2.1(c)]. (b) $C_\lambda(A \cup F) = C_\lambda(A) \cup F$ where F is λ -closed [8, Theorem 2.1(d)].

III. REGULAR SETS IN GTS

Let (X, λ) be a space and $A \subset X$. Let $\alpha, \sigma, \pi, \beta$ be defined as in [3]. A is said to be α -regular (resp. σ -regular, π -regular, β -regular) if $A = i_\lambda C_\lambda i_\lambda(A)$ (resp. $A = C_\lambda i_\lambda(A)$, $A = i_\lambda C_\lambda(A)$, $A = C_\lambda i_\lambda C_\lambda(A)$). Clearly, if $\xi \in \{\alpha, \sigma, \pi, \beta\}$ and $A \subset X$, then A is ξ -regular implies that A is ξ -open. A subset A of X is said to be ξ -clopen if A is both ξ -open and ξ -closed. The following Theorem 2.1. gives the relation between π -regular sets and α -regular sets. Theorem 2.2 gives the relation between σ -regular sets and β -regular sets.

Theorem 3.1. Let (X, λ) be a space and $A \subset X$. Then A is a π -regular set if and only if A is an α -regular set.

Proof. Suppose that A is a π -regular set. Then $A = i_\lambda C_\lambda(A)$ which implies that A is μ -open and so $A = i_\lambda C_\lambda i_\lambda(A)$. Therefore, A is an α -regular set. Conversely, suppose A is an α -regular set. Then $A = i_\lambda C_\lambda i_\lambda(A)$. This implies that $i_\lambda C_\lambda(A) = i_\lambda C_\lambda i_\lambda C_\lambda i_\lambda(A) = i_\lambda C_\lambda i_\lambda(A) = A$ and so $A = i_\lambda C_\lambda(A)$. Therefore, A is a π -regular set.

Theorem 3.2. Let (X, λ) be a space and $A \subset X$. Then A is a σ -regular set if and only if A is a β -regular set.

Proof. Suppose that A is a σ -regular set. Then $A = C_\lambda i_\lambda(A)$ and so A is λ -closed. Therefore, $A = C_\lambda i_\lambda(A) = C_\lambda i_\lambda C_\lambda(A)$ which implies that A is a β -regular set. Conversely, suppose that A is a β -regular set. Since A is a λ -closed set, we have $A = C_\lambda i_\lambda C_\lambda(A) = C_\lambda i_\lambda(A)$. Therefore A is a σ -regular set.

The following theorem characterizes σ -regular sets and σ -clopen sets of generalized topological spaces.



Theorem 3.3. Let (X, λ) be a space and $A \subset X$. Then the following hold.

(a) A is σ -regular if and only if A is σ -open and μ -closed if and only if A is σ -open and π -closed. (b) A is σ -clopen if and only if $A = C_\gamma i_\gamma(A)$.

Proof. (a) If A is γ -regular, then clearly, A is σ -open and λ -closed which implies that A is γ -open and π -closed. Suppose A is γ -open and π -closed. Then $A \subset C_\lambda i_\lambda(A)$ and $C_\lambda i_\lambda(A) \subset A$. Hence $A = C_\lambda i_\lambda(A)$ which implies that A is σ -regular.

(b) If A is γ -open and γ -closed, then clearly, $A = C_\gamma i_\gamma(A)$. Conversely, suppose $A = C_\gamma i_\gamma(A)$. Then A is γ -closed. Also $A = C_\gamma i_\gamma(A) \subset C_\lambda i_\gamma(A) = C_\lambda i_\lambda(A)$, by Lemma 2.4(f) of [7] and so A is γ -open. Hence A is γ -clopen.

The following theorem characterizes β -regular sets and β -clopen sets of generalized topological spaces.

Theorem 3.4. Let (X, λ) be a space and $A \subset X$. Then the following hold.

(a) A is β -regular if and only if A is β -open and λ -closed if and only if A is β -open and α -closed.

(b) A is β -clopen if and only if $A = C_\beta i_\beta C_\beta(A)$.

Proof. (a) Similar to Theorem 2.3(a).

(b) If A is β -clopen, then clearly, $A = C_\beta i_\beta C_\beta(A)$. Conversely, suppose $A = C_\beta i_\beta C_\beta(A)$. Then A is β -closed. Also, $A \subset C_\lambda i_\beta C_\beta(A) \subset C_\lambda i_\beta C_\lambda(A) \subset C_\lambda i_\lambda C_\lambda(A)$, since $i_\beta(A) \subset A \cap C_\lambda i_\lambda C_\lambda(A)$ by Lemma 1.1 of [2]. Hence A is β open which implies that A is β -clopen.

Let (X, λ) be a space. Let $\xi \in \{\pi, \gamma, \alpha, \beta\}$. X is said to be extremally ξ -disconnected if the ξ -closure of every ξ -open set is ξ -open. The following theorem characterizes π -regular sets and π -clopen sets of generalized topological spaces. Example 2.6 below shows that the condition extremally π -disconnected in Theorem 2.5(b) cannot be dropped.

Theorem 3.5. Let (X, λ) be a space and $A \subset X$. Then the following hold.

(a) A is π -regular if and only if A is π -open and γ -closed.

(b) If (X, λ) is extremally π -disconnected, then A is π -clopen if and only if $A = i_\pi C_\pi(A)$.

Proof. (a) A is π -regular if and only if $A = i_\lambda C_\lambda(A)$ if and only if $A \subset i_\lambda C_\lambda(A)$ and $A \supset i_\lambda C_\lambda(A)$ if and only if A is π -open and A is σ -closed.

(b) If A is π -clopen, then clearly, $A = i_\pi C_\pi(A)$. Conversely, suppose $A = i_\pi C_\pi(A)$. Then A is π -open. Since X is extremally π -disconnected, $C_\pi(A)$ is π -open and so $i_\pi C_\pi(A) = C_\pi(A)$ which implies that $A = C_\pi(A)$. Therefore A is π -closed and hence A is π -clopen.

Example 3.6. Let $X = \{a, b, c\}$ and $\mu = \emptyset, X, \{a\}, \{b\}, \{a, b\}$. Then $\pi(\lambda) = \emptyset, \{a\}, \{b\}, \{a, b\}, X$. Since $\{a\}$ is π -open but $C_\pi \{a\} = \{a, c\}$ is not π -open, (X, λ) is not extremely π -disconnected. But $\{a\} = i_\pi C_\pi \{a\}$ and is not π -clopen.

The following theorem shows that the intersection of two π -regular sets is again a π -regular set. Corollary 3.8 follows from Theorem 3.1. Example 3.9 below shows that the intersection of γ -regular sets (resp. β -regular sets) need not be a γ -regular (resp. β -regular) set. Example 3.10 below shows that the intersection of two π -clopen sets is not a π -clopen set even if the generalized topology is strong and extremally disconnected.

Theorem 3.7. Let (X, λ) be a quasi-topological space and $A, B \subset X$. Then, the intersection of two π -regular sets is a π -regular set.

Proof. Let A and B be two π -regular sets. Then $A = i_\lambda C_\lambda(A)$ and $B = i_\lambda C_\lambda(B)$. Then A and B are μ -open and so $A \cap B$ is μ -open, since (X, λ) is a quasi-topological space. Therefore, $A \cap B = i_\lambda(A \cap B) \subset C_\lambda i_\lambda(A \cap B)$ and so $A \cap B \subset i_\lambda C_\lambda i_\lambda(A \cap B) \subset i_\lambda C_\lambda(A \cap B)$. Again, $i_\lambda C_\lambda(A \cap B) \subset i_\lambda C_\lambda(A) \cap i_\lambda C_\lambda(B) = A \cap B$. Thus $A \cap B = i_\lambda C_\lambda(A \cap B)$ which implies that $A \cap B$ is π -regular.

Corollary 3.8. Let (X, λ) be a quasi-topological space and $A \subset X$. Then, the intersection of two α -regular sets is an α -regular set.

Example 3.9. Let $X = \mathbb{R}$, with the usual topology. If $A = [-1, 0]$ and $B = [0, 1]$, then A and B are σ -regular but $A \cap B = \{0\}$ is not σ -regular. By Theorem 3.2, it follows that the intersection of two β -regular sets need not be a β -regular set.

Example 3.10. Let $X = \{1, 2, 3, \dots, n\}$ and $\mu = \{\emptyset, X\} \cup A \subset X \mid A = X - \{i\}$ for some $i \in X$. Then (X, λ) is not a quasi-topological space such that $\pi = \{\emptyset, X\} \cup A \subset X \mid |A| > 1$. If $A = \{1, 2\}$ and $B = \{1, 3\}$, then A and B are π -clopen sets but $A \cap B = \{1\}$ is not a π -clopen set.



IV. MORE ON λ -LOCALLY λ -REGULAR SETS

Let (X, λ) be a generalized topological space, and $\xi \in \{\mu, \alpha, \sigma, \pi, \beta\}$. A subset A of a generalized topological space (X, λ) is said to be μ -locally ξ -regular [6] if $A = U \cap S$ where U is μ -open and S is ξ -regular. A is said to be μ -locally ξ -closed if $A = U \cap S$ where U is μ -open and S is ξ -closed. In this section, we discuss the properties of μ -locally ξ -regular and μ -locally ξ -closed sets.

Theorem 4.1. Let (X, λ) be a space and $A \subset X$. If (X, λ) is strong and A is ξ -closed, then A is μ -locally ξ -closed.

Proof. If (X, λ) is strong, then X is μ -open and so $A = X \cap A$, which implies that A is μ -locally ξ -closed.

Theorem 4.2. Let (X, λ) be a space and $A \subset X$. Then the following hold.

(a) A is a λ -locally γ -regular set if and only if A is λ -locally β -regular.

(b) A is a λ -locally α -regular set if and only if A is λ -locally π -regular.

Proof. The proof follows from Theorem 3.1 and Theorem 3.2.

It is well known that every γ -closed set is a β -closed set. The following Theorem 4.3 shows that the converse holds for λ -locally γ -closed sets in a quasi-topological space. Example 4.4 below shows that the condition quasi-topological space on the space cannot be dropped.

Theorem 4.3. Let (X, λ) be a quasi-topological space and $A \subset X$. If A is a β -closed set and a λ -locally γ -closed set, then A is a γ -closed set.

Proof. Suppose that A is β -closed and λ -locally γ -closed. Then $i_\lambda c_\lambda i_\lambda(A) \subset A = U \cap S$ where U is λ -open and S is γ -closed. Therefore, $i_\lambda c_\lambda(S) \subset S$ which implies that $i_\lambda c_\lambda(S) \subset i_\lambda(S)$. Now $i_\lambda c_\lambda(A) = i_\lambda c_\lambda(U \cap S) \subset i_\lambda c_\lambda(U) \cap i_\lambda c_\lambda(S) \subset i_\lambda c_\lambda(U) \cap i_\lambda(S) = i_\lambda(c_\lambda(U) \cap i_\lambda(S))$ by lemma 2.1(b). Therefore, $i_\lambda c_\lambda(A) \subset i_\lambda c_\lambda((U) \cap i_\lambda(S)) = i_\lambda c_\lambda i_\lambda(U \cap S) \subset A$. Therefore, A is γ -closed.

Example 4.4. Let $X = \{p, q, r\}$ and $\lambda = \{\emptyset, \{p\}, \{q, r\}, \{p, r\}, \{p, q, r\}\}$. Then (X, λ) is not a quasi-topological space and the λ -closed sets are $\{\emptyset, \{q, r\}, \{p\}, \{q\}, \{p, q, r\}\}$. Now $\{r\} = \{p, r\} \cap \{q, r\}$ where $\{p, r\}$ is λ -open and $\{q, r\}$ is γ -closed and so $\{r\}$ is λ -locally γ -closed. Also, $\{r\}$ is β -closed, since $i_\lambda c_\lambda i_\lambda(\{r\}) = i_\lambda c_\lambda(\emptyset) \subset \{r\}$. Hence $\{r\}$ is both β -closed and λ -locally γ -closed, but $\{r\}$ is not γ -closed, since $i_\lambda c_\lambda \{r\} = \{q, r\}$ is not a subset of $\{r\}$.

The following Theorem 4.5 gives a characterization of λ -locally γ -regular sets and Example 4.6 shows that the condition quasi-topological space on the space cannot be dropped.

Theorem 4.5. Let (X, λ) be a quasi-topological space and $A \subset X$. Then the following are equivalent.

(a) A is a λ -locally γ -regular set.

(b) $A = U \cap c_\lambda i_\lambda(A)$ for some λ -open set U .

(c) A is γ -open and λ -locally λ -closed.

(d) A is β -open and λ -locally λ -closed.

Proof. (a) \rightarrow (b). Suppose that A is a λ -locally γ -regular set. Then $A = U \cap S$ where U is λ -open and $S = c_\lambda i_\lambda(S)$. $A \subset S$ implies that $c_\lambda i_\lambda(A) \subset c_\lambda i_\lambda(S) = S$ which implies that $S \cap c_\lambda i_\lambda(A) = c_\lambda i_\lambda(A)$. Now $A = U \cap S = U \cap c_\lambda i_\lambda(S) \subset c_\lambda(U \cap i_\lambda(S))$, since U is λ -open and so $A \subset c_\lambda(i_\lambda(U) \cap i_\lambda(S)) \subset c_\lambda i_\lambda(U \cap S) = c_\lambda i_\lambda(A)$. Therefore, $A = A \cap c_\lambda i_\lambda(A) = U \cap S \cap c_\lambda i_\lambda(A) = U \cap c_\lambda i_\lambda(A)$.

(b) \rightarrow (a). Suppose that $A = U \cap c_\lambda i_\lambda(A)$ for some λ -open set U . Let $G = c_\lambda i_\lambda(A)$. Then $c_\lambda i_\lambda(G) = c_\lambda i_\lambda c_\lambda i_\lambda(A) = c_\lambda i_\lambda(A) = G$ and so G is a γ -regular set. Therefore, A is a λ -locally γ -regular set.

(a) \rightarrow (c). Suppose that A is λ -locally γ -regular. Then $A = U \cap S$ where U is λ -open and S is γ -regular. By Theorem 3.3, S is λ -closed and so A is λ -locally λ -closed. $A = U \cap S = U \cap c_\lambda i_\lambda(S) \subset c_\lambda(U \cap i_\lambda(S)) \subset c_\lambda i_\lambda(U \cap S) = c_\lambda i_\lambda(A)$. Therefore, A is γ -open.

(c) \rightarrow (d). Since $\gamma(\lambda) \subset \beta(\lambda)$, the proof follows.

(d) \rightarrow (a). Assume that A is β -open and λ -locally λ -closed. Then $A = U \cap S$ where U is λ -open and S is λ -closed. Since A is β -open, $A \subset c_\lambda i_\lambda c_\lambda(A)$ which implies that $c_\lambda(A) \subset c_\lambda i_\lambda c_\lambda(A) \subset c_\lambda c_\lambda(A) = c_\lambda(A)$. Therefore, $c_\lambda(A) = c_\lambda i_\lambda c_\lambda(A)$. $A \subset S$ implies that $c_\lambda(A) \subset c_\lambda(S) = S$, since S is λ -closed. Therefore, $U \cap c_\lambda(A) \subset U \cap S = A \subset U \cap c_\lambda(A)$, since $A \subset U$. Hence, $A = U \cap c_\lambda(A) = U \cap c_\lambda i_\lambda c_\lambda(A)$. If $S = c_\lambda i_\lambda c_\lambda(A)$, then $c_\lambda i_\lambda(S) = c_\lambda i_\lambda c_\lambda i_\lambda c_\lambda(A) = c_\lambda i_\lambda c_\lambda(A) = S$. Therefore, S is γ -regular and so A is λ -locally γ -regular.



Example 4.6. (a) \rightarrow (b).

Let $X = \{p, q, r, s, t\}$ be
 $\lambda = \emptyset, X, \{p, s\}, \{s, t\}, \{p, t\}, \{p, q, r\}, \{p, q, r, s\}, \{p, q, r, t\}, \{p, s, t\}, \{q, r\}, \{q, r, s, t\}$. Then $\{p, s\} \cap \{s, t\} = \{s\} \in \lambda$ and so (X, λ) is not a quasi-topological space. The family of all λ -closed sets is $\emptyset, X, \{q, r, t\}, \{p, q, r\}, \{q, r, s\}, \{s, t\}, \{p\}, \{t\}, \{s\}, \{q, r\}, \{p, s, t\}$. Now $\{p, q, r\} = c_\lambda i_\lambda \{p, q, r\}$ and so $\{p, q, r\}$ is γ -regular. Since $\{p\} = \{p, s\} \cap \{p, q, r\}$, where $\{p, s\}$ is λ -open and $\{p, q, r\}$ is γ -regular, $\{p\}$ is λ -locally γ -regular. Again, $c_\lambda i_\lambda (\{p\}) = c_\lambda(\emptyset) = \emptyset$, implies that $U \cap c_\lambda i_\lambda (\{p\}) = \emptyset = \{p\}$ for every λ -open set U and so (a) \rightarrow (b). The following theorem gives a characterization of λ -locally π -regular sets.

Theorem 4.7. Let (X, λ) be a quasi-topological space. Then the following are equivalent.

- (a) A is λ -locally π -regular.
- (b) A is π -open and λ -locally γ -closed.

Proof.

(a) \rightarrow (b). Suppose that A is λ -locally π -regular. Then $A = U \cap S$ where U is λ -open and S is π -regular. By Theorem 4.5, S is γ -closed. Therefore, A is λ -locally γ -closed. Now $A = i_\lambda(U) \cap i_\lambda c_\lambda(S) = i_\lambda(U \cap c_\lambda(S)) \subset i_\lambda c_\lambda(U \cap S)$ and so $A \subset i_\lambda c_\lambda(A)$. Therefore, A is π -open.

(b) \rightarrow (a). Suppose that A is π -open and λ -locally γ -closed. Then $A = U \cap S$ where U is λ -open and S is γ -closed. Since A is π -open, $U \cap S \subset i_\lambda c_\lambda(U \cap S)$ which implies that $A = U \cap S = U \cap U \cap S \subset U \cap i_\lambda c_\lambda(U \cap S) \subset U \cap i_\lambda c_\lambda(U) \cap i_\lambda c_\lambda(S) \subset U \cap i_\lambda c_\lambda(S)$, since U is π -open. Then, $U \cap i_\lambda c_\lambda(S) \subset U \cap S = A$, since S is γ -closed. Therefore, $A = U \cap i_\lambda c_\lambda(S)$. Take $B = i_\lambda c_\lambda(S)$. Then $i_\lambda c_\lambda(B) = i_\lambda c_\lambda i_\lambda c_\lambda(S) = i_\lambda c_\lambda(B) = B$. Therefore, B is π -regular.

The following theorem gives various characterizations of λ -open sets in terms of λ -locally λ -closed, λ -locally γ -closed and λ -locally γ -regular sets.

Theorem 4.8. Let (X, λ) be a quasi-topological space and $A \subset X$. Then the following are equivalent.

- (a) A is λ -open.
- (b) A is α -open and λ -locally γ -regular.
- (c) A is α -open and λ -locally λ -closed.
- (d) A is π -open and λ -locally λ -closed.
- (e) A is π -open and λ -locally γ -closed.
- (f) A is π -open and A is λ -locally γ -regular.

oof. (a) \rightarrow (b). Suppose that A is λ -open. Then A is α -open. Since

$X = c_\lambda i_\lambda(X), A = A \cap X$ and so A is λ -locally γ -regular.

(b) \rightarrow (a). Suppose that A is α -open and λ -locally γ -regular. Then $A \subset i_\lambda c_\lambda i_\lambda(A)$ and $A = U \cap S$ where U is λ -open and $S = c_\lambda i_\lambda(S)$. Now $U \cap S \subset i_\lambda c_\lambda i_\lambda(U \cap S) \subset i_\lambda c_\lambda i_\lambda(U) \cap i_\lambda c_\lambda i_\lambda(S) = i_\lambda c_\lambda(U) \cap i_\lambda(S)$ and so $U \cap S = U \cap U \cap S \subset U \cap i_\lambda c_\lambda(U) \cap i_\lambda(S) \subset U \cap i_\lambda(S)$. Therefore, $A \subset U \cap i_\lambda(S) \subset U \cap S = A$. Hence $A = U \cap i_\lambda(S)$ which implies that A is λ -open as X is quasi-topological.

(a) \rightarrow (c). Suppose that A is λ -open. Then A is α -open. Since X is λ -closed, we have $A = A \cap X$ and so A is λ -locally λ -closed.

(c) \rightarrow (d). The proof follows from the fact that $\alpha(\lambda) \subset \pi(\lambda)$.

(d) \rightarrow (e). Suppose that A is π -open and λ -locally λ -closed. Then $A = U \cap S$ where U is λ -open and $S = c_\lambda(S)$. Since $i_\lambda c_\lambda(S) \subset c_\lambda(S) = S$, S is γ -closed. Therefore, A is λ -locally γ -closed.

(e) \rightarrow (a). Suppose that A is π -open and λ -locally γ -closed. Then $A = U \cap S$ where U is λ -open and $i_\lambda c_\lambda(S) \subset S$ and $A \subset i_\lambda c_\lambda(A)$. $U \cap S \subset i_\lambda c_\lambda(U \cap S) \subset i_\lambda c_\lambda(U) \cap i_\lambda c_\lambda(S) \subset i_\lambda c_\lambda(U) \cap i_\lambda(S)$. Now $U \cap S = U \cap U \cap S \subset i_\lambda c_\lambda(U) \cap i_\lambda(S) \cap (U) \subset U \cap i_\lambda(S) \subset U \cap S$. Hence $A = U \cap i_\lambda(S)$. Therefore, A is λ -open.

(b) \rightarrow (f). The proof follows from the fact that $\alpha(\lambda) \subset \pi(\lambda)$.

(f) \rightarrow (d). Suppose that A is π -open and λ -locally γ -regular. Then $A = U \cap S$ where U is λ -open and S is γ -regular. By Theorem 3.3, S is λ -closed.

Therefore, A is λ -locally λ -closed.



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