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ON REGULAR SEMI GENERALIZED CLOSED SETS

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Abstract. In this paper we introduce the concept of rsg-closed sets and investigate some of its properties in topological spaces. We also define an rsg-regular space and give some of its fundamental properties.

1. Introduction

In 1970, Levine [12] introduced the notion of generalized closed sets in topological spaces. In 1987, Battacharyya and Lahiri [2] used semi-open sets [11] to define the notion of semi-generalized closed sets. In 1990, Arya and Nour [1] introduced the concept of generalized semi-closed sets. The notion of s*g-closed sets was introduced by Rao and Joseph [16]. In this paper, we investigate many properties of rsg-closed sets which are situated between s*g-closed sets and rg-closed sets. We also show that arbitrary intersection of rsg-closed sets in a locally indiscrete space is rsg-closed. Moreover rsg-regular space is defind and some of its basic properties are investigated.

2. Preliminary

Throughout this paper, (X, τ) (or simply X) will always represent a topological space on which no separation axioms are assumed, unless otherwise mentioned. When A is a subset of X, cl(A) and Int(A) denote the closure and interior of a set A, respectively. A subset A of a space X is said to be semi-open [11] if there exists an open set U such that $U \subset A \subset cl(U)$. The complement of a semi-open set is said to be semi-closed. A subset A of a topological space X is said to be semi-regular [6] if it is both semi-open and semi-closed. In [6], it is pointed out that a set is semi-regular if and only if there exists a regular open set U such that $U \subset A \subset cl(U)$. Cameron [4] called semi regular sets regular semi-open.

Definition 2.1. *A subset A of a space X is said to be*

(1): *generalized closed* [12] *(briefly, g-closed) if $cl(A) \subset U$ whenever $A \subset U$ and U is open in X. The complement of a g-closed set is said to be g-open;*
(2): *s*g-closed* [16] *if $cl(A) \subset G$ whenever $A \subset G$ and G is semi-open in X. The complement of an s*g-closed set is said to be s*g-open;*
(3): *regular generalized closed* [15] *(briefly, rg-closed) if $cl(A) \subset U$ whenever $A \subset U$ and U is regular-open in X. The complement of an rg-closed set is said to be rg-open;*
(4): *semi-generalized closed* [3] *(briefly, sg-closed) if $scl(A) \subset U$ whenever $A \subset U$ and U is semi-open in X.*

3. RSG-CLOSED SETS

Definition 3.1. *A subset A of a space X is said to be*

- **(1):** *regular semi generalized closed (briefly, rsg-closed) if* $cl(A) \subset G$ *whenever* $G \subset A$ *for every semi-regular set G in X;*
- **(2):** *regular semi generalized open (briefly, rsg-open) if* $X - A$ *is rsg-closed.*

Theorem 3.2. *A subset A of a space* (X, τ) *is rsg-open if and only if* $G \subset Int(A)$ *whenever* $G \subset A$ *for every semi-regular set G in X.*

Proof. Let A be an rsg- open set and G a semi-regular set such that $G \subset A$. Then $X - A$ is rsg -closed and $X - A \subset X - G$. Since $X - G$ is semi-regular in X, $cl(X - A) \subset X - G$ and hence $X - Int(A) \subset X - G$. Therefore, $G \subset Int(A)$.

Conversely, let $G \subset Int(A)$ whenever $G \subset A$ and G is semi-regular in X. This implies that $X - Int(A) = cl(X - A) \subset X - G$ whenever $X - A \subset X - G$ and X-G is semi-regular in X. This proves that X-A is rsg -closed in X and hence A is rsg-open in X.

Remark 3.3. **(1):** *Every closed set is rsg-closed;*

- **(2):** *Every open set is rsg-open;*
- **(3):** *Semi open sets and rsg- open sets are independent of each other.*

Example 3.4. *Let* $X = \{a, b, c, d\}$ *and let*

- **(1):** $\tau = \{\phi, \{a\}, \{c\}, \{d\}, \{a, c\}, \{a, d\}, \{c, d\}, \{a, c, d\}, X\}$. *Then* $\{a, b, c\}$ *is semi open but not rsg-open, similarly let*
- **(2):** $\tau = \{\phi, \{a\}, \{c, d\}, \{a, c, d\}, \{b, c, d\}, X\}$. *Then* $\{b\}$ *is rsg-open but not semi open.*

Example 3.5. *The union of two rsg-open sets is generally not rsg-open. To see this in Example 3.4(1),* $\{a\}$ *and* $\{b\}$ *are rsg-open sets in X but* $\{a, b\}$ *is not rsg-open. Therefore, the intersection of two rsg-closed sets is generally not rsg-closed.*

Theorem 3.6. *If A and B are rsg-open, then* $A \cap B$ *is rsg-open.*

Proof. If $G \subset A \cap B$ and G is semi-regular, then $G \subset Int(A)$ and $G \subset Int(B)$ and hence $G \subset Int(A) \cap Int(B) = Int(A \cap B)$. By Theorem 3.2, $A \cap B$ is rsg-open.

Theorem 3.7. *The union of two rsg-closed sets is rsg-closed.*

Proof. This is an immediate consequence of Theorem 3.6.

Diagram

$$
\begin{array}{ccccc}
\text{closed} & \longrightarrow & \text{s*g-closed} & \longrightarrow & \text{g-closed} \\
 & & \searrow & & \searrow \\
 & & \text{rsg-closed} & \longrightarrow & \text{rg-closed}
\end{array}
$$

Remark 3.8. *In Example 3.4(1),* $\{a, c, d\}$ *is rsg- closed but it is neither g-closed nor sg-closed.* $\{c, d\}$ *is sg-closed but not rsg-closed. Let* $X = \{a, b, c, d\}$ *and let* $\tau = \{\phi, \{a\}, \{b\}, \{a, b\}, X\}$, *then* $\{c\}$ *is g-closed but not rsg-closed.*

Remark 3.9. *By Remark 3.8, we have*

- **(1):** *rsg-closedness and g-closedness are independent of each other.*
- **(2):** *rsg-closedness and sg-closedness are also independent of each other.*

Theorem 3.10. *If a set A is rsg-closed, then* $cl(A) - A$ *contains no non empty semi-regular set.*

Proof. Let F be a semi-regular subset of $cl(A)-A$. Then $A \subset X-F$ and since A is rsg-closed and $X-F$ is semi-regular, we have $cl(A) \subset X-F$ or $F \subset X-cl(A)$. Thus $F \subset cl(A) \cap (X-cl(A)) = \phi$. Therefore F is empty.

Theorem 3.11. *If A is an rsg-closed subset of X, then $cl(A)-A$ is rsg-open.*

Proof. Let A be an rsg-closed subset of X and G be a semi-regular subset of X such that $G \subset cl(A)-A$. By Theorem 3.10, $G = \phi$ and thus $G \subset Int[cl(A)-A]$. By Theorem 3.2, $cl(A)-A$ is an rsg-open set.

Definition 3.12. *A subset A of a space X is said to be preopen* [14] *if $A \subset Int(cl(A))$.*

Lemma 3.13. *(Dorsett* [8]*). Let A be a preopen set in a space (X,τ), then $SR(A,\tau_A) = SR(X,\tau) \cap A$, where $SR(X,\tau)$ denotes the family of all semi-regular sets of (X,τ).*

Definition 3.14. *A subset B of a space X is said to be rsg-closed relative to A if $cl_A(B) \subset G$ whenever $B \subset G$ for every semi-regular set G in A.*

Theorem 3.15. *Let $B \subset A \subset X$ and X be a space. If B is an rsg-closed set relative to A and A is open and s*g-closed in X, then B is rsg-closed relative to X.*

Proof. Let $B \subset G$ and suppose that G is semi-regular in X. Then $B \subset A \cap G$. Therefore $cl_A(B) \subset A \cap G$ since by Lemma 3.13, $A \cap G$ is semi-regular in A. It follows that $A \cap cl_X(B) \subset A \cap G$ or $A \subset G \cup (X - cl_X(B))$. Since A is s*g-closed, $cl_X(A) \subset G \cup (X - cl_X(B))$ or $cl_X(B) \subset G$. This proves that B is rsg-closed relative to X.

Corollary 3.16. *Let A be an open and s*g-closed subset of the space X and F be a closed subset of X. Then $A \cap F$ is an rsg-closed set.*

Proof. $A \cap F$ is closed in A and hence rsg-closed in A. By Theorem 3.15, $A \cap F$ is rsg-closed relative to X.

Theorem 3.17. *Let $B \subset A \subset X$ and suppose that B is rsg-closed in X and A is pre-open in X. Then B is rsg-closed relative to A.*

Proof. Let $B \subset A \cap G$ and suppose that G is semi-regular in X then by Lemma 3.13, $A \cap G$ is semi-regular in A. Now $B \subset G$ implies that $cl_A(B) \subset G$. It follows that $A \cap cl_X(B) \subset A \cap G$. This gives $cl_A(B) \subset A \cap G$. This proves that B is rsg-closed relative to A.

Corollary 3.18. *Let $B \subset A \subset X$ where A is open and s*g-closed. Then B is rsg-closed relative to A if and only if B is rsg-closed in X.*

Proof. This is an immediate consequence of Theorems 3.15 and 3.17.

Theorem 3.19. *If B is a subset of a space X such that $A \subset B \subset cl(A)$ and A is an rsg-closed set in X, then B is also rsg-closed in X.*

Proof. Let G be a semi-regular set containing B, then $A \subset G$. Since A is rsg-closed, therefore $cl(A) \subset G$. This gives $cl(B) \subset G$. Hence B is rsg-closed in X.

Corollary 3.20. *If B is a subset of a space X such that $Int(A) \subset B \subset A$, where A is an rsg-open set in the space X, then B is also rsg-open in X.*

Proof. Let F be any semi-regular set contained in B. Then $F \subset A$. Since A is rsg-open, therefore $F \subset Int(A)$. This gives $F \subset Int(B)$. Hence B is rsg-open.

Definition 3.21. *A space X is said to be locally indiscrete* [7] *if every open set in it is closed.*

Theorem 3.22. *In a locally indiscrete space X, a subset A is rsg-open in X if and only if $G = X$ whenever G is semi-regular and $Int(A) \cup (X - A) \subset G$.*

Proof. Necessity. Suppose that G is semi-regular and that $Int(A) \cup (X - A) \subset G$. Now $(X - G) \subset cl(X - A) \cap A = cl(X - A) - (X - A)$. Since $(X - G)$ is semi-regular and $(X - A)$ is rsg-closed, by Theorem 3.10 it follows that $(X - G) = \phi$ or $X = G$.

Sufficiency. Suppose that F is a semi-regular set and $F \subset A$. It suffices to show that $F \subset Int(A)$. Now $Int(A) \cup (X - A) \subset Int(A) \cup (X - F)$ and hence $Int(A) \cup (X - F) = X$. It follows that $F \subset Int(A)$.

Theorem 3.23. *If $A \subset Y \subset X$ where A is rsg-open relative to Y and Y is open in X, then A is rsg-open relative to X.*

Proof. Let F be any semi-regular subset of X contained in A. Since Y is open, therefore by Lemma 3.13, F is semi-regular in Y. Since A is rsg-open relative to Y, therefore $F \subset Int_Y(A)$. Since Y is open in X, $F \subset Int_Y(A) = Int_X(A)$. This proves that A is rsg-open in X.

Theorem 3.24. *For each $x \in X$, either $\{x\}$ is semi-regular or $X - \{x\}$ is rsg-closed.*

Proof. If $\{x\}$ is not semi-regular, then the only semi-regular superset of $X - \{x\}$ is X itself. Hence the closure of $X - \{x\}$ is contained in each of its semi-regular neighbourhoods and $X - \{x\}$ is rsg-closed.

Theorem 3.25. *Let A and B be subsets of spaces X and Y, respectively, then A and B are rsg-closed in X and Y, respectively, if $A \times B$ is rsg-closed in $X \times Y$.*

Proof. Let G and H be semi-regular subsets of X and Y, respectively, such that $A \subset G$ and $B \subset H$. This implies $A \times B \subset G \times H$ where $G \times H$ is semi-regular in $X \times Y$. Since $A \times B$ is rsg-closed in $X \times Y$, therefore $cl(A \times B) = cl(A) \times cl(B) \subset G \times H$ or $cl(A) \subset G$ and $cl(B) \subset H$. This proves that A and B are rsg-closed in X and Y, respectively.

Theorem 3.26. *Let X and Y be two spaces and A be a subset of a space X,*

- **(1):** *If $A \times Y$ is rsg-open in $X \times Y$, then A is rsg-open in X;*
- **(2):** *If $A \times Y$ is rsg-closed in $X \times Y$, then A is rsg-closed in X.*

Proof. (1) Let G be a semi-regular set in X such that $G \subset A$. Since $G \times Y$ is a semi-regular set in $X \times Y$, then by definition $G \times Y \subset Int(A \times Y) = Int(A) \times Int(Y) = Int(A) \times Y$. This gives that $G \subset Int(A)$. This proves that A is rsg-open in X.

(2) Let G be a semi-regular set in X such that $A \subset G$. Since $G \times Y$ is semi-regular in $X \times Y$ and $A \times Y \subset G \times Y$. By definition $cl(A) \times Y = cl(A) \times cl(Y) = cl(A \times Y) \subset G \times Y$. This gives that $cl(A) \subset G$. This proves that A is rsg-closed in X.

Theorem 3.27. *Let A be an open and rsg-closed set, then $cl(A)$ is clopen in X.*

Proof. Since A is open, $Int(A) = A \subset Int(cl(A))$. Since $Int(cl(A))$ is semi-regular and A is rsg-closed, we obtain $cl(A) \subset Int(cl(A))$. This proves that $cl(A)$ is clopen.

Theorem 3.28. *A regular open and rsg-closed set is clopen.*

Proof. Let A be regular open then A is semi-regular. This gives that $cl(A) \subset A$. But $A \subset cl(A)$. Therefore A is closed.

Theorem 3.29. *In a locally indiscrete space X, every semi-closed set is rsg-closed.*

Proof. Let A be semi-closed. Then $X - A \in SO(X)$. Since X is locally indiscrete, $SO(X) = RO(X)$ ([9], Theorem 3.3). This shows that $X - A$ is regular open in X or A is regular-closed in X. Therefore A is rsg-closed.

Definition 3.30. *The intersection of all semi-regular subsets of a space X containing a set A is called the semi-regular kernel of A and is denoted by $srker(A)$.*

Lemma 3.31. *A subset A of a space X is rsg-closed if and only if $cl(A) \subset srker(A)$.*

Proof. Assume that A is an rsg-closed set in X. Then $cl(A) \subset G$ whenever $A \subset G$ and G is semi-regular in X. This implies $cl(A) \subset \cap\{G : A \subset G$ and $G \in SR(X)\} = srker(A)$

Conversely. Assume that $cl(A) \subset srker(A)$. This implies $cl(A) \subset \cap\{G : A \subset G$ and $G \in SR(X)\}$. This shows that $cl(A) \subset G$ for any semi-regular set G containing A. This proves that A is rsg-closed.

Lemma 3.32. *(Jankovic and Reilly [10]). Let x be a point of a space X. Then $\{x\}$ is either nowhere dense or preopen.*

Theorem 3.33. *Arbitrary intersection of rsg-closed sets in a locally indiscrete space X is rsg-closed.*

Proof. Let $\{A_\alpha : \alpha \in I\}$ be an arbitrary collection of rsg-closed sets in a space X and let $A = \cap_{\alpha\in I} A_\alpha$. Let $x \in cl(A)$. In view of Lemma 3.32, we consider the following two cases.

Case I. Let $\{x\}$ be nowhere dense. If $x \notin A$, then for some $j \in I$, we have $x \notin A_j$. Since nowhere dense subsets are semi-closed and X is locally indiscrete, therefore $X - \{x\}$ is a regular open set containing A_j. Hence $x \notin srker(A_j)$. On the other hand, by Lemma 3.31, since A_j is rsg-closed, $x \in cl(A) \subset cl(A_j) \subset srker(A_j)$. By contradiction, $x \in A$ and hence $x \in srker(A)$.

Case II. Let $\{x\}$ be preopen. Set $F = Int(cl(\{x\}))$. Assume that $x \notin rsker(A)$. Then there exists a semi-regular set C containing x such that $C \cap A = \phi$. Now by ([5], Theorem 1.2) $x \in F = Int(cl(\{x\})) \subset Int(cl(C)) \subset C$. Since F is an open set containing x and $x \in cl(A)$, therefore $F \cap A \neq \phi$. Since $F \subset C$, $C \cap A \neq \phi$. By contradiction $x \in srker(A)$. Thus in both cases $x \in srker(A)$. By Lemma 3.31, A is rsg-closed.

Corollary 3.34. *For a locally indiscrete space X, the family of all rsg-open sets of X is a topology for X.*

Proof. This is an immediate consequence of Theorems 3.6 and 3.33.

4. rsg-Regular Spaces

In this section, we define an rsg-regular space and investigate some of its fundamental properties.

Definition 4.1. *A space (X, τ) is said to be s-regular [13] if for each closed set F and any point $x \in X - F$, there exist disjoint semi-open sets U and V in X such that $x \in U$ and $F \subset V$.*

Definition 4.2. *A space (X, τ) is said to be rsg-regular if for every rsg-closed set F and $x \in X - F$ there exist disjoint open sets U and V in X such that $x \in U$ and $F \subset V$.*

Remark 4.3. *Every rsg-regular space is regular as well as s-regular but the converse is not true in general.*

Example 4.4. *Let $X = Y \cup Z$ where $Y \cap Z = \phi$ and Y, Z are infinite sets. Let $\tau = \{\phi, Y, Z, X\}$ then (X, τ) is a regular space. If $\phi \neq A \subset Y$ and $x \in Y - A$, then A is an rsg-closed set but A and x can not be separated by disjoint open sets. Hence (X, τ) fails to be an rsg-regular space.*

Theorem 4.5. *The following are equivalent for a space (X, τ):*

- **(1):** *(X, τ) is rsg-regular.*
- **(2):** *For every rsg-open set U containing $x \in X$, there exists an open set G in X such that $x \in G \subset cl(G) \subset U$.*

Proof. (1) ⇒ (2) *Let U be any rsg-open set containing $x \in X$. Then $x \notin X - U$, where $X - U$ is rsg-closed in X. Hence there exist disjoint open sets G and H such that $x \in G$ and $X - U \subset H$ or $x \in G \subset cl(G) \subset X - H \subset U$. This proves (2).*

(2) ⇒ (1) *Let F be an rsg-closed set and $x \in X - F$. By hypothesis, there exists an open set G in X such that $x \in G \subset cl(G) \subset X - F$ or $x \in G$ and $F \subset X - cl(G)$where $G \cap (X - cl(G)) = \phi$. This proves that X is rsg-regular.*

Definition 4.6. *A space (X, τ) is said to be rsg-regular at a point $x \in X$ if every rsg-open neighbourhood of x contains a closed neighbourhood of x.*

Theorem 4.7. *A space (X, τ) is rsg-regular if and only if it is rsg-regular at each of its points.*

Proof. Suppose X is rsg-regular and $x \in X$. Let U be any rsg-open neighbourhood of $x \in X$. Then $X - U$ is rsg-closed and $x \notin X - U$. Since X is rsg-regular, there exist disjoint open sets G and H such that $x \in G$ and $X - U \subset H$. Now $G \cap H = \phi$ implies $x \in G \subset X - H \subset U$. This proves that X is rsg-regular at each of its points.

Conversely, let X be rsg-regular at each of its points. Let F be an rsg-closed set and $x \in X - F$, where $X - F$ is an rsg-open neighbourhood of x. By hypothesis there exists an open set V of X such that $x \in V \subset cl(V) \subset X - F$. By Theorem 4.5, X is rsg-regular.

Theorem 4.8. *Every open and s*g-closed subspace of an rsg-regular space is rsg-regular.*

*Proof. Suppose X is an rsg-regular space and Y is an open and s*g-closed subspace of X. Let A be an rsg-closed set in Y. By Theorem 3.15, A is an rsg-closed in X. Let $x \in Y - A$, then $x \in X - A$ implies that there exist open sets U and V in X such that $x \in U$, $A \subset V$ and $U \cap V = \phi$; hence $x \in U \cap Y$, $A \subset V \cap Y$, where $U \cap Y$ and $V \cap Y$ are disjoint open sets in Y. This proves that Y is an rsg-regular space.*

Lemma 4.9. *In an rsg-regular space every rsg-open set is the union of open sets.*

Proof. Let U be an rsg-open subset of an rsg-regular space X such that $x \in U$. If $A = X - U$, then A is an rsg-closed set and $x \in X - A$. By hypothesis there exist disjoint open sets W_x and W of X such that $x \in W_x$ and $A \subset W$. It follows that $x \in W_x \subset U$. This completes the proof.

Corollary 4.10. *In an rsg-regular space every rsg-closed set is the intersection of closed sets.*

Definition 4.11. *A space (X,τ) is called a $T_r-space$ if every rsg-closed subset of X is closed.*

Lemma 4.12. *A space (X,τ) is rsg-regular if and only if (X,τ) is a regular and $T_r - space$.*

Proof. Let X be an rsg-regular space, then X is a regular space. Let A be an rsg-closed subset of X. Let $x \in cl(A)$. If $x \notin A$, then by hypothesis, there exist disjoint open sets U and V containing x and A, respectively. This contradicts that $x \in cl(A)$. Therefore $x \in A$ and hence A is closed.

Conversely, let (X,τ) be a regular and $T_r - space$. Let A be an rsg-closed subset of X and $x \in X - A$. By definition 4.11, A is closed and by regularity of X, there exist disjoint open sets U and V containing x and A, respectively. This proves that X is an rsg-regular space.

Theorem 4.13. *For a space (X,τ), the following are equivalent:*

(1): *(X,τ) is a $T_r - space$.*

(2): *Every singleton subset of X is either open or semi-regular.*

Proof. (1) $\Rightarrow$ (2) *Let $x \in X$. Suppose $\{x\}$ is not a semi-regular subset of X. This gives $X - \{x\}$ is not semi-regular and therefore X is the only semi-regular super set of $X - \{x\}$. Trivially $X - \{x\}$ is rsg-closed. By hypothesis, $X - \{x\}$ is closed or $\{x\}$ is open.*

(2) $\Rightarrow$ (1) *Let A be an rsg-closed subset of X. Let $x \in cl(A)$. By hypothesis $\{x\}$ is either open or semi-regular. If $\{x\}$is open, then $\{x\} \cap A \neq \phi$ implies $x \in A$. If $\{x\}$ is semi-regular and $x \notin A$, then $x \in cl(A) - A$. This implies that $cl(A) - A$ contains a nonempty semi-regular set. This contradicts Theorem 3.10. Hence $x \in A$. This proves (1).*

Remark 4.14. *In T_r − space, closed sets, s*g-closed sets and rsg-closed sets coincide.*

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