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ON LOCALLY s-CLOSED SPACES

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ABSTRACT. In the present paper, the concepts of s-closed sub-spaces, locally s-closed spaces have been introduced and characterized. We have seen that local s-closedness is a semi-regular property; the concept of s-θ-closed mapping has been introduced here and the following important properties are established :-
Let $f : X \to Y$ be an s-θ-closed surjection with s-set (Maio and Noiri [8]) point inverses. Then :

(a) If f is completely continuous (Arya and Gupta [1]) and Y is a locally compact T_2-space, then, X is locally s-closed.

(b) If f is γ-continuous (Ganguly and Basu [5]) and X is a locally compact T_2-space, then, Y is locally s-closed.

KEY WORDS AND PHRASES. s-closed subspace, s-set, locally s-closed, s-θ-closed mapping, γ-continuous and completely continuous mapping, regular open set, s-θ-open set, local compactness.
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1. INTRODUCTION. S-closed spaces (Thompson [14]) and s-closed (Maio and Noiri [8]) spaces originated from almost compact spaces by the use of semi-open sets as introduced by Levine [7]. Ganster and Reilly [6] had shown, towards the distinction between these concepts, that every infinite topological space can be embedded as a closed connected subspace of an S-closed space which is not an s-closed space. Noiri [13] further generalized S-closed spaces to locally S-closed spaces. In this paper we generalize s-closed spaces to locally s-closed spaces and study s-closed subspaces. Certain important characterizations and properties of locally s-closed spaces have also been established. s-θ-closed mapping is introduced and characterized and we have seen, under certain conditions on the domain and co-domain spaces, that an s-θ-closed mapping would be a continuous mapping. Completely continuous and γ-continuous mappings were introduced respectively by Arya and Gupta [1] and Ganguly and Basu [5]; by the help of these mappings we have been able to establish certain properties which corelate locally compact T_2-spaces with locally s-closed spaces.

Throughout the present paper, by (X,T) or simply by X we shall mean a topological space. A subset A of a topological space is said to be regular open (resp. regular closed) if int(cl(A))=A (resp. cl(int(A))=A), where cl(A) (resp. int(A)) denotes the closure (resp. interior) of A. A subset A of a space X is said to be semi-open [7] if there exists an open set O such that $O \subset A \subset cl(O)$. The complement of a semi-open set is called semi-closed (Crossley and Hildebrand [3]). The semi-closure of a subset A of a space, denoted by sclA, is the intersection of all semi-closed sets containing A (Crossley and Hildebrand [3]). A set A which is both semi-open as well as semi-closed is called a semi-regular set (Maio and Noiri [8]). The collection of all semi-open (resp. semi-regular, regular open) sets containing a point x of X will be denoted by SO(x) (resp. SR(x), RO(x)) and for the whole space X these will be denoted by SO(X) (resp. SR(X), RO(X)). A point x of X is said to be s-θ-cluster [8] point of a subset A of X if for every $U \in SO(x)$, $sclU \cap A \neq \emptyset$. Since, for a semi-open set U, sclU is a semi-regular set [8], a point x of X is said to be an s-θ-cluster point of A iff $R \cap A \neq \emptyset$, for all $R \in SR(x)$. The collection of all s-θ-cluster points of A will be denoted by s-θ-clA ($[A]_{s-\theta}$, for short). A set A is s-θ-closed if $A=[A]_{s-\theta}$. A complement of an s-θ-closed set is called an s-θ-open set. For a space (X,T), RO(X,T) is a base for a topology T_S on X coarser than T and (X,T_S) is called the semi-regularization space of (X,T). A topological property P is said to be semi-regular property if whenever a space (X,T) possesses that property P so does its semi-regularization space (X,T_S). A subset A of X is s-closed [8] (resp. S-closed (Noiri [11])) relative to X or simply an s-set (resp. S-set) if every cover $\mathcal{U}$ of A by sets of SO(X) admits a finite subfamily $\mathcal{U}_0$ such that $A \subset \bigcup_{U \in \mathcal{U}_0} sclU$ (resp. $A \subset \bigcup_{U \in \mathcal{U}_0} clU$). In case A = X and A is an s-set (resp. S-set), then X is called s-closed [8] (resp. S-closed [14]). A subset A is called Nearly compact (NC-set (Carnahan [2]), for short) if every cover $\mathcal{U}$ of A by means of open sets of X has a finite subfamily $U_1, \ldots, U_n$ (say) such that $A \subset \bigcup_{i=1}^{n} intclU_i$. Clearly every s-set (resp. compact) set, is an NC-set, but not conversely. A subset A of a space X is said to be an α-set (Noiri [10]) if $A \subset int(cl(int(A)))$.

2. s-CLOSED SUBSPACES. At the very outset, an example is given to assert that, every set, s-closed relative to X, is not necessarily an s-closed subspace of X.

EXAMPLE 1. Every countable set in an uncountable set X with co-countable topology T is s-closed relative to (X,T), but is not even an S-closed subspace.

DEFINITION 1. A subset A of X is said to be pre-open (Mashour et al. [9]) if $A \subset intclA$. This collection includes all open sets and, even more, all α-open sets.

LEMMA 1. (See Dorsett [4]) Let (X,T) be a topological space and let A be pre-open set in (X,T), then $SR(A,T_A)=SR(X,T) \cap A$, where T_A is the subspace topology on A.

THEOREM 1. A pre-open set A of X is s-closed as a subspace iff it is s-closed relative to X.

PROOF. Let A be s-closed relative to X and also let $\{V_\alpha : \alpha \in I\}$ be a cover of A by semi-regular sets of the subspace A. Then by Lemma 1, there exists a semi-regular set U_α in X, for each $\alpha \in I$, such that $V_\alpha = U_\alpha \cap A$. Therefore, $A \subset \bigcup_{\alpha \in I} U_\alpha$. Since A is s-closed relative to X, there exists a finite subset I_0 of I such that $A \subset \bigcup_{\alpha \in I_0} U_\alpha$, which shows that $A \subset \bigcup_{\alpha \in I_0} (U_\alpha \cap A)$ i.e., $A \subset \bigcup_{\alpha \in I_0} V_\alpha$. Therefore, A is s-closed as a sub-space.

Conversely, let A be s-closed as a subspace. Let $\{V_\alpha : \alpha \in I\}$ be a cover of A by semi-regular sets of X. Then $A = \bigcup_{\alpha \in I} (V_\alpha \cap A)$. Since A is s-closed as a subspace, there exists a finite subset I_o of I such that $A = \bigcup_{\alpha \in I_o} (V_\alpha \cap A)$, which shows that $A \subset \bigcup_{\alpha \in I_o} V_\alpha$. Therefore A is s-closed relative to X.

THEOREM 2. Let B be a pre-open set in (X,T). Then a subset A of B is s-closed relative to the subspace B iff A is s-closed relative to X.

PROOF. The proof follows by Lemma 1.

COROLLARY 1. Let A and B be open sets of a space X such that $A \subset B$. Then A is an s-closed subspace of B iff A is an s-closed subspace of X.

PROOF. Applying Theorem 1 and Theorem 2, we get the result.

DEFINITION 2. Let (X,T) be a topological space, then SR(X,T) forms a sub-base for a topology called T_{SR}-topology on X.

LEMMA 2. A subset A of a space (X,T) is s-closed relative to (X,T) iff A is compact in (X,T_{SR}).

PROOF. Let A be s-closed relative to (X,T). Then every cover of A by sets of SR(X,T) has a finite subcover. But SR(X,T) forms a sub-base for (X,T_{SR}). So every sub-basic open cover of (X,T_{SR}) has a finite subcover. Therefore by Alexander sub-base theorem A is compact in (X,T_{SR}).

Coversely, if A is compact in (X,T_{SR}) then every sub-basic open cover has a finite subcover. So every cover by sets of SR(X,T) has a finite subcover. Therefore A is s-closed relative to (X,T).

THEOREM 3. Let B be a T_{SR}-closed set in X and let A be any subset of X which is s-closed relative to (X,T). Then $A \cap B$ is s-closed relative to (X,T).

PROOF. Let $\{U_\alpha : \alpha \in I\}$ be a T_{SR}-open cover of $A \cap B$. Then clearly $\{U_\alpha : \alpha \in I\} \cup (X-B)$ is a T_{SR}-open cover of A. By Lemma 2, A is compact relative to (X,T_{SR}); and so, there exists a finite subset I_o of I such that $A \subset \{\bigcup_{\alpha \in I_o} U_\alpha\} \cup (X-B)$, which implies that $A \cap B \subset \bigcup_{\alpha \in I_o} U_\alpha$ .. Therefore $A \cap B$ is compact in (X,T_{SR}). Then by Lemma 2, $A \cap B$ is s-closed relative to (X,T).

COROLLARY 2. If B is regular open or regular closed and A is any subset of X which is s-closed relative to X, then $A \cap B$ is s-closed relative to X.

PROOF. Since every regular closed or regular open set is semi-regular, the corollary follows from Theorem 2.

COROLLARY 3. If X is an s-closed space and A is a regular open set of X, then A is an s-closed subspace of X.

PROOF. The proof follows from Theorem 1 and Theorem 3.

COROLLARY 4. If A is s-closed open subspace of X and B is a regular open set of X, then $A \cap B$ is an s-closed subspace of X and (hence of A and B).

PROOF. The proof follows from Corollary 2 and Theorem 1 and second part follows from Corollary 1.

THEOREM 4. If A_i, i = 1,2,...,n are s-sets i.e., s-closed relative to X. then $\bigcup_{i=1}^{n} A_i$ is s-closed relative to X.

PROOF. Straightforward.

THEOREM 5. Let X be an s-closed space and let A be a closed set of X and let frontier of A, denoted by Fr(A), be s-closed relative to X. Then A is s-closed relative to X.

PROOF. Since X is s-closed, by Corollary 3 and Theorem 1, intA is s-closed relative to X whenever A is a closed set. Since A=intA$\cup$Fr(A), by Theorem 4, A is s-closed relative to X.

3. LOCALLY s-CLOSED SPACES

DEFINITION 3. A space X is said to be locally s-closed iff each point belongs to a regular open neighbourhood (nbd. for short) which is an s-closed subspace of X.

REMARK 1. Clearly every s-closed space is a locally s-closed space. However, the converse is not true, ingeneral, because any uncountable set with discrete topology is locally s-closed but not s-closed.

THEOREM 6. A topological space (S,T) is locally s-closed iff for each point $x \in X$, there exists a regular open set U containing x such that U is locally s-closed.

PROOF. Sufficiency : At first we prove that if A is a regular-open set in (X,T) then every regular-open set in the subspace (A,T_A) is also regular-open in (X,T). Let $V \subset A$ be regular-open in the subspace (A,T_A). Then $V = \mathrm{int}_A \mathrm{cl}_A V = \mathrm{int}_A(A \cap \mathrm{cl}_X V) = \mathrm{int}_X(A \cap \mathrm{cl}_X V) = \mathrm{int}_X A \cap \mathrm{int}_X \mathrm{cl}_X V = A \cap \mathrm{int}_X \mathrm{cl}_X V = \mathrm{int}_X \mathrm{cl}_X V$ (as $V \subset A$ implies $\mathrm{int}_X \mathrm{cl}_X V \subset \mathrm{int}_X \mathrm{cl}_X A = A$). Therefore V is regular open in (X,T). Now let x be any point of X. Then, by hypothesis, there exists a regular-open set U of (X,T) containing x such that U is locally s-closed. Then there exists a regular open set V in U such that $x \in V$ and V is an s-closed subspace of U. Therefore V is a regular-open set in (X,T) and by Corollary 1, V is s-closed subspace of X. Therefore (X,T) is locally s-closed.

Necessity : The proof is straightforward.

THEOREM 7. Let (X,T) be a topological space. The following are equivalent :

(i) X is locally s-closed;

(ii) every point has a regular-open set which is s-closed relative to X;

(iii) every point x of X has an open nbd U such that $\mathrm{int}_X \mathrm{cl}_X U$ is s-closed relative to X;

(iv) every point x of X has an open nbd U such that sclU is s-closed relative to X;

(v) for every point x of X, there exists an α-open set V containing x such that sclV is s-closed relative to X;

(vi) for every point x of X, there exists an α-open set V containing x such that $\mathrm{int}_X \mathrm{cl}_X V$ is s-closed relative to X;

(vii) for each $x \in X$, there exists a pre-open set V containing x such that sclV is s-closed relative to X;

(viii) for every x of X, there exists a pre-open set V containing x such that $\mathrm{int}_X \mathrm{cl}_X V$ is s-closed relative to X;

(ix) for every $x \in X$, there exists a pre-open set V containing x such that $\mathrm{int}_X \mathrm{cl}_X V$ is an s-closed subspace of X.

PROOF. (i) $\rightarrow$ (ii) : Follows from Theorem 1 and from the fact that every regular-open set is pre-open set. (ii) $\rightarrow$ (iii) is obvious.

(iii) $\rightarrow$ (iv) : Follows from the fact that for an open set U, sclU = intclU (Maiò and Noiri [8]). (iv) $\rightarrow$ (v) is evident, since every open set is α-open.

(v) $\rightarrow$ (vi), (vi) $\rightarrow$ (vii), (vii) $\rightarrow$ (viii) and (viii) $\rightarrow$ (ix) are straightforward because of the facts that every α-open set is pre-open and a set V is pre-open iff sclV = intclV (Dorsett [4]). (ix) $\rightarrow$ (i) follows from Theorem 1.

THEOREM 8. A topological space (X,T) is locally s-closed iff, its semi-regularization space (X,T_S) is locally s-closed.

PROOF. Let (X,T) be locally s-closed. Dorsett [4] proved that $SR(X,T)=SR(X,T_S)$ and hence a subset A of X is s-closed relative to (X,T) iff A is s-closed relative to (X,T_S). We know that if U is an open and V a closed subset of (X,T), then $cl_T U = cl_{T_S} U$ and $int_T V = int_{T_S} V$. Using these results we can easily prove that for a regular-open set U of (X,T), $int_T cl_T U = int_{T_S} cl_{T_S} U$. Therefore every regular-open set in (X,T) is regular open in (X,T_S) and vice-versa. So (X,T) and (X,T_S) have the same collection of regular-open sets. Therefore, by definition, (X,T) is locally s-closed iff (X,T_S) is locally s-closed.

REMARK 2. Local s-closedness is a semi-regular property.

DEFINITION 4. A function $f : X \to Y$ is said to be <u>s-θ-closed</u> if image of each s-θ-closed set in X is closed in Y.

THEOREM 9. A function $f : X \to Y$ is s-θ-closed iff $cl(f(A)) \subset f([A]_{s-\theta})$ for any subset A of X.

PROOF. Let f be s-θ-closed and A be any subset of X. Then $f([A]_{s-\theta})$ is closed in Y (since $[A]_{s-\theta}$ is s-θ-closed set). Clearly $f(A) \subset f([A]_{s-\theta})$ and hence $cl(f(A)) \subset f([A]_{s-\theta})$.

Conversely, let A be an arbitrary s-θ-closed set in X. By hypothesis $f(A) \subset cl(f(A)) \subset f([A]_{s-\theta}) = f(A)$. Therefore $f(A) = cl(f(A))$ and hence $f(A)$ is closed in Y.

THEOREM 10. A surjective function $f : X \to Y$ is s-θ-closed iff for each subset A in Y and each s-θ-open set U in X containing $f^{-1}(A)$, there exists an open set V in Y containing A such that $f^{-1}(V) \subset U$.

PROOF. Sufficiency : Suppose that the given hypothesis holds. Let A be any s-θ-closed set in X. Let y be an arbitrary point in $Y-f(A)$; then $X-A$ is an s-θ-open set containing $f^{-1}(y)$; by hypothesis, there exists an open set V_y containing y such that $f^{-1}(V_y) \subset X-A$. This shows that $y \in V_y \subset Y-f(A)$. Therefore $Y-f(A) = \bigcup \{ V_y : y \in Y-f(A) \}$. Hence $Y-f(A)$ is an open set i.e., $f(A)$ is closed in Y.

Necessity : Let $V = Y - f(X-U)$. Since $f^{-1}(A) \subset U$, it shows that $A \subset V$. As f is s-θ-closed, $f(X-U)$ is closed and hence V is open in Y. Therefore, $f^{-1}(V) \subset X-f^{-1}[f(X-U)] \subset U$.

LEMMA 3. A subset A of a space X is an s-set iff every cover of A by s-θ-open sets has a finite subfamily which covers A.

PROOF. Sufficiency part is straightforward.

Necessity : Let A be an s-set. Let $\mathcal{U} = \{ U_\alpha : \alpha \in I \}$ be an s-θ-open cover of A and also let $x \in A$. Then there exists $U_{\alpha_x} \in \mathcal{U}$ such that $x \in U_{\alpha_x}$. But U_{α_x} being an s-θ-open set, there exists a semi-open set V_x such that $x \in V_x \subset sclV_x \subset U_{\alpha_x}$. Therefore the family $\{ V_x : x \in A \}$ is a cover of A by semi-open sets of X. Hence there exist points say $x_1, \ldots, x_n$ such that $A \subset \bigcup_{i=1}^{n} sclV_{x_i}$. Hence $A \subset \bigcup_{i=1}^{n} U_{\alpha_{x_i}}$. Therefore $\mathcal{U}$ has a finite subfamily which covers A.

THEOREM 11. Let $f : X \to Y$ be an s-θ-closed surjection with s-set point inverses; if A is any compact set in Y then $f^{-1}(A)$ is an s-set in X.

PROOF. Let $\mathcal{U} = \{ U_\alpha : \alpha \in I \}$ be any cover of $f^{-1}(A)$ by s-θ-open sets of X. For each point $y \in A$, $f^{-1}(y) \subset \bigcup_{\alpha \in I} U_\alpha$. By hypothesis $f^{-1}(y)$ is an s-set, by Lemma 3, there exists a finite subfamily I_o of I such that $f^{-1}(y) \subset \bigcup \{ U_\alpha : \alpha \in I_o \}$. Since we know that Union of any collection s-θ-open sets is s-θ-open and since f is an s-θ-closed function, by Theorem 10, there exists an open set V_y of Y containing y such that $f^{-1}(V_y) \subset \bigcup_{\alpha \in I_o} U_\alpha$. $\{ V_y : y \in A \}$ is a cover of a compact set A and hence there exist points $y_1, \ldots, y_n$ of A such that $A \subset \bigcup_{i=1}^{n} V_{y_i}$ which shows that $f^{-1}(A)$ is covered by a finite number of s-θ-open sets from $\mathcal{U}$ and hence $f^{-1}(A)$ is an s-set.

COROLLARY 5. Let $f : X \to Y$ be an s-θ-closed surjection with s-set point inverses; if X is T_2 and Y is compact then f is continuous.

PROOF. Let A be a closed set in Y. Therefore A is also compact; by Theorem 11, $f^{-1}(A)$ is an s-set in X. Since every s-set is an NC-set and X is T_2, by Theorem 2.1 of T. Noiri [12], $f^{-1}(A)$ is closed and hence f is continuous.

DEFINITION 5. A function $f : X \to Y$ is said to be <u>completely continuous</u> (Arya and Gupta [1]) if inverse image of each open set in Y is regular-open in X.

THEOREM 12. Let $f : X \to Y$ be a completely-continuous s-θ-closed surjection with s-set point inverses. If Y is locally compact T_2, X is locally s-closed.

PROOF. Since Y is locally compact T_2, for each point $x \in X$, there exists a closed compact nbd. U of f(x). Since f is completely continuous, $f^{-1}(\text{int } U)$ is a regular open set containing x. But it is easy to see that every regular-open set is semi-regular and hence an s-θ-closed set (see Maio and Noiri [8]). Since U is compact and f is an s-θ-closed function, by Theorem 11, $f^{-1}(U)$ is an s-set in X and $x \in f^{-1}(\text{int } U) \subset f^{-1}(U)$. Hence, by Corollary 2, $f^{-1}(\text{int } U)$ is an s-set in X. Therefore X is locally s-closed.

DEFINITION 6. A function $f : X \to Y$ is said to be <u>γ-continuous</u> (Ganguly and Basu [5]) if for each $x \in X$ and each $W \in SO(f(x))$, there is an open set V containing x such that $f(V) \subset \text{scl}W$. Equivalently f is γ-continuous iff the inverse image of each semi-regular set is clopen.

LEMMA 4. If $f : X \to Y$ is γ-continuous and $K \subset X$ is compact; then f(K) is an s-set in Y.

PROOF. Let $\{ U_\alpha : \alpha \in I \}$ be a cover of f(K) by semi-regular sets of Y. Then $\{ f^{-1}(U_\alpha) : \alpha \in I \}$ is a cover of K by open sets of X. Since K is compact, there exists a finite subset I_o of I such that $K \subset \bigcup_{\alpha \in I_o} f^{-1}(U_\alpha)$ i.e., $f(K) \subset \bigcup_{\alpha \in I_o} U_\alpha$. So f(K) is an s-set in Y.

LEMMA 5. (See [12]) Let X be a T_2-space. Then for any disjoint NC-sets A and B, there exist disjoint regular open sets U and V such that $A \subset U$ and $B \subset V$.

THEOREM 13. If $f : X \to Y$ is an s-θ-closed, γ-continuous surjection with s-set point inverses and if X is locally compact T_2, then Y is locally s-closed.

PROOF. We shall first prove that Y is T_2. Let y_1 and y_2 be two distinct points of Y. Then $f^{-1}(y_1)$ and $f^{-1}(y_2)$ are disjoint s-sets and hence disjoint NC-sets. By Lemma 5, there exist disjoint regular-open sets U_1 and U_2 such that $f^{-1}(y_1) \subset U_1$ and $f^{-1}(y_2) \subset U_2$. But every regular-open set is an s-θ-open set and so, by Theorem 10, there exist open sets V_j, j = 1,2 containing y_j in Y such that $f^{-1}(V_j) \subset U_j$ where j=1,2. Thus Y is T_2. Let X be locally compact T_2; for each point x of $f^{-1}(y)$, there exists a compact closed nbd. U_x of x in X. Since interior of a closed nbd. is a regular-open set, it is semi-regular as well. Therefore the family $\{ \text{int} U_x : x \in f^{-1}(y) \}$ is a cover of an s-set $f^{-1}(y)$ by semi-regular sets. By Proposition 4.1

of Maio and Noiri [8], there exist points $x_1, \ldots, x_n$ in $f^{-1}(y)$ such that $f^{-1}(y) \subset \bigcup_{i=1}^{n} \mathrm{int}U_{x_i}$. Let $U = \bigcup_{i=1}^{n} U_{x_i}$. Then $f^{-1}(y) \subset \bigcup_{i=1}^{n} \mathrm{int}U_{x_i} \subset \mathrm{int}U$. Since intU is clearly an s-θ-open set containing $f^{-1}(y)$ and since, f is an s-θ-closed function by Theorem 10, there exists an open set V_y containing y such that $f^{-1}(V_y) \subset \mathrm{int}U$ i.e., $y \in V_y \subset f(\mathrm{int}U) \subset f(U)$. But f being $\mathcal{Y}$-continuous, f(U) is an s-set by Lemma 4. Since Y is T_2, f(U) is closed by Theorem 2.1 of Noiri [12]. Therefore $y \in V_y \subset \mathrm{intcl}V_y \subset f(U)$. Clearly $\mathrm{intcl}V_y$ is a regular-open set and hence by Corollary 2, $\mathrm{intcl}V_y$ is an s-set. Hence Y is locally s-closed.

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