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العدد التاسع عشر
يوليو 2021م

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Fibrewise Separation axioms in Fibrewise Topological Group

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Abstract: In this paper we will introduce and study the notion of fibrewise separation axioms in fibrewise topological group and show that fibrewise T_2 space \Rightarrow fibrewise T_1 space \Rightarrow fibrewise T_0 space.

1. Introduction

The fibrewise viewpoint is standard in the theory of fibre bundles, however, it has been recognized relatively recently that the same viewpoint is also of as important in other areas such as general topology. A fibrewise topological space over B is just a topological space X together with a continuous function $p: X \rightarrow B$ called projection. Most of the results obtained so far in this field can be found in James [4] (1984) and James [5] (1989). Our aim in this paper is to study the fibrewise separation axioms in fibrewise topological group. We study many properties and obtained some new results. Also we investigate some important theorems and properties of fibrewise separation axioms in fibrewise topological groups , especially for the fibre G_{e_B} over the identity element e_B of B .

2. Preliminaries

Throughout this section we give the basic concepts and notations which we shall use in this paper:

2.1. Fibrewise topological space [5]

Definition 2.1.1: Let B be any set. Then a fibrewise set over B consists of a set X together with a function $p: X \rightarrow B$, called the projection, where B is called a base set.

For each $b \in B$, the fibre over b is the subset $X_b = p^{-1}(b)$ of X . Also for each subset W of B , we regard $X_W = p^{-1}(W)$ is a fibrewise set over W with the projection determined by p .

Proposition 2.1.2: Let X be a fibrewise set over B , with projection p . Then Y is fibrewise set over B with projection $p\alpha$ for each set Y and function $\alpha : Y \rightarrow X$.



In particular X' is a fibrewise set over B with projection P/X' for each subset X' of X . Also X is fibrewise set over B' with projection βp for each superset B' of B and function $\beta : B \rightarrow B'$.

Definition 2.1.3: If X and Y are fibrewise sets over B , with projections p and q respectively, a function $\varphi : X \rightarrow Y$ is said to be fibrewise function if $q\varphi = p$, in other words $\varphi(X_b) \subseteq Y_b$ for each $b \in B$.

Definition 2.1.4: Let $\{X_r\}$ be an index family of fibrewise sets over B . Then the fibrewise product $\prod_B X_r$ is defined, as a fibrewise set over B , and comes equipped with the family of fibrewise projections $\pi_r: \prod_B X_r \rightarrow X_r$. Specifically the fibrewise product is defined as the subset of the ordinary product $\prod X_r$, in which the fibres are the products of the corresponding fibres of the factors X_r .

Definition 2.1.5: Let B be a topological space. Then a fibrewise topology on a fibrewise set X over B is any topology on X for which the projection p is continuous.

A fibrewise topological space over the space B is defined to be a fibrewise set over B with fibrewise topology.

The coarsest fibrewise topology on a fibrewise set X over B is the topology induced by p , in which the open sets of X are precisely the inverse images of the open sets of the B , this is called the fibrewise indiscrete topology, and the discrete topology on a fibrewise set X over B is called fibrewise discrete.

Definition 2.1.6 : The fibrewise topological space X over B is called fibrewise closed (fibrewise open) if the projection p is closed (open).

Definition 2.1.7: Let X be a fibrewise topological space over B . If $x \in X_b$, where $b \in B$, then the family Γ of family neighborhoods of $x \in X$ is fibrewise basic if for each neighborhood U of x , there exists a neighborhood W of b in B such that $X_W \cap V \subseteq U$, for some member V of Γ .

Definition 2.1.8: Let X be a fibrewise topological space over B . Then:

- i. X is fibrewise T_0 (T_1) if whenever $x, y \in X_b$, where $b \in B$, and $x \neq y$, either there exist a neighborhood of x which does not contain y , or there exists a neighborhood of y which does not contain x (there exists a neighborhood of x which does not contain y and there exists a neighborhood of y which does not contain x).
- ii. X is fibrewise Hausdorff (T_2) if whenever $x, y \in X_b$, where $b \in B$, and $x \neq y$, there exists disjoint neighborhoods V, U of x, y , respectively, in X .



- iii. X is fibrewise R_0 if for each point $x \in X_b$, where $b \in B$, and each neighborhood V of x in X , there exists a neighborhood W of b in B such that $X_W \cap \overline{\{x\}} \subset V$.
- iv. X is fibrewise functionally Hausdorff if whenever $x, y \in X_b$, where $b \in B$, and $x \neq y$, there exists a neighborhood W of b in B and a continuous function $\alpha : X_W \rightarrow I$ such that $\alpha(x) = 0$ and $\alpha(y) = 1$.
- v. X is fibrewise regular if for each point $x \in X_b$, where $b \in B$, and each neighborhood V of x in X , there exists neighborhood W of b in B and a neighborhood U of x in X_W such that $X_W \cap \overline{U} \subset V$. A fibrewise regular and fibrewise T_0 is called fibrewise T_3 .
- vi. X is fibrewise completely regular if for each $x \in X_b$, where $b \in B$, and for each neighborhood V of x in X , there exists neighborhood W of b in B and a continuous function $\alpha : X_W \rightarrow I$ such that $\alpha(x) = 1$ and $\alpha(x) = 0$ for all x away from V .
- vii. X is fibrewise normal if for each point b of B and for each pair H, K of disjoint closed sets of X , there exists a neighborhood W of b in B and a pair U, V of disjoint neighborhoods of $X_W \cap H, X_W \cap K$ in X_W .
- viii. X is fibrewise functionally normal if for each point b of B and for each pair H, K of disjoint closed sets of X , there exists a neighborhood W of b in B and a continuous function $\alpha : X_W \rightarrow I$ such that $\alpha = 0$ throughout H_W and $\alpha = 1$ throughout K_W .

2.2. Topological group, Fibrewise Group and fibrewise topological group

Definition 2.2.1[3]: A topological group G is a group which is also a topological space on G such that the maps $g \rightarrow g^{-1}$ and $(g, h) \rightarrow gh$ are continuous.

Theorem 2.2.2[3]: A group G endowed with any topology, is a topological group if and only if, the mapping $(g, h) \rightarrow gh^{-1}$ is continuous.

Theorem 2.2.3[3]: Let a be a fixed element of a topological group G , then $r_a : g \rightarrow ga$ and $l_a : g \rightarrow ag$ of G onto G are homeomorphisms of G .

Corollary 2.2.4[3]: Let F be a closed set, E be an open set, A be any subset of a topological group G and $a \in G$. Then aF, Fa, F^{-1} are closed sets, aE, Ea, E^{-1}, AE, EA are all open sets.

Proposition 2.2.5[3]: For each neighborhood U of the identity e in a topological group G there exists a symmetric neighborhood V of e such that $VV \subset U$.

Corollary 2.2.6[3]: Let U be any neighborhood of the identity e in a topological group G . Then there is a neighborhood V of e such that $\overline{V} \subset U$. And this is true at each $g \in G$.



Theorem 2.2.7[3]: Let G be a topological group, let e denoted the identity in G , and let F be a closed subset of G such that $e \notin F$. Then there is a continuous function $f: G \rightarrow [0,1]$ such that $f(e) = 0$ and $f(x) = 1$ for every $x \in F$.

Definition 2.2.8[10]: Let B be a group. A fibrewise group over B is a fibrewise set G with any binary operation makes G a group such that the projection $p : G \rightarrow B$ is homomorphism.

Definition 2.2.9[10]: Let G be a fibrewise group over B . Then any subgroup H of G is a fibrewise group over B with projection $p_{/H}: H \rightarrow B$, we call this group a fibrewise subgroup of G over B .

Definition 2.2.10[10]: Let G and K be two fibrewise groups over B . Then any homomorphism $\varphi : G \rightarrow K$ is called a fibrewise homomorphism if φ is a fibrewise map.

Definition 2.2.11[10]: A bijective fibrewise homomorphism is called a fibrewise isomorphism.

Theorem 2.2.12[10]: Let G be a fibrewise group over B with projection p and H be a fibrewise normal subgroup of G . Then G/H is fibrewise group over B , with projection $q : G/H \rightarrow B$ such that $q\pi = p$.

Theorem 2.2.13[10]: let $\varphi : G \rightarrow K$ be a fibrewise function, where G and K are fibrewise groups over B , with p, q respectively. Then:

1. If q is injective then φ is a fibrewise homomorphism, and consequently:
 - i.) $\varphi(e_G) = e_K$, where e_G, e_K denotes the identities of G, K respective.
 - ii) $\varphi(\ker(P)) = e_K$.
 - iii) If H is fibrewise subgroup of G , then $\varphi(H)$ is fibrewise subgroup of K .
 - iv) If H' is fibrewise subgroup of K , then $\varphi^{-1}(H')$ is fibrewise subgroup of G .
 - v) If H is fibrewise normal subgroup of G , then $\varphi(H)$ is fibrewise normal subgroup of K .
2. If p is bijective and q is injective then if G is abelian then K is abelian.
3. If q is bijective and p is surjective then if G is cyclic then K is cyclic.
4. If p, q are bijective then φ is fibrewise isomorphism.

Definition 2.2.14[11]: A fibrewise topological group G is a fibrewise group endowed with fibrewise topology such that the mapping $g \rightarrow g^{-1}$ of G onto G and $(g, h) \rightarrow gh$ of $G \times G$ onto G are fibrewise continuous maps.

Proposition 2.2.15[11]: Let G be a fibrewise topological group over B . Then G_{B^*} is fibrewise topological group over B^* for each subgroup B^* of B .



Proposition 2.2.16[11]: Let G be a fibrewise topological group over B with projection p and H be a fibrewise normal subgroup of G . Then the quotient group G/H is a fibrewise topological group with projection $q: G/H \rightarrow B$ such that $q\pi = p$.

3. Fibrewise Separation Axioms

In fibrewise topology X , if X is fibrewise T_2 then X is fibrewise T_1 , but the converse does not hold in general, however If G is a fibrewise topological group we will prove in this section, that the converse is true.

Theorem 3.1: Let G be a fibrewise topological group over B . G is fibrewise Hausdorff (fibrewise T_1 , fibrewise T_0) if and only if G_{e_B} is Hausdorff (fibrewise T_1 , fibrewise T_0).

Proof:

First, if G is fibrewise Hausdorff then from the definition the fibre G_{e_B} is Hausdorff

Second, let $b \in B$ and $x, y \in G_b : x \neq y \Rightarrow xy^{-1} \neq e_G$ and $x, y \in G_b \Rightarrow p(x) = p(y) = b \Rightarrow p(x)(p(y))^{-1} = e_B \Rightarrow p(x)p(y^{-1}) = e_B \Rightarrow p(xy^{-1}) = e_B \Rightarrow xy^{-1} \in G_{e_B}$ but $e_G \in G_{e_B}$ and $xy^{-1} \neq e_G$. Since G_{e_B} is Hausdorff then there exist open sets U, V such that $xy^{-1} \in U, e_G \in V$ and $U \cap V = \emptyset$. now $xy^{-1} \in U \Rightarrow x \in Uy$ and $y \in Vy$, where Uy, Vy open sets and to show that $Uy \cap Vy = \emptyset$, suppose $Uy \cap Vy \neq \emptyset$, this implies there exist an element $a \in (Uy \cap Vy) \Rightarrow \exists r_1 \in U, r_2 \in V$ such that $a = r_1y = r_2y \Rightarrow r_1 = r_2$, then $r_1 \in U \cap V$ but $U \cap V = \emptyset$ and this is a contradiction, hence $Uy \cap Vy = \emptyset$, thus G is fibrewise Hausdorff. Similarly, we can prove the case of fibrewise T_1 and fibrewise T_0 .

The following results prove the converse : "If a fibrewise topological group is fibrewise T_0 then it is fibrewise T_1 " (If a fibrewise topological group is fibrewise T_0 then it is fibrewise T_1)

Proposition 3.3: Let G be a fibrewise topological group over B . If G is fibrewise T_0 then G is fibrewise T_1 .

Proof:

Let G be a fibrewise T_0 and for $b \in B$ let $x, y \in G_b, x \neq y$ then $xy^{-1} \neq e_G$ and $xy^{-1} \in G_{e_B}$ but $e_G \in G_{e_B}$ since G is fibrewise T_0 , then there exist open set U of G contains e_G and does not contain xy^{-1} from Proposition 2.2.5 \Rightarrow exist open symmetric neighborhood V of e_G such that $VV \subseteq U$, then Vx is open and contains x but does not contain y , and Vy is open and contain y



but does not contain x . Where if $y \in Vx$ then exist $v_1 \in V$ such that $y = v_1x \Rightarrow xy^{-1} = v_1^{-1} \in V^{-1} = V \subseteq U$. This is contradiction.

And, if $x \in Vy$ then exist $v_2 \in V$ such that $x = v_2y \Rightarrow xy^{-1} = v_2 \in V \subseteq U$. This is contradiction. Then G is fibrewise T_1 .

Proposition 3.4 : Let G be a fibrewise topological group over B . If G is fibrewise T_1 then G is fibrewise T_2 .

Proof:

Let G be a fibrewise T_1 and any $b \in B$ let $x, y \in G_b: x \neq y$ then $xy^{-1} \neq e_G$ and $xy^{-1} \in G_{e_B}$ but $e_G \in G_{e_B}$ since G is fibrewise T_1 , then there exist open set U of G contains e_G and does not contain xy^{-1} from Proposition 2.2.5 \Rightarrow exist open symmetric neighborhood V of e_G such that $VV \subseteq U$, then Vx, Vy are open sets contains x and y respectively and $Vx \cap Vy = \emptyset$. Where if $Vx \cap Vy \neq \emptyset$ then there exist an element $r \in (Vx \cap Vy)$ and there exist two elements v_1, v_2 in V such that $r = v_1x = v_2y$ hence $xy^{-1} = v_1^{-1}v_2 \in V^{-1}V = VV \subseteq U$. This is a contradiction, then G is fibrewise T_2 .

Proposition 3.5: Let G and K be fibrewise topological groups over B . Let $\varphi: G \rightarrow K$ be a continuous fibrewise homomorphism and let the kernel(φ) = $\{e_G\}$. Then if K is fibrewise T_0 (fibrewise T_1 , fibrewise T_2) then G is so.

Proof:

Let K be a fibrewise T_0 and any $b \in B$ let $x, y \in G_b: x \neq y$ then $xy^{-1} \neq e_G$ and $\varphi(xy^{-1}) \neq e_K$ this is implies $\varphi(x)\varphi(y^{-1}) \neq e_K$, hence $\varphi(x) \neq \varphi(y)$, since K is fibrewise T_0 and $\varphi(x), \varphi(y) \in K_b$ then there exist a neighborhood V of $\varphi(x)$ in K which does not contain $\varphi(y)$ or vice versa, then $\varphi^{-1}(V)$ is neighborhood of x in G which does not contain y . The proof is similar for the cases if fibrewise T_1 and fibrewise T_2 .

Proposition 3.6 : Let G be a fibrewise Hausdorff over B . Then $G_{B'}$ is fibrewise Hausdorff over B' for each subgroup B' of B .

Proof:

Let B' be any subgroup of B and any $b' \in B'$ let $x, y \in G_{b'}: x \neq y$ since $b' \in B' \subseteq B$ and G is fibrewise Hausdorff then there exist disjoint neighborhoods U, V of x, y in G . let $U' = U \cap G_{b'}$,

$V' = V \cap G_{b'}$, then U', V' are disjoint neighborhoods of x, y in $G_{b'}$ this is implies $G_{B'}$ is fibrewise Hausdorff.



Theorem 3.7 : Any fibrewise topological group is fibrewise regular.

Proof:

Let G be a fibrewise topological group over B and any $b \in B$ let $x \in G_b$ and W be neighborhood of b , then from Corollary 2.2.6 any neighborhood U of x there exist neighborhood V of x such that $\bar{V} \subseteq U$, then $G_W \cap \bar{V} \subseteq \bar{V} \subseteq U$. Hence G is fibrewise regular.

Theorem 3.8 : Any fibrewise topological group is fibrewise R_0 .

Proof:

Let G be a fibrewise topological group over B and any $b \in B$ let $x \in G_b$, then any neighborhood U of x in G there exist neighborhood V of x in G such that $\bar{V} \subseteq U$ from Corollary 2.2.6. Hence any neighborhood W of b in B is $G_W \cap \overline{\{x\}} \subseteq G_W \cap \bar{V} \subseteq \bar{V} \subseteq U$. This implies G is fibrewise R_0 .

Corollary 3.9: If G is fibrewise T_2 then G is fibrewise T_3 .

Proof:

Let G be fibrewise T_2 , then G is fibrewise T_0 and from Theorem 3.8 G is fibrewise R_0 . Hence G is fibrewise T_3 .

Theorem 3.10 : If G is a fibrewise topological group over B , which is fibrewise T_1 , then G is fibrewise completely regular.

Proof:

Let G be a fibrewise T_1 and any $b \in B$ let $x \in G_b$ and F be a closed set of G such that $x \notin F$. Then $x^{-1}F$ is closed set of G not containing e_G and from Theorem 2.2.7 there is a continuous function $f: G \rightarrow I$ such that $f(e_G) = 0$ and $f(y) = 1$ for $y \in x^{-1}F$. Now, the function $\alpha(g) = f(x^{-1}g)$, $g \in G$ is continuous from G to I , then any neighborhood W of b , the restricted $\alpha_{G_W}: G_W \rightarrow I$ is continuous and $\alpha_{G_W}(x) = f(e_G) = 0$ and $\alpha_{G_W}(x') = f(x^{-1}x') = 1$, for $x' \in F \cap G_W \subseteq F$. Hence G is fibrewise completely regular.

Proposition 3.11 : A closed fibrewise subgroup of fibrewise normal space is fibrewise normal.

Proof:

Let G be a fibrewise normal space and let H be a closed fibrewise subgroup of G . Let E, F be disjoint closed sets of H and $b \in B$, then E, F are disjoint closed sets of G . Since G is fibrewise normal then there exists a neighborhood W of b in B and two disjoint neighborhoods U, V of



$G_W \cap E$, $G_W \cap F$ in G_W . Let $U' = U \cap H_W$, $V' = V \cap H_W$ where $H_W = G_W \cap H$. Then U' , V' are disjoint neighborhoods of $H_W \cap E$, $H_W \cap F$ in H_W . Hence H is fibrewise normal space.

Proposition 3.12: Let G be a fibrewise topological group over B . If G is fibrewise Hausdorff then G is fibrewise functionally Hausdorff.

Proof:

Let G be a Hausdorff and any $b \in B$ let $x, y \in G_b$ $x \neq y$ then $xy^{-1} \neq e_G$ and $xy^{-1} \in G_{e_B}$ but $e_G \in G_{e_B}$ since G is fibrewise Hausdorff then there exist two disjoint open sets U, V such that $xy^{-1} \in U$, $e_G \in V$ then V^c is closed and does not contain e_G from Theorem 2.2.7 there exist a continuous function $f: G \rightarrow I$ such that $f(e_G) = 0$, $f(g) = 1$ for $g \in V^c$ and $xy^{-1} \in V^c \Rightarrow f(xy^{-1}) = 1$. And $\alpha(h) = f(hy^{-1})$ is continuous function from G to I and $\alpha(y) = f(e_G) = 0$, $\alpha(x) = f(xy^{-1}) = 1$ and any nbd W of b the restricted function $\alpha_{G_W}: G_W \rightarrow I$ is continuous and $\alpha_{G_W}(y) = 0$, $\alpha_{G_W}(x) = 1$. Hence G is fibrewise functionally Hausdorff.

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الفهرس

الصفحة	اسم الباحث	عنوان البحث	ر.ت
1-23	يونس يوسف أبونايجي	وضع الضاهر موضع الضمير ودلالته على المعنى عند المفسرين	1
24-51	محمد خليفة صالح خليفة محمود الجداوي	دراسة استقصائية حول مساهمة تقنية المعلومات والاتصالات في نشر ثقافة الشفافية ومحاربة الفساد	2
52-70	Ebtisam Ali Haribash	An Interactive GUESS Method for Solving Nonlinear Constrained Multi-Objective Optimization Problem	3
71-105	احمد علي الهادي الحويج احمد محمد سليم معوال	العوامل الخمسة الكبرى للشخصية وعلاقتها بالذكاء الوجداني لدى طلبة مرحلة التعليم الثانوي	4
106-135	محمد عبد السلام دخيل	في المجتمع الليبي التحضر وانعكاساته على الحياة الاجتماعية "دراسة ميدانية في مدينة الخمس"	5
136-158	سالم فرج زويبيك	الاستعارة التهكمية في القرآن الكريم	6
159-173	أسماء جمعة القلعي	دور الرياضات العملية الصوفية في تهذيب السلوك	7
174-183	S. M. Amsheri N. A. Abouthferah	On Coefficient Bounds for Certain Classes of Analytic Functions	8
184-191	N. S. Abdanabi	Fibrewise Separation axioms in Fibrewise Topological Group	9
192-211	Samah Taleb Mohammed	Investigating Writing Errors Made by Third Year Students at the Faculty of Education El-Mergib University	10
212-221	Omar Ali Aleyan Eissa Husen Muftah AL remali	SOLVE NONLINEAR HEAT EQUATION BY ADOMIAN DECOMPOSITION METHOD [ADM]	11
222-233	حسن احمد قرقد عبدالباسط محمد قريصة مصطفى الطويل	قياس تركيز بعض العناصر الثقيلة في المياه الجوفية لمدينة مصراته	12
234-244	ربيعة عبد الله الشبير عائشة أحمد عامر عبير مصطفى الهصيك	تعادم الدوال الكروية المناظرة لقيم ذاتية على سطح الكرة	13
245-255	Khadiga Ali Arwini Entisar Othman Laghah	λ -Generalizations And g - Generalizations	14



256-284	خيري عبدالسلام حسين كليب عبدالسلام بشير اشتيوي بشير ناصر مختار كصارة	Impact of Information Technology on Supply Chain management	15
285-294	Salem H. Almadhun, Salem M. Aldeep, Aimen M. Rmis, Khairia Abdulsalam Amer	Examination of 4G (LTE) Wireless Network	16
295-317	نور الدين سالم فريوع	التجربة الجمالية لدى موريس ميرلوبوتي	17
318-326	ليلى منصور عطية الغويج هدى على التقبي	Effect cinnamon plant on liver of rats treated with trichloroethylene	18
327-338	Fuzi Mohamed Fartas Naser Ramdan Amaizah Ramdan Ali Aldomani Husamaldin Abdualmawla Gahit	Qualitative Analysis of Aliphatic Organic Compounds in Atmospheric Particulates and their Possible Sources using Gas Chromatography Mass Spectrometry	19
339-346	E. G. Sabra A. H. EL- Rifae	Parametric Tension on the Differential Equation	20
347-353	Amna Mohamed Abdelgader Ahmed	Totally Semi-open Functions in Topological Spaces	21
354-376	زينب إمام أبو راس حواء بشير بالنور	كتاب الخصائص لابن جني دراسة بعض مواضع الحذف من ت"392" المسمى: باب في شجاعة العربية	22
377-386	لطيفة محمد الدالي	Least-Squares Line	23
387-397	نادية محمد الدالي ايمان احمد اخميرة	THEORETICAL RESEARCH ON AI TECHNOLOGIES FOR LEARNING SYSEM	24
398-409	Ibrahim A. Saleh Tarek M. Fayez Mustafah M. A. Ahmad	Influence of annealing and Hydrogen content on structural and optoelectronic properties of Nano-multilayers of a-Si:H/a-Ge: H used in Solar Cells	25
410-421	أسماء محمد الحبشي	The learners' preferences of oral corrective feedback techniques	26
422-459	أمينة محمد العكاشي ربيعة عثمان عبد الجليل عفاف محمد بالحاج فتحية علي جعفر	التقدير الإيجابي المسبق لفاعلية الذات ودوره في التغلب على مصادر الضغوط النفسية " دراسة تحليلية "	27



460-481	Aisha Mohammed Ageal Najat Mohammed Jaber	English Pronunciation problems Encountered by Libyan University Students at Faculty of Education, Elmergib University	28
482-499	الحسين سليم محسن	The Morphological Analysis of the Quranic Texts	29
500-507	Ghada Al-Hussayn Mohsen	Cultural Content in Foreign Language Learning and Teaching	30
508-523	HASSAN M. ALI Mostafa M Ali	The relationship between <i>slyA</i> DNA binding transcriptional activator gene and <i>Escherichia coli</i> fimbriae and related with biofilm formation	31
524-533	Musbah A. M. F. Abduljalil	Molecular fossil characteristics of crude oils from Libyan oilfields in the Zalla Trough	32
534-542	سعدون شهبوب محمد	تلوث المياه الجوفية بالنترات بمنطقة كعام، شمال غرب ليبيا	33
543-552	Naima M. Alsharif Mahmoud M. Buazzi	Analysis of Genetic Diversity of <i>Escherichia Coli</i> Isolates Using RAPD PCR Technique	34
553-560	Hisham mohammed alnaib alshareef aisha mohammed elfagaeh aisha omran alghawash abdualaziz ibrahim lawej safa albashir hussain kaka	The Emergence of Virtual Learning in Libya during Coronavirus Pandemic	35
561-574	Abdualaziz Ibrahim Lawej Rabea Mansur Milad Mohamed Abduljalil Aghnayah Hamza Aabeed Khalafllaa ³	ATTITUDES OF TEACHERS AND STUDENTS TOWARDS USING MOTHER TONGUE IN EFL CLASSROOMS IN SIRTE	36
575-592	صالحة التومي الدروقي أمال محمد سالم أبوسته	دافع الانجاز وعلاقته بالرضا الوظيفي لدى معلمي مرحلة التعليم الأساسي "ببلدية ترهونة"	37
593-609	آمنة سالم عبد القادر قدورة نجية علي جبريل انبية	الإرشاد النفسي ودوره في مواجهة بعض المشكلات الأسرية الراهنة	38
610-629	Hanan B. Abousittash, Z. M. H. Kheiralla Betiha M.A.	Effect Mesoporous silica silver nanoparticles on antibacterial agent Gram- negative <i>Pseudomonas aeruginosa</i> and Gram-positive <i>Staphylococcus aureus</i>	39
630-652	حنان عمر بشير الرمالي	برنامج التربية العملية وتطويره	40
653-672	Abdualla Mohamed Dhaw	Towards Teaching CAT tools in Libyan Universities	41



673-700	عثمان علي أميمن سليمة رمضان الكوت زهرة عثمان البرق	سبل إعادة أعمار وتأهيل سكان المدن المدمرة بالحرب ومعوقات المصالحة الوطنية في المجتمع الليبي: مقارنة نفس-اجتماعية	42
701-711	Abdulrhman Mohamed Egnebr	Comparison of Different Indicators for Groundwater Contamination by Seawater Intrusion on the Khoms city, Libya	43
712-734	Elhadi A. A. Maree Abdualah Ibrahim Sultan Khaled A. Alurffi	Hilbert Space and Applications	44
735-759	معتوق علي عون عمار محمد الزليطني عرفات المهدي قرينات	الموارد الطبيعية اللازمة لتحقيق التنمية الاقتصادية بشمال غرب ليبيا وسبل تحقيق الاستدامة	45
760-787	سهام رجب العطوي هدى المبروك موسى	الخلج وعلاقته بمفهوم الذات لدى تلاميذ الشق الثاني بمرحلة التعليم الاساسي بمنطقة جنزور	46
788-820	هنية عبدالسلام بالوص زهرة المهدي أبو راس	الصلابة النفسية ودورها الوقائي في مواجهة الضغوط النفسية	47
821-847	عبد الحميد مفتاح أبو النور محي الدين علي المبروك	ودوره في الحد من التمر التوجيه التربوي والإرشاد النفسي المدرسي	48
848	الفهرس		52