International Journal of Mathematical Archive-8(6), 2017, 8-14
Available online through www.ijma.info ISSN 2229 – 5046

TENSOR PRODUCT OF A NEAR-FIELD SPACE AND SUB NEAR-FIELD SPACE OVER A NEAR-FIELD

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Received On: 21-05-17; Revised & Accepted On: 03-06-17)

ABSTRACT

A tensor product of near-field space and sub near-field space over a near-field defined. But it turned out to be an abelian group. In order to avoid this special situation, this concept is generalized further by Dr N V Nagendram in this paper. Now there are two tensor products for the same pair of sub near-field spaces of a near-field space over a near-field. This situation fits better in the theory of near-field spaces and their sub near-field spaces over a near-field. It has been seen here that there may be two dual near-field spaces for a pair of sub near-field spaces over a near-field.

Keywords: *sub near-field space, near-field space, semi simple near-field space, ordered Euclidean near-field spaces, vector lattices.*

2000 Mathematics Subject Classification: *43A10, 46B28, 46H25, 46H99, 46L10, 46M20, 51 M 10, 51 F 15, 03 B 30.*

SECTION 1: INTRODUCTION

We write maps on the right and hence use left near-field spaces and the traditional sub near-field spaces are right sub near-field spaces.

Definition 1.1 (N-sub near-field space): Let (N, +, .) be a left near-field space. A sub near-field space (M, +) is called an N-sub near-field space i.e. traditional one if there is a near-field space homo-morphism $\theta : N \to Map(M)$. As usual, we write gn to mean $g(n\theta)$ for $g \in M$ and $n \in N$. In this case the group elements distribute over the near-field spaces.

Definition 1.2 (Complementary N-near-field space): M is called a complementary N-sub near-field space or N – co sub near-field space, for short, if there is a semi sub near-field space elements distribute over the sub near-field space elements and the action of N is usually written on the left of the elements of M.

Definition 1.3 ((N, T) – bi sub near-field space): Let N and T be two left near-field spaces. A sub near-field space M is called an (N, T) – bi sub near-field space if

(a) M is an N-co sub near field space
(b) M is an T-sub near-field space and (c) $(ng)t = n(gt)$, $\forall\, g \in M, n \in N, t \in T$.

Definition 1.4 (left strong N-sub near-field space): M is called left strong N-sub near-field space if the action of N is defined on the left of M satisfying the following conditions $\forall\, n, n' \in N$ and $g, g' \in M$

(a) $(nn')g = n(n'g)$
(b) $n(g + g') = ng + ng'$ and (c) $(n + n')g = ng + n'g$.

Note-1.5: A right strong N-sub near-field space is defined similarly. (N, +) is an (N – N) – bi sub near-field space for the left as well as right near-field space N over a near-field. If N is distributive near-field space then (N, +) is a left as well as right strong N-sub near-field space. Many more examples of these structures are given in near-field space related topic.

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Definition 1.6 (N-homomorphism): Let M and K be two N-sub near-field spaces (N-co sub near-field space. A sub near-field space homomorphism $\theta : M \to K$ is called an N-homomorphism if for any $g \in M$ and $n \in N$, $(gn)\theta = (g\theta)n$, $((rg)\theta = r(g\theta))$.

Note-1.7: An (N – T) – homomorphism for (N – T)-bi sub near-field space are defined in a similar way.

SECTION 2: TENSOR PRODUCT

Let N be left near-field space, A an N-sub near-field space and B an N-co sub near-field space. Let E be the free collection of sub near-field spaces on $A \times B$. Let P and Q be the normal sub near-field spaces of E generated by
$\{(a + a|, b) – (a', b) – (a, b), (ar, b) – (a, rb) \mid a, a' \in A, b \in B, r \in N\}$ and
$\{(a, b + b') – (a, b') – (a, b), (ar, b) – (a, rb) \mid a \in A, b, b' \in B, r \in N\}$ respectively.

We call E/P the left tensor product of A and B and denote it by $A_N \otimes B$ and call E/Q the right tensor product of A and B and denote it by $A \otimes_N B$. The coset (a, b) + P is denoted by $a_l \otimes b$ and (a, b) + Q is denoted by $a \otimes_r b$. The coser P is denoted by 0 in both cases. Since E is generated by $A \times B$, $E/P = A_N \otimes B$ and $E/Q = A \otimes_N B$ are generated by $\{a_l \otimes b/a \in A, b \in B\}$ and $\{a \otimes_r b|a \in A, b \in B\}$ respectively. An element of $A_N \otimes B$ ($A \otimes_N B$) is a finite sum of the form $\sum \in_i (a_i\, l \otimes \otimes b_i)(\sum \in_i (a_i \otimes_r b_i))$, where each $\in_i = \pm 1$.

The following result is a direct consequence of the definition of tensor product of near-field space and sub near-field space over a near-field.

Theorem 2.1: $\forall\, a, a' \in A$, $b \in B$, $r \in N$ the following are satisfied in $A_N \otimes B$:

(i) $(a + a')_l \otimes b = a_l \otimes b + a'_l \otimes b$
(ii) $ar_{l \otimes} b = a_; \otimes rb$
(iii) $0_{Al} \otimes b = 0$
(iv) $(-a)_l \otimes b = - (a_l \otimes b)$.

Theorem 2.2: $\forall\, a \in A$, $b, b' \in B$, $r \in N$ the following are satisfied in $A \otimes_N B$:

(i) $(a\,)_l \otimes (b + b')' = a \otimes_r b + a \otimes_r b'$
(ii) $ar \otimes_r b = a \otimes_r rb$
(iii) $a \otimes_r Bb = 0$
(iv) $a \otimes_r (-b) = - (a \otimes_r b)$.

Remark 2.3: In general $(a + a')r \neq ar + a'r$ in A as A is an N-sub near-field space. But we have

$$\begin{aligned}(a + a')r_l \otimes b &= (a + a')_l \otimes rb = a_l \otimes rb + a'_l \otimes rb \\ &= ar_l \otimes b + a'r_l \otimes b \\ &= (ar + a'r)_l \otimes b.\end{aligned}$$

This shows that in $A_N \otimes B$ with $b \neq 0$.

Remark 2.4: It is possible that $a \otimes_r b = 0$ in $A \otimes_N B$, with $b \neq 0$. Later on we will show these by examples and we generalize the definition of a middle linear map.

Definition 2.5 (left N-middle linear map(LNMLM)): Let N, A and B be as before and let C be any sub near-field space with a map $f : A \times B \to C$. then we call f a left N-middle linear map if $(a + a', b) f = (a, b) f + (a' , b) f$, $(ar, b) f = (a, rb) f$, $\forall\, a, a' \in A$, $b \in B$, $r \in N$.

Definition 2.6 (Right N-middle linear map(RNMLM)): Let N , A and B be as before and let C be any sub near-field space with a map $f : A \times B \to C$. then we call f a left N-middle linear map if $(a, b + b') f = (a, b) f + (a , b') f$, $(ar, b) f = (a, rb) f$, $\forall\, a, a' \in A$, $b,b' \in B$, $r \in N$.

It is easy to see that $\theta_l = j\pi_P : A \times B \to A_N \otimes B = E/P$, $(a, b) \mapsto a_l \otimes b$ and
$\theta_l = j\pi_Q : A \times B \to A \otimes_N B = E/Q$, $(a, b) \mapsto a \otimes rb$ are

LNMLM and RNMLM respectively. Here $j : A \times B \to E$ is the inclusion map and $\pi_P : E \to E/P$ and $\pi_Q : E \to E/Q$ are the natural homomorphisms. We call θ_l (θ_r) the canonical LNMLM (RNMLM).

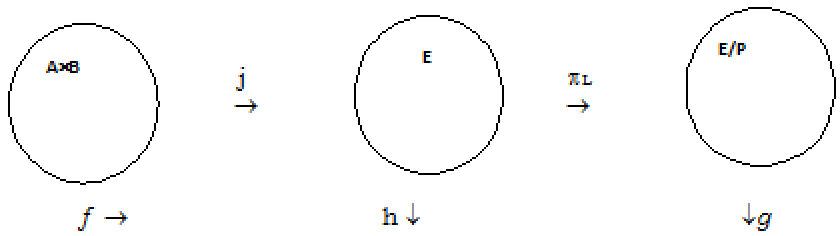
Now we prove the universal property of the tensor product of near-field space and sub near-field space over a near-field N.

Theorem 2.7: Let N be a left-near field space, *A* be an N-sub near-field space and B an N-co sub near-field space. Let C be a group with a function $f : A \times B \rightarrow C$, and θ_l (θ_r) be as above.

(a). If *f* is a LNMLM, then there exists a unique sub near-field space homomorphism $g : A_N \otimes B \rightarrow C$, such that $\theta_l\, g = f$
(b). If *f* is a RNMLM, then there exists a unique sub near-field space homomorphism $g : A \otimes_N B \rightarrow C$, such that $\theta_r\, g = f$.

Proof: Given N be a left-near field space, *A* be an N-sub near-field space and B an N-co sub near-field space. Let C be a group with a function $f : A \times B \rightarrow C$.

To prove (a): Let us consider the following diagrammatic expression of near-field spaces over a near-field N.



where h is the unique homomorphism extending *f*, as E is the free sub near-field space on A × B. Since *f* is an LNMLM, P ⊆ Ker h. This gives us a unique sub near-field space homomorphism g: E/P → C, such that $\pi_P g = h$. It follows then $\theta_l g = j\pi_L g = jh = f$. Now for the uniqueness let g' be another homomorphism from E/P to C with $\theta_l g' = f$. then
$(a_l \otimes b)g' = (a, b)\,\theta_l g' = (a, b) f = (a, b)jh = (a, b)\, j\pi_L g = (a, b)\theta_l g = (a_l \otimes b)g$.

Therefore, g and g' agree on the generators of $A_N \otimes B$ and hence are equal.

Hence proved (b). In similar manner (b) can be proved. This comples the proof of the theorem.

Corollary 2.8: Let A, A′ be N-sub near-field spaces and B, B′ be N-co sub near-field spaces over a near-field N, $f : A \rightarrow A'$ and $g : B \rightarrow B'$ be N-homomorphisms of N-sub near-field spaces and N-co sub near-field spaces respectively. Then there are unique sub near-field space homomorphisms $\phi : A_N \otimes B \rightarrow A'_N \otimes B'$ and $\Psi : A \otimes_N B \rightarrow A' \otimes_N B'$ such that $(a_l \otimes b)\phi = af_l \otimes bg$ and $(a \otimes_r b)\,\Psi = af \otimes_r bg$.

Note-2.9: The homomorphism ϕ and Ψ in the above corollary are denoted by $f_l \otimes g$ and $f \otimes_r g$ respectively.

If A, A′, A″ are N-sub near-field spaces of a near-field space over a near-field N and B, B′, B″ are N-sub near-field spaces of a near-field space over a near-field N with N-homomorphisms $f : A \rightarrow A'$, $f' : A \rightarrow A''$, $g : B \rightarrow B'$ and $g' : B \rightarrow B''$, then $(f_l \otimes g)(f'_l \otimes g') = ff'_l \otimes gg'$ and $(f \otimes_r g)(f' \otimes \otimes_r g') = f f' \otimes_r gg'$. Moreover, if *f* and *g* are isomorphisms then $f_l \otimes g$ and $f \otimes_r g$ are isomorphisms.

Theorem 2.10: Let N and T be left near-field spaces over a near-field, A an (N – T) - bi sub near-field space and B an T- co sub near-field space over a near-field. The $A_T \otimes B$ and $A \otimes_T B$ are N – co sub near-field spaces over a near-field N.

Proof: ∀ n ∈ N, define $\alpha_n : A \times B \rightarrow A_T \otimes B$ by $(a, b)\,\alpha_n = na_l \otimes b$, for all (a, b) ∈ A × B. We claim that α_n is a LTMPM. For all $a, a' \in A$, b ∈ B and t ∈T then we have the following relation as
$(a + a', b)\,\alpha_n = n(a + a')_l \otimes b = (na + na')_l \otimes b = na_l \otimes b + na'_l \otimes b = (a, b)\,\alpha_n + (a', b)\,\alpha_n$.
$(at, b)\,\alpha_n = n(at)_l \otimes b = (na)\,t_l \otimes b = na_l \otimes sb = (a, sb)\,\alpha_n$.

By theorem 2.9 there is a unique endomorphism β_n of $A_T \otimes B$ such that $\theta_l\, \beta_n = \alpha_n$, where θ_l is the canonical LTMPM : $A \times B \rightarrow A_T \otimes B$. The action of N on $A_T \otimes B$ is now defined by $nu = u\beta_n$ for n ∈ N and $u \in A_T \otimes B$. We claim that this action defines $A_T \otimes B$ as an N-co sub near-field space over a near-field N. For all $u, u' \in A_T \otimes B$ and n, n′ ∈ N we have $n(u + u') = (u + u')\,\beta_n = u\,\beta_n + u'\,\beta_n = nu + nu'$. In order to prove that $(nn')u = n(n'u)$, it is enough to prove that $\beta_{nn'} = \beta_{n'}\beta_n$ for all n, n′ ∈ N. we look at their action on generators of $A_T \otimes B$.

$(a_l \otimes b)\,\beta_{nn'} = (a, b)\theta_l\,\beta_{nn'} = (a, b)\,\alpha_{nn'} = (nn')a_l \otimes b = n(n'a)_l \otimes b = (n'a, b)\alpha_n = (n'a_l \otimes b)\,\beta_n = (a, b)\,\alpha_{n'}\,\beta_n = (a_l \otimes b)\,\beta_{n'}\beta_n$. The fact that $A_T \otimes B$ is N-co sub near-field space over a near-field and similar manner one can prove that $A \otimes_T B$ is an N-co sub near-field space over a near-field. This completes the proof of the theorem.

Note-2.11: $N_N \otimes B$ and $N \otimes_N B$ are co sub near-field spaces for any N-co sub near-field space B over a near-field.

Note-2.12: Let N be a left near-field space with 1, and B be any unital N-co sub near-field space. Then for $n \in N$ and $b \in B$, we have $n_l \otimes b = 1_l \otimes nb$ and $n \otimes_n b = 1 \otimes_n nb$. Therefore we have the following results:

(a) $N_N \otimes B$ is generated by $\{ 1_l \otimes b \mid b \in B \}$
(b) $N \otimes_N B$ is generated by $\{0 \otimes_n b, 1 \otimes_n b / b \in B \setminus \{0\}\}$.
(c) $\theta_b : N \to N_N \otimes B$ defined by $n\theta_b = n_l \otimes b$ is a sub near-field space homomorphism .
(d) $\theta_b : N \to N \otimes_N B$ defined by $n\theta_b = n \otimes_n b$ is not a sub near-field space homomorphism in general.

Theorem 2.13: let N and T be left near-field spaces, A an N-sub near-field space and B an (N – T)-bi sub near-field space. Then $A_N \otimes B$ is an T-sub near-field space with T acting on the right. If in addition B is a right strong T-sub near-field space then $A \otimes_N B$ is also a T-co sub near-field space with T acting on the right.

Proof: For $t \in T$ define $\alpha_t : A \times B \to A_N \otimes B$ by $(a, b)\, \alpha_t = a_l \otimes bt$. It is easy to see that α_t is a LNMLM.

This gives us a unique endomorphism β_t of $A_N \otimes B$ such that $\theta_l\, \beta_t = \alpha_t$, where θ_l: $A \times B \to A_N \otimes B$ is the canonical LNMLM. For all $(a_l \otimes b) \in A_N \otimes B$, we have $(a_l \otimes b)\, \beta_t = (a, b)\, \theta_l\, \beta_t = (a, b)\, \alpha_t = a_l \otimes (bt)$.

Now we define an action of T on $A_N \otimes B$ by $ut = u\beta_t\ \forall\ u \in A_N \otimes B$. Clearly, $(u + u')t = ut + u't,\ \forall\ u, u' \in A_N \otimes B$.

For the other condition we need to show that $\beta_{tt'} = \beta_t\, \beta_{t'}\ \forall\ t, t' \in T$. It is enough to look at their behaviour on the generators.
$(a_l \otimes b)\, \beta_{tt'} = a_l \otimes b\,(tt') = a_l \otimes (bt)\, t' = (a_l \otimes (bt))\, \beta_{t'} = (a_l \otimes b)\, \beta_t\, \beta_{t'}$. The second part can be proved in similar manner. This completes the proof of the theorem.

Corollary 2.14: $A_N \otimes B$ is an N-co sub near-field space with N acting on the right. If N is distributive near-field space then $A_N \otimes N$ and $A \otimes_N N$ is an N- co sub near-field space with N acting on the right.

Note-2.15: Let N be a left near-field space with 1 and A be a unital N-sub near-field space. Then we have $A_N \otimes N$ is generated by notation of a set $\{a_1 \otimes 1, a_l \otimes 0 \mid a \in A \setminus \{0\}\}$ and $A \otimes_N N$ is generated by $\{a \otimes_r 1 \mid a \in A\}$.

Note-2.16: If A is any sub near-field space and B is an abelian sub near-field space then $A_Z \otimes B$ and $A \otimes_Z B$ are right Z-co sub near-field spaces and hence are abelian sub near-field spaces over a near-field N.

Note-2.17: If N is a near-field and A is an N-sub near-field space in the near-field spaces sense, that is (A, +) is not necessarily abelian, then $A_N \otimes B$ and $A \otimes_N B$ can be constructed, which may be different.

The structure of tensor products of near-field spaces can be explored further and these proofs here to show the importance of this concept.

ACKNOWLEDGEMENT

The author being a Professor is indebted to the referee for his various valuable comments leading to the improvement of the advanced research article. This work was supported by the chairman Sri B Srinivasa Rao, Kakinada Institute of Technology & Science (K.I.T.S.), R&D education Department S&H (Mathematics), Divili 533 433. Andhra Pradesh INDIA.

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Source of support: Nil, Conflict of interest: None Declared.