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A CONNECTION BETWEEN p-ADIC BANACH SPACES AND LOCALLY CONVEX COMPACTOIDS

by

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Report 8736
December 1987

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ABSTRACT. For a vector space $E$ over a non-archimedean valued field $K$ a correspondence $p \leftrightarrow p^0$ is established between seminorms $p$ on $E$ and compactoids $p^0$ in $E^\ast$. Examination of it yields the solution of two open problems (see §4 and §8) and a reformulation of Serre's renorming problem (see §2). As a by-product results on metrizable compactoids are obtained (see §6).

§0 THE CORRESPONDENCE $p \leftrightarrow p^0$.

Throughout this note $K$ is a non-archimedean valued field, complete with respect to the metric induced by the nontrivial valuation $| |$. Let $E$ be a $K$-vector space, let $E^\ast$ be its algebraic dual. A (non-archimedean) seminorm $p$ on $E$ is polar ([3], Definition 3.1), if

$$p = \sup \{|f| : f \in E^\ast, |f| \leq p\}$$

Let $P_E$ be the set of all polar seminorms on $E$. For each $p \in P_E$ we set

$$p^0 = \{f \in E^\ast : |f| \leq p\}$$

Then $p^0$ is an absolutely convex, edged ([3],§1b) subset of $E^\ast$. It is easy to see that $p^0$ is a closed compactoid ([3],§1e) with respect to the topology $\sigma(E^\ast, E)$, hence complete.
Let $C_{E^*}$ be the set of all closed absolutely convex, edged compactoids in $E^*$ with respect to $\sigma(E^*, E)$.

**PROPOSITION 0.** The map $p \mapsto p^0$ is a bijection of $P_E$ onto $C_{E^*}$. Its inverse assigns to every $A \in C_{E^*}$ the seminorm $p$ given by

$$p(x) = \sup \{|f(x)| : f \in A\} \quad (x \in E)$$

**Proof.** We shall prove surjectivity of $p \mapsto p^0$ leaving the (easy) rest of the proof to the reader. So, let $A \in C_{E^*}$; we shall prove that $A = p^0$ where $p(x) = \sup \{|f(x)| : f \in A\}$.

Obviously, $A \subseteq p^0$. Now let $g \in E^* \setminus A$, we prove that $g \notin p^0$. The space $E^*$ is of countable type hence strongly polar ([3], Theorem 4.4). So by [3], Theorem 4.7, there exists a $\theta \in (E^*, \sigma(E^*, E))'$ such that $|\theta| \leq 1$ on $A$, $|\theta(g)| > 1$. But, by [3], lemma 7.1, $\theta$ has the form $f \mapsto f(x)$ for some $x \in E$. Thus, $|f(x)| \leq 1$ for $f \in A$, $|g(x)| > 1$ i.e., $p(x) \leq 1$ and $|g(x)| > 1$ and it follows that $g \notin p^0$.

**Remarks.**

1. Let $K$ be spherically (= maximally) complete. Then each nonarchimedean seminorm $p$ on $E$ for which $p(x) \leq |x|$ ($x \in E$) is polar ([3], Remark following 3.1).

2. Let $\tau$ be the locally convex topology on $E$ induced by all nonarchimedean seminorms i.e., $\tau$ is the strongest among all locally convex topologies on $E$. It is not hard to see that $(E, \tau)$ is a complete polar ([3], Definition 3.5) space and that $(E, \tau)$ and $(E^*, \sigma(E^*, E))$ are each others strong dual spaces.
§1 NORMS $p$ FOR WHICH $p^0$ IS $c'$-COMPACT

Recall that an absolutely convex subset $A$ of a locally convex space $F$ over $K$ is $c'$-compact if for each neighbourhood $U$ of 0 in $F$ there exist $x_1, \ldots, x_n \in A$ (rather than $x_1, \ldots, x_n \in F$) such that $A \subset U + \text{co} \{x_1, \ldots, x_n\}$. (Here $\text{co}$ indicates the absolutely convex hull)

THEOREM 1.1. For a polar seminorm $p$ on a $K$-vector space $E$ the following are equivalent.

(a) $p(x) \in |K|$ for each $x \in E$. Each one-dimensional subspace of $E$ has a $p$-orthocomplement.

(b) $p^0$ is $c'$-compact.

Proof. $(a) \Rightarrow (b)$. By [7], Theorem 3.2, it suffices to prove that for each $\phi \in (E^*, \sigma(E^*, E))'$

$$\max \{ |\phi(f)| : f \in p^0 \}$$

exists. Since $\phi$ is an evaluation map we therefore have to show that

$$\max \{ |f(x)| : f \in p^0 \}$$

exists for each $x \in E$. This is obviously true if $p(x) = 0$. So assume $p(x) > 0$. Since $p(x) \in |K|$ we may assume that $p(x) = 1$. For such $x$ we must prove

$$\max \{ |f(x)| : f \in p^0 \} = 1$$

By $(a)$, $Kx$ has a $p$-orthocomplement $H$. The function

$$f : \lambda x + h \mapsto \lambda \quad (\lambda \in K, h \in H)$$
is in $E^*$. We have $|f(x)| = 1$. For $\lambda \in K$, $h \in H$

$$|f(\lambda x + h)| = |\lambda| p(\lambda x) \leq \max(p(\lambda x), p(h)) = p(\lambda x + h)$$

so that $f \in p^0$.

$(\delta) \Rightarrow (\alpha)$. Let $x \in E$. The map $f \mapsto |f(x)|$ ($f \in E^*$) is a continuous seminorm on $(E^*, \sigma(E^*, E))$. By $c'$-compactness its restriction to $p^0$ has a maximum so there exists a $g \in p^0$ with $|g(x)| = p(x)$ (It follows that $p(x) \in |K|$). We prove that $\text{Ker} \cdot g$ is a $p$-orthocomplement of $Kx$. In fact, for $z \in \text{Ker} g$ we have

$$p(x+z) \geq |g(x+z)| = |g(x)| = p(x)$$

Then also

$$p(x+z) \geq p(z)$$

completing the proof of Theorem 1.1.

Note. It is not hard to see that $(a)$ of above is equivalent too.

$(\gamma)$ For each $x \in E$ there exists an $f \in E^*$ with $|f(x)| = p(x)$ and $|f| \leq p$.

For spherically complete $K$ we obtain a simpler form of Theorem 1.1.

COROLLARY 1.2. Let $K$ be spherically complete, let $p$ be a seminorm on $E$ for which $p(x) \in |K|$ for all $x \in E$.

Then the following are equivalent.

$(\alpha) p(x) \in |K|$ for each $x \in E$.

$(\beta) p^0$ is $c'$-compact.

Proof. By [1], lemma 4.35, each onedimensional subspace has a p-orthocomplement.
§2 APPLICATION: A NEW LIGHT ON SERRE'S RENORMING PROBLEM.

Consider the following two statements (*) and (**).

(*) Let $E$ be a $K$-vector space and let $||\cdot||$ be a norm on $E$. Then there exists a norm $||\cdot||'$ on $E$, equivalent to $||\cdot||$, such that $||x||' \leq |K|$ for all $x \in E$.

(**) Let $K$ be spherically complete and let $A$ be a complete absolutely convex compactoid in a Hausdorff locally convex space over $K$. Then there exist a $\lambda \in K$ with $|\lambda| > 1$ and a $c'$-compact $B$ such that $A \subset B \subset \lambda A$.

The question as to whether (*) is true or not is known as Serre's renorming problem. See [2] for more details. We are able to reformulate this problem in terms of compactoids:

PROPOSITION 2.1. The above statements (*) and (**) are equivalent.

Proof. Assume (*). To prove (**) we may assume that $A$ is edged. By [8], Theorem 3, $A$, as a topological module over $B(0,1) := \{ \lambda \in K : |\lambda| \leq 1 \}$, is isomorphic to a bounded submodule of $K^I$ for some set $I$. Let $E$ be the algebraic direct sum $\bigoplus_{i \in I} K_i$ where $K_i = K$ for all $i \in I$.

Then $(E^*, \sigma(E^*, E))$ is in a natural way isomorphic to $K^I$ with the product topology. So we may assume that $A = p^0$ where $p$ is a seminorm on $E$.

By (*) there exists a seminorm $q$, equivalent to $p$, such that $q(x) \in |K|$ for all $x \in E$. By a suitable scalar multiplication we can arrange that, in addition, $p \leq q \leq |\lambda| p$ for some $\lambda \in K$, $|\lambda| > 1$. Then

$$p^0 \leq q^0 \leq \lambda p^0$$
and $q^0$ is $c'$-compact by Corollary 1.2. This proves (**). Now assume (**).

To prove (*) we may assume (see [2]), that $K$ is spherically complete.

Let $p$ be a norm on $E$. By (**) there is a $c'$-compact $B$ and a $\lambda \in K$, $|\lambda| > 1$
with $p^0 \subseteq B \subseteq \lambda p^0$. Then $B = q^0$ for some seminorm $q$ on $E$. We have

$$p \leq q \leq |\lambda| p$$

and $q(x) \in |K|$ for all $x \in E$ by Corollary 1.2.

Note. Serre's renorming problem is still unsettled as far as I know.

§3 Norms $p$ for which $p^0$ Is a Krein-Milman Compactoid.

Recall that an absolutely convex subset $A$ of a locally convex space
over $K$ is a $KM$-compactoid if it is complete and if $A = \overline{co X}$ where $X$ is
compact. (Here $\overline{co X}$ is the closure of $co X$).

Before stating the theorem we first make some simple observations. Let $p$ be a norm on $E$. We say that a collection $(e_i)_{i \in I}$ in $E$ is a

$p$-orthonormal base of $E$ if for each $x \in E$ there exist a unique

$(\lambda_i)_{i \in I} \in K^I$ such that $\{i \in I, |\lambda_i| > \epsilon\}$ is finite for each $\epsilon > 0$ and

$$x = \sum_{i \in I} \lambda_i e_i$$

$$p(x) = \max_{i} |\lambda_i|$$

If $(E,p)$ is complete this definition coincides with the usual one.

**Lemma 3.1.** Let $(E,p)$ be a normed space, let $(\hat{E},\hat{p})$ be its completion.

Then $(E,p)$ has a $p$-orthonormal base if and only if $(\hat{E},\hat{p})$ has a

$p$-orthonormal base.
Proof. It is not hard to see that each p-orthonormal base of \((E, p)\) is also a p-orthonormal base of \((\hat{E}, \hat{p})\). Conversely, let \((e_i)_{i \in I}\) be a p-orthonormal base of \((\hat{E}, \hat{p})\). For each \(i \in I\), choose an \(f_i \in \hat{E}\) with \(p(e_i - f_i) \leq \frac{1}{2}\).

By [1], Exercise 5.C, \((f_i)_{i \in I}\) is a p-orthonormal base of \((\hat{E}, \hat{p})\).

Clearly \((f_i)_{i \in I}\) is a p-orthonormal base of \((E, p)\).

THEOREM 3.2. For a polar norm \(p\) on a \(K\)-vector space \(E\) the following are equivalent.

(a) \((E, p)\) has a p-orthonormal base

(b) \(p^0\) is a KM-compactoid.

Proof. (a) \(\Rightarrow\) (b). Let \((e_i)_{i \in I}\) be a p-orthonormal base of \((E, p)\). The formula

\[
\phi(f) = (f(e_i))_{i \in I}
\]

defines a map \(\phi : p^0 \rightarrow B(0,1)^I\). Straightforward verifications show that \(\phi\) is an isomorphism of topological \(B(0,1)^I\)-modules. From [8], Theorem 16 we obtain that \(B(0,1)^I\), hence \(p^0\), is a KM-compactoid.

(b) \(\Rightarrow\) (a). Suppose \(p^0 = \text{co} X\) where \(X\) is a compact subset of \(E^*\).

Let \(C(X^*K)\) be the Banach space of all continuous functions \(X^*K\), with the supremum norm \(||\cdot||_w\). Then \(C(X^*K)\) has an orthonormal base. ([1], Theorem 5.22).

The formula

\[
\phi(x)(f) = f(x) \quad (f \in X)
\]

defines a \(K\)-linear map \(\phi : E \rightarrow C(X^*K)\). From
\[ ||f(x)||_\infty = \max_{f \in X} |f(x)| = \sup_{f \in \mathcal{C}(X,K)} |f(x)| = p(x) \]

we obtain that \( \phi \) is an isometry \((E,p) \to (\mathcal{C}(X,K), ||||_\infty)\).

By Gruson's Theorem ([1], 5.9) \( \phi(E) \) has an orthonormal base. Then so has \( \phi(E) \) by Lemma 3.1 and has \( E \).

§4 APPLICATION: A COMPLETE \( c' \)-COMPACT SET WHICH IS NOT A KM-COMPACTOID.

We shall give a negative answer to the Problem following Theorem 1.7 of [6].

PROPOSITION 4.1. Let \( K \) be spherically complete, let \( |K| = [0,\infty) \).

Then there exist a locally convex space \( F \) over \( K \) and a complete \( c' \)-compact subset \( A \subset F \) which is not a KM-compactoid.

Proof. Let \( E := l^\infty \) and let \( F := (l^\infty)' \) (with the topology we agreed upon in §0). Let \( p \) be the standard norm on \( l^\infty \), and set \( A := p^0 \). Since, trivially, \( p(x) \in |K| \) for all \( x \in l^\infty \), we have that \( p^0 \) is \( c' \)-compact (Corollary 1.2).

However, it is known ([1], Cor. 5.19) that \( l^\infty \) has no orthogonal base so that (Theorem 3.2) \( p^0 \) is not a KM-compactoid.

§5 NORMS \( p \) FOR WHICH \( p^0 \) IS METRIZABLE.

THEOREM 5.1. For a polar seminorm \( p \) on a \( K \)-vector space \( E \) the following are equivalent.

(a) \( (E,p) \) is of countable type ([3], Definition 4.3).

(β) \( p^0 \) is metrizable.
Proof. (a) ⇒ (b). There exist \( e_1, e_2, \ldots \) in \( E \) with \( p(e_i) \leq 1 \) for each \( i \) such that the \( K \)-linear span of \( e_1, e_2, \ldots \) is \( p \)-dense in \( E \). The formula

\[
\phi(f) = (f(e_1), f(e_2), \ldots)
\]

defines a map \( \phi : p^0 \to B(0,1)^N \). Straightforward verifications show that \( \phi \) is an isomorphism of topological \( B(0,1) \)-modules of \( p^0 \) onto a submodule of \( B(0,1)^N \).

Now \( B(0,1)^N \) is metrizable (the product topology is induced by the metric

\[
(a,b)_i = \sup_{i \in \mathbb{N}} |a_i - b_i| 2^{-i}
\]

hence so is \( p^0 \).

(b) ⇒ (a). Let \( \lambda \in K, |\lambda| > 1 \). Since \( p^0 \) is a metrizable compactoid there exist, by [3], Proposition 8.2, \( f_1, f_2, \ldots \in \lambda p^0 \) with \( \lim_{n \to \infty} f_n = 0 \) such that

\[
p^0 = \overline{\sup \{f_1, f_2, \ldots\}} \leq \lambda p^0
\]

The map

\[
\phi : x \mapsto (f_1(x), f_2(x), \ldots) \quad (x \in E)
\]

is \( K \)-linear, \( \phi(E) \subset c_0 \). We have for \( x \in E \)

\[
||\phi(x)|| = \sup_{n \in \mathbb{N}} |f_n(x)| = \sup \{ |g(x)| : g \in \overline{\sup \{f_1, f_2, \ldots\}} \}
\]

It follows that

\[
p(x) \leq ||\phi(x)|| \leq |\lambda| p(x)
\]

so that \( p \) is equivalent to \( x \mapsto ||\phi(x)|| \), a seminorm of countable type. Hence, \( p \) is of countable type.
§6 APPLICATION: DESCRIPTION OF METRIZABLE COMPACTOIDS.

THEOREM 6.1. Let $A$ be an absolutely convex subset of a Hausdorff locally convex space $F$ over $K$. The following are equivalent.

(a) $A$ is a metrizable compactoid.

(b) As a topological $B(0,1)$-module, $A$ is isomorphic to a submodule of $B(0,1)^\mathbb{N}$.

(c) As a topological $B(0,1)$-module, $A$ is isomorphic to a compactoid in $C_0$.

(d) For each $\lambda \in K$, $|\lambda| > 1$ then exist $e_1, e_2, \ldots \in \lambda A$ with $\lim_{n \to \infty} e_n = 0$ and $A \subseteq \overline{\langle e_1, e_2, \ldots \rangle}$.

(e) There exist $e_1, e_2, \ldots \in F$ with $\lim_{n \to \infty} e_n = 0$ and $A \subseteq \overline{\langle e_1, e_2, \ldots \rangle}$.

(f) There exists an ultrametrizable compact $X \subseteq F$ with $A \subseteq \overline{X}$.

Proof. (a) $\Rightarrow$ (b). It is not hard to see, by using the absolute convexity of $A$, that $\overline{A}$ is also metrizable. As there is no harm in taking $F$ complete we therefore may assume that $A$ is complete. To prove (b) we also may assume that $A$ is edged. By [8], Theorem 3, $A \subseteq B(0,1)^I \subseteq K^I$ for some set $I$. Like in the proof of Proposition 2.1 we may conclude that $A = p^I$ where $p$ is a polar seminorm on $\oplus K_i$ ($K_i = K$ for each $i$). Then $p$ is of countable type by Theorem 5.1. From the proof of (a) $\Rightarrow$ (b) of that Theorem we obtain an isomorphism $A = p^I : B(0,1)^\mathbb{N}$.

(b) $\Rightarrow$ (c). Choose $\lambda_1, \lambda_2, \ldots \in K$, $|\lambda_1| > |\lambda_2| > \ldots$, $\lim_{n \to \infty} \lambda_n = 0$. The formula

$$\phi((a_i)_{i \in \mathbb{N}}) = (\lambda_1 a_1, \lambda_2 a_2, \ldots) \in c_0$$

defines a $B(0,1)$-module isomorphism of $B(0,1)^\mathbb{N}$ onto $C := \overline{\langle \lambda_1 e_1, \lambda_2 e_2, \ldots \rangle}$ where $e_1, e_2, \ldots$ are the standard unit vectors in $c_0$. $\phi$ is a homeomorphism.
B(0,1) \N \to C, and maps A onto a compactoid in c_0.

\( (\gamma) \Rightarrow (\delta) \). See [3], Proposition 8.2.

\( (\delta) \Rightarrow (\varepsilon) \) is trivial.

\( (\varepsilon) \Rightarrow (\eta), \{0,e_1,e_2,\ldots\} \) is compact and ultrametrizable.

\( (\eta) \Rightarrow (\alpha) \). We may assume that F is complete. It suffices to prove the
metrizability of \( B := \overline{co X} \).

B is a complete, edged compactoid. As before we may assume that \( B = p^0 \)
for some polar seminorm \( p \) en some K-vector space \( E \) while \( B \subseteq E^* \). The
map \( \phi : E \to C(X \to K) \) defined by

\[ \phi(x)(f) = f(x) \quad (f \in X) \]

is an isometry \( (E,p) \to (C(X \to K), |||\cdot|||_\omega) \).

Now \( X \) is ultrametrizable so by [1], Exercise 3.5, \( C(X \to K) \) is of
countable type. Hence so is \( p \). By Theorem 5.1, \( B = p^0 \) is metrizable.

§7 NORMS \( p \) FOR WHICH \( (p^0)_1 \) IS OF FINITE TYPE.

Recall that an absolutely convex set \( A \) in a locally convex space \( F \) over
K is of finite type if for each zero neighbourhood \( U \) in \( F \) there exists
a finite-dimensional bounded set \( S \subseteq A \) such that \( A \subseteq U + S \).

Let us say that a seminorm \( p \) on a K-vector space \( E \) is of finite type
if \( \text{Ker } p = \{ x \in E : p(x) = 0 \} \) has finite codimension.

**Lemma 7.1.** Let \( A \) be an absolutely convex subset of a locally convex
space \( F \) whose topology is generated by a collection of seminorms of
finite type. Then the following are equivalent.

(\( \alpha \)) \( A \) is a compactoid of finite type.

(\( \beta \)) For each closed linear subspace \( H \) of finite codimension there is a
finite dimensional bounded set \( S \subseteq A \) with \( A \subseteq H + S \).
Proof. \((a) \Rightarrow (\beta)\). (Note. This implication holds for any locally convex space \(F\).) We may assume \([A] = F\).

\(H\) has the form \(D^1 := \{x \in F : f(x) = 0 \text{ for all } f \in D\}\) where \(D\) is a finite dimensional subspace of \(F'\). Let \(f_1, \ldots, f_n\) be a base of \(D\). There exist \(x_1, \ldots, x_n \in F\) with \(f_i(x_j) = \delta_{ij} (i, j \in \{1, \ldots, n\})\). Since \([A] = F\) there exists a \(\lambda \in K, \lambda \neq 0\) such that \(\lambda x_i \in A\) for each \(i \in \{1, \ldots, n\}\).

Set

\[
U := \bigcap_{i=1}^n \{x \in F : |f_i(x)| \leq |\lambda|\}
\]

Then \(U\) is a zero neighbourhood in \(F\). \(A\) is a compactoid of finite type, so there exists a finite dimensional set \(S_1 \subseteq A\) with \(A \subseteq U + S_1\). Let \(x \in U\). Write \(x = y + z\) where

\[
y := x - \sum_{i=1}^n f_i(x) x_i
\]

\[
z := \sum_{i=1}^n f_i(x) x_i
\]

Now, since \(x \in U\), \(|f_i(x)| \leq |\lambda|\) for each \(i\) so that \(z = \sum_{i=1}^n f_i(x) x_i \in A\).

Further, for each \(j \in \{1, \ldots, n\}\)

\[
f_j(y) = f_j(x) - \sum_{i=1}^n f_i(x) f_j(x_i) = f_j(x) - f_j(x) = 0
\]

and it follows that \(y \in D^1 = H\). So \(x = y + z \in H + [x_1, \ldots, x_n] \cap A\). We see that

\[
A \subseteq U + S_1 \subseteq H + S_2 + S_1
\]

where \(S_2 := [x_1, \ldots, x_n] \cap A\). Then \((\beta)\) is proved with \(S := S_1 + S_2\).

\((\beta) \Rightarrow (a)\). Let \(U\) be a zero neighbourhood in \(F\). Since continuous seminorms are of finite type, \(U\) contains a closed subspace \(H\) of finite codimension. By \((\beta)\) there exists a finite dimensional set \(S \subseteq A\) with \(S\) bounded and
A \subset H + S. Then A \subset U + S.

From now on we assume that the valuation on K is dense.

Recall that for an absolutely convex set B we have \( B^* := \bigcup_{|\lambda| < 1} \lambda B \).

**Theorem 7.2.** Let \( p \) be a polar norm on a K-vector space \( E \). Then the following are equivalent.

(a) For each finite dimensional subspace \( D \) of \( E \) there exists a seminorm \( q \) on \( E \), \( q \) of finite type, \( q \leq p \) and \( q = p \) on \( D \).

(b) \((p^0)^i\) is of finite type.

**Proof.** (a) \(\Rightarrow\) (b). As each continuous seminorm on \( E^* \) is of finite type it suffices to prove, by Lemma 7.1, that for a closed subspace \( H \) of \( E^* \) of finite codimension there exists a finite dimensional set \( S \in (p^0)^i \) such that \((p^0)^i \subset H + S\).

Now, by (a), there is a seminorm \( q \) of finite type, \( q \leq p \) on \( E \) and \( q = p \) on \( D := H^1 \). Let

\[ S_1 := \{ f \in E^*: |f| \leq q \}. \]

We see that \( S_1 \) is finite dimensional and since \( q \leq p \) we have \( S_1 \subset p^0 \).

We now shall prove that \((p^0)^i \subset H + S\) where \( S := (S_1)^i \).

In fact, let \( f \in (p^0)^i \). Then there is a \( \lambda \in K \), \( 0 < |\lambda| < 1 \) with \( |f| \leq |\lambda| p \).

Choose \( \lambda' \in K \) with \( |\lambda| < |\lambda'| < 1 \).

We have \( |f| \leq |\lambda| q \) on \( D \) (since \( p = q \) on \( D \)) so we can extend \( f \) to a \( g \in E^* \) with \( |g| \leq |\lambda'| q \) on \( E \). (This is because \( q \) is of finite type so that \((E,q)\) is strongly polar.) Now write

\[ f = f - g + g \]

Since \( f = g \) on \( D \) we have \( f - g \in D^1 = H \).
Also, $|(\lambda')^{-1}g| \leq q$ so that $(\lambda')^{-1}g \in S_1$ i.e. $g \in (S_1)_{-1} = S$.

By lemma 7.1 there exists a finite dimensional set $S \subset (p^0)^i$ so that $(p^0)^i = D^\perp \cap (p^0)^i + S$.

Set $q(x) := \sup_{h \in S}|h(x)|$. \hspace{1cm} (x \in E).

Then $q(x) = 0$ for all $x$ in the space $S^\perp$ which has finite codimension.

So $q$ is of finite type.

Further, for $x \in E$ we have

$$q(x) = \sup_{h \in S}|h(x)| = \sup_{h \in (p^0)^i}|h(x)| = p(x),$$

so $q \leq p$. Finally, if $x \in D$ then

$$p(x) = \sup_{f \in p}|f(x)| = \sup_{f \in (p^0)^i}|f(x)| = \sup_{h \in D \cap (p^0)^i}|h(x) + t(x)|$$

$$= \sup_{t \in S}|t(x)| = q(x).$$

Hence, $p = q$ on $D$.

§8 APPLICATION: A COMPLETE COMPACTOID IN $c_0$ THAT IS NOT OF FINITE TYPE.

If $K$ is spherically complete each complete absolutely convex compactoid
is of finite type (See [4], 2.3).

If $K$ is not spherically complete the unit ball of $c_0$ is a complete
compactoid for the weak topology but not of finite type (See [5], 1.6).

This is a non-metrizable compactoid. A compactoid in $(c_0, || ||)$, not
of finite type, is given in [5], 1.4. However this compactoid is not
closed. The following example provides an answer to the Problem
following 1.5 in [5].
PROPOSITION 8.1. Let $K$ be not spherically complete. Then there exists an absolutely convex complete compactoid in $c_0$ that is not of finite type.

**Proof.** Let $(K^V, | |)$ be the spherical completion of $(K, | |)$ in the sense of [1], Theorem 4.49. Let $E$ be a $K$-subspace of $K^V$ of countably infinite dimension and let $p$ be the valuation $||$ restricted to $E$. Then $x, y \in E$, $x \perp y$ in the sense of $p$ implies $x = 0$ or $y = 0$. Obviously, the norm $p$ is of countable type (hence polar) so, by Theorem 5.1, $p^0$ is metrizable and is by Theorem 6.1, isomorphic to a compactoid in $c_0$.

Suppose $p^0$ were of finite type. Then so would $(p^0)^\dagger$ ([5], Proposition 2.4). By Theorem 7.2 we would have a seminorm $q$ on $E$, $q \leq p$, $q$ of finite type, $q(x) = p(x)$ for some $x \in E$, $x \neq 0$. But then $x \perp \text{Ker } q$ in the sense of $p$ (If $q(y) = 0$ then $p(x-y) \geq q(x-y) = q(x) = p(x)$) which is impossible. So, $p^0$ is not of finite type.
REFERENCES


