Central nilpotency of skew braces

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Expanded group

Definition

An algebra (A, Ω) is called an *expanded group*, if there exist a binary operation $+$, a unary operation $-$ and a constant 0 such that the retract $(A, +, -, 0)$ is a group.

Definition

Let A be an expanded group. A polynomial $f(x_1, \dots, x_k)$, with $k > 1$, is called *absorbing*, if, for all $1 \leqslant i \leqslant k$, and for all $a_j \in A$, with $1 \leqslant j \leqslant k$,

$$f(a_1, \dots, a_{i-1}, 0, a_{i+1}, \dots, a_k) = 0.$$

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Absorbing polynomials

Groups:

$$-x-y+x+y=[x,y]$$

$$[[x,y],z]$$

Rings:

$$x\cdot y$$

Vector spaces:

$$0x+0y+0z$$

Lie algebras:

$$[x,y]$$

Loops:

$$((x+y)+z)-(x+(y+z))$$

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Center

Definition

Let A be an expanded group. An element $c \in A$ is called *central* if, for all binary absorbing polynomial f and for all $a \in A$,

$$f(a,c) = f(c,a) = 0.$$

The *center* $Z(A)$ of A is the subset of all central elements of A.

Definition

An expanded group A is called *abelian* if $Z(A) = A$.

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Examples of centers

Groups:

$$Z(A) = \{c \mid \forall a \in A:\ a + c = c + a\}$$

Rings:

$$Z(A) = \{c \mid \forall a \in A:\ a \cdot c = c \cdot a = 0\} = \mathrm{Ann}_R(R)$$

Vector spaces:

$$Z(A) = A$$

Lie algebras:

$$Z(A) = \{c \mid \forall a \in A:\ [a, c] = 0\} = \mathrm{Rad}([,])$$

Loops:

$$Z(A) = \{c \mid \forall a, b \in A:\ a + c = c + a \ \&\ c + (a + b) = (c + a) + b\}$$

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Nilpotency

Definition

A subalgebra I an expanded group A is called an *ideal* if there exists an endomorphism φ of A such that $\varphi(a) = 0$ if and only if $a \in I$.

Definition

An expanded group A is *nilpotent of class n* if there exists a chain of ideals

$$0 = I_0 \leqslant I_1 \leqslant \cdots \leqslant I_n = A,$$

such that $I_{j+1}/I_j \leqslant Z(A/I_j)$, for every $0 \leqslant j < n$.

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Nilpotent commutative rings

Proposition

A commutative ring R is nilpotent of class n if and only if $R^{n+1} = 0$.

Proof.

Let $I_{j+1} = \{c \in R \mid \forall a \quad a \cdot c \in I_j\}$; then $I_{j+1}/I_j = \mathrm{Ann}(R/I_j)$.
Moreover $I_j = \{c \mid \forall a_1, \ldots, a_j \in A \quad c \cdot a_1 \cdots a_j = 0\}$. □

Here $0 \leqslant I_1 \leqslant \cdots \leqslant I_n$ is the *upper central series*.
The *lower central series* is $R \geqslant R^2 \geqslant R^3 \geqslant \cdots R^n \geqslant 0$.

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Skew braces

Definition

An algebra $(A, +, \circ, 0)$ is called a *skew brace* if

- $(A, +, 0)$ is a group
- $(A, \circ, 0)$ is a group
- $a \circ (b + c) = a \circ b - a + a \circ c$, for all $a, b, c \in A$.

Examples

- Let $(A, +, 0)$ be a group and let $a \circ b = b + a$.
- Let $(A, +, 0)$ be $(\mathbb{Z}_{p^n}, +, 0)$, for some prime p and $n > 1$. Let $0 < k < n$ and let $a \circ b = a + abp^k + p \mod p^n$.
- Let $(R, +, *, 0)$ be a radical ring. If we define $a \circ b = a + a * b + b$ then $(R, +, \circ, 0)$ is a brace.

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Absorbing polynomials of a skew brace

We denote

$$x * y = -x + (x \circ y) - y$$

Observation

Absorbing polynomials for a skew brace are

- $[x, y]_+$,
- $[x, y]_\circ$,
- $x * y$,
- $y * x$.

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Center of a skew brace

Theorem (M. B. & P. J.)

Let B be a skew brace. Then

$$Z(B) = \{c \mid \forall a \in B: \; c + a = a + c = c \circ a = a \circ c\}.$$

Corollary

A skew brace B is abelian if and only if $(B, +)$ is an abelian group and $a + b = a \circ b$, for all $a, b \in B$.

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(Central) nilpotency of skew braces

Upper central series:

$$\zeta_0(B) = 0$$
$$\zeta_n(B) = \{c \mid \forall a \in A: \ c * a, a * c, [a, c]_+ \in \zeta_{n-1}(B)\}$$

Lower central series:

$$\Gamma_0(B) = B$$
$$\Gamma_n(B) = \langle \Gamma_{n-1}(B) * B, B * \Gamma_{n-1}(B), [\Gamma_{n-1}(B), B]_+ \rangle_+$$

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Other notions of nilpotency

Definitions (W. Rump; Ag. Smoktunowicz)

Let B be a skew brace. We define

$$B^1 = B, \qquad B^{n+1} = B * B^n,$$
$$B^{(1)} = B, \qquad B^{(n+1)} = B^{(n)} * B,$$
$$B^{[1]} = B, \qquad B^{[n+1]} = \left\langle \bigcup_{i=1}^{n} B^{[i]} * B^{[n+1-i]} \right\rangle_+ .$$

We say that B is

- *left nilpotent* if $B^n = 0$,
- *right nilpotent* if $B^{(n)} = 0$,
- *nilpotent* if $B^{[n]} = 0$,

for some $n \in \mathbb{N}$.

Relations among nilpotencies

Theorem (F. Cedó, T. Gateva-Ivanova, Ag. Smoktunowicz)

A brace is right nilpotent of class n if and only if its associated set-theoretic solution of Yang-Baxter equation is multipermutational of level n.

Proposition (M. B. & P. J.)

Let B be a skew brace. Then the following properties are equivalent:

- *B is centrally nilpotent,*
- *B is a nilpotent brace and $(B, \circ)$ is a nilpotent group,*
- *B is a right nilpotent brace and both $(B, \circ)$ and $(B, +)$ are nilpotent groups.*

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Commutator of ideals

Definition

Let A be an expanded group and let I, J be two ideals. We define the *commutator* of I, J as the ideal

$$[\![I, J]\!] = \langle f(a, b) \mid a \in I, b \in J, f \text{ absorbing} \rangle.$$

Groups:

$$[\![I, J]\!] = [I, J] = \{[a, b] \mid a \in I, b \in J\}$$

Lie algebras:

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$$[\![I, J]\!] = IJ + JI$$

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Commutator of ideals 2

In general, absorbing polynomials may contain constants from $A \setminus (I \cup J)$.

Loops:

$$
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Solvability

Definitions

Let A be an expanded group. We define

$$A_0 = A \qquad \text{and} \qquad A_{i+1} = [\![A_i, A]\!].$$

If there exists n such that $A_0 = 0$ then A is *nilpotent of class n*.
We define

$$A^{(0)} = A \qquad \text{and} \qquad A^{(i+1)} = [\![A^{(i)}, A^{(i)}]\!].$$

If there exists n such that $A_0 = 0$ then A is *solvable of class n*.

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Supernilpotency

Definition

An expanded group A is called *supernilpotent of class n* if every $(n+1)$-ary absorbing polynomial is constant.

Theorem (E. Aichinger & J. Ecker)

A group is supernilpotent of class n if and only if it is nilpotent of class n.

Theorem (E. Aichinger & N. Mudrinski)

Every supernilpotent expanded group is nilpotent.

Theorem

Every finite supernilpotent expanded group is a product of expanded p-groups.

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Definition

An expanded group A is called *supernilpotent of class n* if every $(n+1)$-ary absorbing polynomial is constant.

Theorem (E. Aichinger & J. Ecker)

A group is supernilpotent of class n if and only if it is nilpotent of class n.

Theorem (E. Aichinger & N. Mudrinski)

Every supernilpotent expanded group is nilpotent.

Theorem

Every finite supernilpotent expanded group is a product of expanded p-groups.