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GROUP ALGEBRAS WHOSE GROUP OF UNITS IS POWERFUL

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Abstract

A p-group is called powerful if every commutator is a product of pth powers when p is odd and a product of fourth powers when $p = 2$. In the group algebra of a group G of p-power order over a finite field of characteristic p, the group of normalized units is always a p-group. We prove that it is never powerful except, of course, when G is abelian.

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Throughout this note G is a finite p-group and F is a finite field of characteristic p. Let

$$V(FG) = \left\{ \sum_{g \in G} \alpha_g g \in FG \;\middle|\; \sum_{g \in G} \alpha_g = 1 \right\}$$

be the group of normalized units of the group algebra FG. Clearly $V(FG)$ is a finite p-group of order

$$|V(FG)| = |F|^{|G|-1}.$$

A p-group is called powerful if every commutator is a product of pth powers when p is odd and a product of fourth powers when $p = 2$. The notion of powerful groups was introduced in [5] and it plays an important role in the study of finite p-groups (for example, see [2, 4] and [7]). Our main result is the following.

THEOREM. *The group of normalized units $V(FG)$ of the group algebra FG of a group G of p-power order over a finite field F of characteristic p, is never powerful except, of course, when G is abelian.*

In view of the fact that a pro-p-group is powerful if and only if it is the limit of finite powerful groups, this has an immediate consequence.

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COROLLARY. *The group of normalized units $V(F[[G]])$ of the completed group algebra $F[[G]]$ of a pro-p-group G over a finite field F of characteristic p, is never powerful except, of course, when G is abelian.*

We denote by $\zeta(G)$ the center of G. We say that $G = A \curlyvee B$ is a central product of its subgroups A and B if A and B commute elementwise and $G = \langle A, B\rangle$, provided also that $A \cap B$ is the center of (at least) one of A and B. If H is a subgroup of G, then we denote by $\mathfrak{I}(H)$ the ideal of FG generated by the elements $h-1$ where $h \in H$. Set $(a, b) = a^{-1}b^{-1}ab$, where $a, b \in G$. Denote by $|g|$ the order of $g \in G$. Put $\Omega_k(G) = \langle u \in G \mid u^{p^k} = 1\rangle$ and $\widehat{H} = \sum_{g\in H} g \in FG$. If $H \trianglelefteq G$ is a normal subgroup of G, then $FG/\mathfrak{I}(H) \cong F[G/H]$ and

$$V(FG)/(1+\mathfrak{I}(H)) \cong V(F[G/H]). \tag{1}$$

We freely use the fact that every quotient of a powerful group is powerful [2, Lemma 2.2(i)]).

PROOF. We prove the theorem by assuming that counterexamples exist, considering one of minimal order, and deducing a contradiction. Suppose then that G is a counterexample of minimal order. If G had a nonabelian proper factor group G/H, that would be a smaller counterexample, for, by (1), $V(F[G/H])$ would be a homomorphic image of the powerful group $V(FG)$. Thus all proper factor groups of G are abelian, that is, G is just nilpotent of class 2 in the sense of Newman [6]. As Newman noted in the lead-up to his Theorem 1, this means that the derived group has order p and the center is cyclic. Of course it follows that all pth powers are central, so the Frattini subgroup $\Phi(G)$ is central and also cyclic.

Suppose $p > 2$. Then a finite p-group with only one subgroup of order p is cyclic [3, Theorem 12.5.2], so G must have a noncentral subgroup $B = \langle b\rangle$ of order p. Now $(b, a) = c \neq 1$ for some a in G and some c in G'. Of course $\langle c\rangle = G' \leq \zeta(G)$, $a^{-1}b^i a = b^i c^i = c^i b^i$ and $b^i\widehat{B} = \widehat{B}$ for all i, so

$$\begin{aligned}(a\widehat{B})^2 &= a^2(1 + a^{-1}ba + \cdots + a^{-1}b^{p-1}a)\widehat{B}\\ &= a^2(1 + cb + \cdots + c^{p-1}b^{p-1})\widehat{B}\\ &= a^2\widehat{G'}\widehat{B}.\end{aligned} \tag{2}$$

Noting that

$$(\widehat{G'})^2 = 0, \tag{3}$$

we get

$$\begin{aligned}(a\widehat{B})^3 &= a^2\widehat{G'}\widehat{B}\cdot a\widehat{B} = a^2\widehat{G'}a^{-1}\cdot(a\widehat{B})^2\\ &= a^2\widehat{G'}a^{-1}\cdot a^2\widehat{G'}\widehat{B} = a^3(\widehat{G'})^2\widehat{B} = 0.\end{aligned} \tag{4}$$

Therefore $|1 + a\widehat{B}| = p$. We know from 4.12 of [7] that $\Omega_1(V(FG))$ has exponent p, so it must be that $((1 + a\widehat{B})b)^p = 1$ as well. However,

$$b^i ab^{-i} = a(a, b^{-i}) = ac^i = c^i a, \tag{5}$$

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which allows one to calculate that

$$\begin{aligned}((1+a\widehat{B})b)^p &= (1+a\widehat{B})(1+bab^{-1}\widehat{B})\cdots(1+b^{p-1}ab^{-(p-1)}\widehat{B})\cdot b^p \\ &= (1+a\widehat{B})(1+ca\widehat{B})\cdots(1+c^{p-1}a\widehat{B}) && \text{by (5)} \\ &= 1+\widehat{G}'(a\widehat{B})+\tfrac{1}{2}(p-1)\widehat{G}'(a\widehat{B})^2 && \text{by (4)} \\ &= 1+\widehat{G}'(a\widehat{B})+\tfrac{1}{2}(p-1)(\widehat{G}')^2a^2\widehat{B} && \text{by (2)} \\ &= 1+\widehat{G}'(a\widehat{B}) && \text{by (3)} \\ &\neq 1.\end{aligned}$$

(To see that the third line is equal to the second, it helps to think in terms of polynomials with $a\widehat{B}$ as the indeterminate and FG' as the coefficient ring, the critical point being that in the third line the coefficients of all positive powers of $a\widehat{B}$ are integer multiples of $\widehat{G}'$.) This contradiction completes the proof when $p > 2$.

Next, we turn to the case $p = 2$. Then $G' = \langle c \mid c^2 = 1\rangle$ and the ideal $\mathfrak{I}(G')$ is spanned by the elements of the form $\widehat{G}'g$, while FG is spanned by the elements h of G. It is clear that $\widehat{G}'g$ and h commute, because

$$\widehat{G}'gh = \widehat{G}'(ghg^{-1}h^{-1})hg \quad \text{and} \quad \widehat{G}'(ghg^{-1}h^{-1}) = \widehat{G}',$$

so $\mathfrak{I}(G')$ is central in FG and $1+\mathfrak{I}(G')$ is central in $V(FG)$. As $(\widehat{G}')^2 = 0$, it also follows that $(\mathfrak{I}(G'))^2 = 0$ and so the square of every element of $1+\mathfrak{I}(G')$ is 1. As $V(FG)/(1+\mathfrak{I}(G')) \cong V(F[G/G'])$, the derived group V' of $V(FG)$ lies in $1+\mathfrak{I}(G')$, a central subgroup of exponent 2. It follows that in $V(FG)$ all squares are central.

Let $w \in V'$. By [5, Proposition 4.1.7], this is the fourth power of some element u of $V(FG)$. Write u as $\sum_{g\in G}\alpha_g g$ with each α_g in F. In the commutative quotient modulo $\mathfrak{I}(G')$, $u^2 = \sum_{g\in G}\alpha_g^2 g^2$, hence

$$u^2 = v + \sum_{g\in G}\alpha_g^2 g^2$$

for some v in $\mathfrak{I}(G')$. Of course then v and all the g^2 are central in FG and $v^2 = 0$, so we may conclude that $w = u^4 = \sum_{g\in G}\alpha_g^4 g^4$.

In particular, as $V(FG)$ is not abelian, the exponent of G must be larger than 4. Recall that $\Phi(G)$ is central, the center is cyclic, and $|G'| = 2$, so [1, Theorem 2] applies and for this case gives the structure of G as

$$G = G_0 \curlyvee G_1 \curlyvee \cdots \curlyvee G_r$$

where $G_1, \ldots, G_r$ are dihedral groups of order 8 and G_0 is either cyclic of order at least 8 (and in this case $r > 0$) or an $M(2^{m+2})$ with $m > 1$, where

$$M(2^{m+2}) = \langle a, b \mid a^{2^{m+1}} = b^2 = 1,\, a^b = a^{1+2^m}\rangle.$$

One of the conclusions we need from this is that every fourth power in G is already a fourth power in G_0, thus every element of V' is an element of FG_0^4. In particular, when w is the unique nontrivial element of G', the linear independence of G as subset of FG implies that w itself is the fourth power of some element of G_0.

It is easy to verify that, in $M(2^{m+2})$ with $m \geq 1$, the inverse of the element $1 + a + b$ is

$$(a^{2^m-3} + a^{-3} + a^{-2} + a^{-1}) + (a^{2^m-2} + a^{2^m-2} + a^{-3})b$$

and so

$$(1 + a + b, a) = (1 + a^{2^m-2} + a^{-2}) + (a^{2^m-2} + a^{2^m-1} + a^{-2} + a^{-1})b.$$

Of course the left-hand side is an element of V', but the right-hand side is not an element of $\langle a \rangle$. When $G_0 \cong M(2^{m+2})$, this shows that there is an element in V' which does not lie in FG_0^4. When G_0 is cyclic, then $G_1 \cong M(2^{m+2})$ with $m = 1$, and we have an element in V' which does not even lie in FG_0. In either case, we have reached the promised contradiction and the proof of the theorem is complete. □

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