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# A CHARACTERIZATION OF $\overline{NC} - p$-GROUPS

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**Abstract**

In this work, presented is a partial characterization of a perfect locally nilpotent $p$-group in which every proper subgroup is nilpotent-by-Chernikov.

## 1. Introduction

Let $G$ be a locally finite group. If every proper subgroup of $G$ is nilpotent-by-finite ($NF$-group) while $G$ is not nilpotent-by-finite, then $G$ is called a **minimal non nilpotent-by-finite group ($\overline{NF}$-group)**. If in the above definition "finite" is replaced by "Chernikov", then one obtains $NC$-groups and $\overline{NC}$-groups, respectively. Bruno in [4] showed, among other things, that if $G$ is a non-perfect $\overline{NF}$-group for a prime $p$, then $G/G' \cong C_{p\infty}, G'$ is nilpotent and $G'$ is not properly supplemented in $G$. The first example of such a group was constructed by Heineken and Mohamed in [8]. For this reason groups of this type are called $HM$-groups. Later, Meldrum in [9] and Hartley in [6] gave similar constructions. Bruno and Phillips in [5] constructed an $HM$-group with a metabelian derived subgroup. Recently, Menegazzo in [10] constructed $HM$-groups with derived subgroups either abelian of infinite exponent or solvable of arbitrary derived length. Thus the structure of nonperfect $\overline{NF} - p$-groups is known. However it is not known yet whether or not perfect $\overline{NF} - p$-groups exist.

Otal and Peña in [12] extended some of the results of [4] to $\overline{NC}$-groups. Later $\overline{NC} - p$-groups were considered in [1], [2] and [3]. Theorem A of [2] (see also the end of this section) shows that an $\overline{NC} - p$-group must be perfect. Another consequence of the same theorem is that a perfect $\overline{NF} - p$-group has a proper epimorphic image in which every proper subgroup is nilpotent of finite exponent. Of course, the determination of $\overline{NC} - p$-groups will be useful in the investigation of perfect locally nilpotent $p$-groups, about which not much is known yet. In this work the first question is considered. The main results of this work are stated below.

**Theorem.** *Let $G$ be an $\overline{NC} - p$-group. Then $G$ contains a proper normal subgroup $K$ such that every proper subgroup of $G/K$ is a Chernikov extension of a nilpotent subgroup of finite exponent and one of the following holds:*

(i) *$G/K$ is an $\overline{NF}-p$-group.*

(ii) *$G/K = \bigcup_{i=1}^{\infty}(T_i/K)'$, where for each $i \geq 1$, $T_i/K$ is an $HM^*$-subgroup of $G/K$ such that $(T_i/K)/(T_i/K)' \cong C_{p^\infty}$ and $T_i/K \leq T_{i+1}/K$.*

(iii) *$G/K$ is generated by its normal $HM^*$-subgroups $T/K$ such that $(T/K)/(T/K)' \cong C_{p^\infty}$.*

(The definition of an $HM^*$-group is given below)

**Corollary.** *Let $G$ be an $\overline{NC}-p$-group satisfying the normalizer condition. Then $G$ contains a proper normal subgroup $K$ such that every proper subgroup of $G/K$ is a Chernikov extension of a nilpotent subgroup of finite exponent and (i) or (iii) of the theorem holds.*

It is not known whether or not (ii) and (iii) are necessary in the above results.

In the study of $\overline{NC}-p$-groups certain subgroups, similar to the Heineken-Mohamed group, are unavoidable. To single them out, they were called $HM^*$-groups in [2]. By definition a locally nilpotent $p$-group $X \neq 1$ is called an **$HM^*$-group** if $X'$ is nilpotent and

$$X/X' \cong C_{p^\infty}^{(n)} = C_{p^\infty} \times \cdots \times C_{p^\infty}$$

is $n$ copies for some $n \geq 1$. If $n = 1$, $X' \neq 1$ and every proper subgroup of $X$ is subnormal in $X$ (in which case $X'$ is not properly suplemented in $X$ by Lemma 2.2 (iii)) then $X$ is called a **group of Heineken-Mohamed type** or an **$HM$-group** for brevity.

Elementary properties of $HM^*$-groups were collected in [2] and [3] but they will be restated here (see §2) in order to make this work self-contained.

For any group $X, X^\circ$ denotes the unique maximal normal radicable abelian subgroup of $X$, whenever it exits. We end this section by stating Theorem A of [2].

**Theorem A.** *Let $G$ be locally nilpotent $p$-group which does not have any proper subgroup of finite index. Suppose that every proper subgroup of $G$ is an $NC$-group. Then the following hold.*

(i) *If $G = G'$, then $G$ is the union of an ascending chain of normal nilpotent subgroups. Furthermore, $G$ has a normal nilpotent subgroup $N$ such that in $G/N$ every proper subgroup is a Chernikov extension of a nilpotent subgroup of finite exponent and, for every normal nilpotent subgroup $K$ of $G, KN/N$ has finite exponent.*

(ii) *If $G' \neq G$, then $G$ is an $NC$-group.*

## 2. Properties of $HM^*$-Groups

**Lemma 2.1.** Let $A$ be a nilpotent $p$-group and $B$ be a normal subgroup of $A$ of finite exponent $m$ such that $A/B \cong C_{p^\infty}^{(n)} = C_{p^\infty} \times \cdots \times C_{p^\infty}$, $n$ factors for some $n \geq 1$. Then $A = TB$, where $T = A^\circ$.

**Proof.** We may use induction on the nilpotency class $c$ of $A$. First suppose that $c = 1$. Then $A$ is abelian. Define $f : A \to A$ by $f(a) = a^m$. Then $f$ is a homomorphism with kernel $K = \{a : a^m = 1\}$. Also, $B \leq K$. Therefore $f(A) \cong A/K \cong C_{p^\infty}^{(n)}$ since $K$ has finite exponent. So if we put $T = f(A)$ then $TB/B \cong C_{p^\infty}^{(n)} \cong A/B$ which implies that $TB = A$.

Next suppose that $c > 1$ and the assertion holds for $c - 1$. Let $R = K_c(A)$, the $c$th term of the lower central series of $A$ and put $\overline{A} = A/R$. Let $\overline{U} = \overline{A}^\circ$. By induction hypothesis $\overline{A} = \overline{UB}$. Also, since $\overline{U} \cong C_{p^\infty}^{(n)}$ and $R \leq Z(U)$, it is easy to see that $U$ is abelian and so $U = VR$, where $V = U^\circ$ by the first paragraph. Substituting this in $A = UB$ gives that $A = VB$. Also $V = A^\circ$ since $B$ has finite exponent. This completes the proof of the lemma. □

**Lemma 2.2.** Let $X$ be an $HM^*$-group for a prime $p$. Then the following hold.

(i) $X' = [X, X']$.

(ii) There does not exist any proper normal subgroup $N$ of $X$ satisfying $X = NX'$. In particular, $X/N$ cannot have finite exponent.

(iii) If $X$ satisfies the normalizer condition then $X'$ is not properly supplemented in $X$.

**Proof.** (i) Let $\overline{X} = X/[X, X']$. Then $\overline{X}' \leq Z(\overline{X})$ and so $\overline{X}$ is nilpotent and $\overline{X}/\overline{X}'$ is radicable abelian which implies that $\overline{X}$ is abelian and, hence, $X' \leq [X, X']$ by Theorem 9.23 of [13].

(ii) Assume that $X = NX'$ for some proper normal subgroup $N$ of $X$. Then

$$\begin{aligned} X' = [X', NX'] &= [X', N]X'' \\ &= [X', N] \\ &\leq N \end{aligned}$$

and so $X = N$ by (i) and by Lemma 2.22 of [13], which is a contradiction. Also, if $X/N$ has finite exponent then, as $X/NX'$ is radicable abelian and has finite exponent, it follows that $X = NX'$ and so $X = N$ by the first part of (ii), which is another contradiction.

(iii) Assume that $X = CX'$ for some $C < X$. Let $D = C \cap X'$ and put $\overline{X} = X/DX''$. Then $\overline{X} = \overline{CX}'$ and $\overline{C}$ is radicable abelian and Chernikov. Let

$\overline{Y} = N_{\overline{X}}(\overline{C})$. Then $\overline{Y} = \overline{C}(\overline{Y} \cap \overline{X}')$ which implies that $\overline{Y}$ is nilpotent since $\overline{C}$ and $\overline{Y} \cap \overline{X}'$ are normal nilpotent subgroups of $\overline{Y}$. In particular, $\overline{C} \leq Z(\overline{Y})$ by Lemma 3.13. of [13]. Assume that $\overline{Y} < \overline{X}$ and put $\overline{V} = N_{\overline{X}}(\overline{Y})$. Then $\overline{Y} < \overline{V}$ by hypothesis. But since $\overline{V} = \overline{C}(\overline{V} \cap \overline{X}')$ it follows as in the first case that $\overline{C} \leq Z(\overline{V})$ and so $\overline{V} \leq \overline{Y}$ which is a contradiction. Consequently, it follows that $\overline{Y} = \overline{X}$ and so $\overline{C} \leq Z(\overline{X})$. But now

$$\begin{aligned} \overline{X}' = [\overline{X}', \overline{X}] &= [\overline{X}', \overline{C}\overline{X}'] \\ &= [\overline{X}', \overline{X}'] \\ &= \overline{X}'' \end{aligned}$$

which is possible only if $\overline{X}' = 1$ and so $X' \leq DX'' \leq D \leq C$ by Lemma 2.22 of [13] since $X'$ is nilpotent. This a contradiction since $C < X$. □

**Lemma 2.3.** Let $X$ be an $NC-p$-group and $T$ be an $HM^*$-subgroup of $X$. If $N$ is a normal subgroup of $X$ such that $X/N$ is Chernikov then $T' \leq N$.

**Proof.** Let $D = T' \cap N$ and put $\overline{T} = T/D$. Then $\overline{T}'$ is nilpotent and Chernikov so the Corollary to Theorem 3.29 (2) of [13] gives that $\overline{T}/C_{\overline{T}}(\overline{T}')$ is finite which implies that $\overline{T} = C_{\overline{T}}(\overline{T}')$ and hence $\overline{T}' = [\overline{T}', \overline{T}] = 1$ by (ii) and (i) of Lemma 2.2. This means that $T' \leq D \leq N$, which was to be shown. □

**Lemma 2.4.** Let $X$ be an $NC-p$-group and $N$ be a normal nilpotent subgroup of finite exponent of $X$ such that $X/N$ is infinite Chernikov. Then $X$ contains a maximal normal $HM^*$-subgroup $T$ such that $X/T$ has finite exponent. Furthermore, $T$ is unique.

**Proof.** We use induction on the nilpotency class $c$ of $N$. If $c = 0$ then $N = 1$ and $X$ is Chernikov so, then, we may let $T = X^\circ$. Now suppose that $c \geq 1$ and the assertion holds for $c-1$. Let $Z = Z(N)$ and put $\overline{X} = X/Z$. By induction hypothesis $\overline{X}$ contains a maximal $HM^*$-subgroup $\overline{T}$ such that $\overline{X}/\overline{T}$ and, hence, also $X/T$ has finite exponent. Also $T'Z = [T', T]Z$ since $\overline{T}' = [\overline{T}', \overline{T}]$. Moreover, $T' \leq N$ by Lemma 2.3.

□

Next put $\overline{T} = T/[T', T]$. Then $\overline{T}' \leq Z(\overline{T})$ and so $\overline{T}$ is nilpotent. Also, $\overline{T}' = \overline{Z}$ by the preceding paragraph which implies that $\overline{T}/\overline{Z} \cong C_{p^\infty}^{(n)}$ for some $n \geq 1$. Therefore, $\overline{T} = \overline{S}\overline{Z}$ by Lemma 2.1 since $\overline{Z}$ has finite exponent, where $\overline{S}$ is the maximal radicable abelian subgroup of $\overline{T}$. In fact $\overline{S} \cong C_{p^\infty}^{(n)}$ since $\overline{Z}$ has finite exponent. Furthermore, as $\overline{T}$ is nilpotent, $\overline{S} \leq Z(\overline{T})$ by Lemma 3.13 of [13], which yields that $\overline{T}$ is abelian and, hence, $T' = [T', T]$. Consequently it follows that $S/T' \cong C_{p^\infty}^{(n)}$.

We claim that $S$ is a normal $HM^*$-subgroup of $X$ such that $X/S$ has finite exponent. Since $S$ is characteristic in $T$ and $T$ is normal in $X$, it follows that $S$ is normal in $X$. Moreover, $T/S$ has finite exponent as does $X/T$, since $T = SZ$ and $Z$ has finite exponent. Therefore, $X/S$ has finite exponent. Now put $\overline{T} = T/S'$. Then $\overline{T} = \overline{SZ}$ and so $\overline{T}$ is nilpotent. Also, by Lemma 2.1 $\overline{S} = \overline{V}\,\overline{T}'$, where $\overline{V}$ is the maximal radicable abelian subgroup of $\overline{S}$ since $T' \leq N$ by Lemma 2.3 and $N$ has finite exponent. Substituting this above yields that $\overline{T} = \overline{VT'Z}$, which yields as before that $\overline{T} = \overline{VZ}$ is abelian and hence $T' = S'$. Thus it follows that $S$ is an $HM^*$-subgroup of $X$.

Now let $U$ be any $HM^*$-subgroup of $X$. Then $U \cap S$ is a normal subgroup of $U$ such that $U/U \cap S$ has finite exponent which yields that $U = U \cap S \leq S$ by Lemma 2.2 (ii). Therefore $S$ is the unique maximal $HM^*$-subgroup of $X$ such that $X/S$ has finite exponent.

**Lemma 2.5.** Let $X$ be an $HM^*$-group for a prime $p$ such that $X'$ has finite exponent. Then $X$ is a product of a finite number of normal $HM^*$-subgroups $T$ such that $T/T' \cong C_{p^\infty}$.

**Proof.** There exists an $n \geq 1$ such that

$$X/X' = Y_1/X' \times \cdots \times Y_n/X'$$

and $Y_i/X' \cong C_{p^\infty}$ for $i = 1, \ldots, n$. By Lemma 2.4 each $Y_i$ contains a unique normal $HM^*$-subgroup $T_i$ such that $Y_i/T_i$ has finite exponent and $T_i/T_i' \cong C_{p^\infty}$, since $X'$ has finite exponent. Evidently, $T_1T_2\cdots T_n$ is a normal subgroup of $X$ such that $X/T_1T_2\cdots T_n$ has finite exponent which implies that

$$X = T_1T_2\cdots T_n$$

by Lemma 2.2(ii), as claimed. □

## Proof of the Theorem

**Lemma 3.1.** Let $G$ be an $\overline{NC} - p$-group. Then $G$ is countably infinite.

**Proof.** By hypothesis $G$ is infinite and every proper subgroup of it, being an $NC$-group, is solvable. However $G$ is not solvable since it is perfect by Theorem A(ii) (see the end of §1). Therefore, for each $n \geq 1$ we can find a finite subgroup $F_n$ of $G$ of derived length equal to $n$. Let $F = \langle F_n : n \geq 1\rangle$. Then $F$ is countably infinite but not solvable which implies that $F = G$, since every proper subgroup of $G$ is solvable.

□

**Lemma 3.2.** Let $G$ be a locally nilpotent $p$-group such that every proper subgroup of $G$ is an $NC$-subgroup. If every finite subgroup of $G$ is subnormal in $G$, then $F^G$ is nilpotent of finite exponent for every finite subgroup $F$ of $G$.

**Proof.** Assume that every finite subgroup of $G$ is subnormal in $G$. Let $F$ be a finite subgroup of $G$ and put $H = F^G$. First suppose that $H$ is nilpotent. Since $H/H'$, being abelian, has finite exponent it follows from the Corollary to Theorem 2.26 of [13] that $H$ has finite exponent. Thus to complete the proof we must show that $H$ is nilpotent.

If $G$ is perfect, then by Theorem A(i) of [2] $G$ contains a normal nilpotent subgroup $N$ such that $F \leq N$. Then $H = F^G \leq N$, and so $H$ is nilpotent. So suppose that $G$ is not perfect. Then $G$ is an $NC$-group by Theorem A(ii), that is, $G$ contains a normal nilpotent subgroup $K$ such that $G/K$ is Chernikov. Since $HK/K = F^G K/K = (FK)^G/K$ is Chernikov, $F$ is finite and subnormal, it is easy to see that $HK/K$ is finite. Thus $HK = LK$ for some finite subgroup $L$ of $H$. Moreover, $LK$ is nilpotent by (1) Lemma of [11] since $L$ is subnormal, which implies that $H$ is nilpotent.

□

In a locally nilpotent $p$-group $G$ in which every proper subgroup is an $NC$-group, let $W(G)$ be the set of all $HM^*$-subgroups $T$ of $G$ such that $T/T' \cong C_{p^\infty}$ and let $K$ be the subgroup of $G$ which is generated by all the maximal elements of $W(G)$. Of course, $W(G)$ might be empty or it may not have maximal elements, in which case $K$ is not defined.

**Lemma 3.3.** Let $G$ be a locally nilpotent $p$-group such that every proper subgroup of $G$ is a Chernikov extension of a nilpotent subgroup of finite exponent. Suppose that every finite subgroup of $G$ is subnormal in $G$. Then every maximal element of $W(G)$ is normal in $G$.

**Proof.** Let $T$ be a maximal element of $W(G)$. Without loss of generality we may suppose that $T \neq G$. Then $T'$ has finite exponent by hypothesis and by Lemma 2.3. Let $a \in G$ and put $H = a^G$. By Lemma 3.2 $H$ is nilpotent of finite exponent. Put $L = HT$. Since $HT'$ has finite exponent, it must be nilpotent by hypothesis. Thus by Lemma 2.4. $L$ contains a unique maximal $HM^*$-subgroup $R$. Then $T \leq R$ and $HT = HR$. Hence

$$\begin{aligned} R/R \cap HT' \cong RH/HT' &= TH/HT' \\ &\cong T/T \cap HT' \\ &\cong C_{p^\infty}, \end{aligned}$$

which yields that $R/R' \cong C_{p^\infty}$, since $HT'$ has finite exponent. Clearly then $R = T$ by the maximality of $T$ and hence $L$ normalizes $T$. In particular, $a$ normalizes $T$ since $a \in L$. Since $a$ is any element of $G$, it follows that $G$ normalizes $T$.

□

**Lemma 3.4.** Let $G$ be an $\overline{NC}-p$-group such that every proper subgroup of $G$ is a Chernikov extension of a nilpotent subgroup of finite exponent. Then one of the following holds.

(i) $G$ has an epimorphic image which is an $\overline{NF}$-group.

(ii) $G = \bigcup_{i=1}^{\infty} T_i$,
where for each $i \geq 1$, $T_i \in W(G)$ and $T_i \leq T_{i+1}$.

(iii) $G = K$.

**proof** Assume that (i) and (ii) do not hold. Partially, order $W(G)$ by set inclusion. Let $\{T_i : i \geq 1\}$ be a chain in $W(G)$ and put

$$E = \bigcup_{i=1}^{\infty} T_i.$$

(It sufficies to consider only the chains of the above form since $G$ is countable by Lemma 3.1). By assumption $E \neq G$, so by Lemma 2.4 $E$ contains a unique maximal $HM^*$-subgroup $Y$. Then $E = Y$, since $T_i \leq Y$ for all $i \geq 1$. Thus $E$ is an $HM^*$-subgroup of $G$. Also $E'$ has finite exponent by hypothesis and by Lemma 2.3 and, for the some reason, $T_i' \leq E'$ for all $i \geq 1$. Hence it follows that

$$E'T_i = E'T_{i+1}$$

for all $i \geq 1$, since $T_i \leq T_{i+1}$ and $T_i/T_i' \cong C_{p^\infty}$. Clearly this yields that $E = E'T_1$ and so $E/E' \cong C_{p^\infty}$, that is $E \in W(G)$. Thus by Zorn's Lemma $W(G)$ contains maximal elements and so $K$ is defined.

By Theorem A(i) every finite subgroup of $G$ is subnormal in $G$. Therefore every maximal element of $W(G)$ is normal in $G$ by Lemma 3.3. This means that $K$ is normal in $G$.

Suppose that $K \neq G$. Put $\overline{G} = G/K$. Since $\overline{G}$ is not an $\overline{NF}-p$-group, it contains a proper subgroup $\overline{X}$ such that $\overline{X}$ is not nilpotent. Then $X$ is also not nilpotent. Also, $X$ contains a normal nilpotent subgroup $U$ of finite exponent such that $X/U$ is Chernikov. Evidently $X/U$ has infinite exponent since $X$ is not nilpotent. Thus by Lemma 2.4 $X$ contains a normal $HM^*$-subgroup $Y$ such $X/Y$ has finite exponent. But, since $Y \leq K$ by Lemma 2.5, it follows that $\overline{X}$ has finite exponent, which is a contradiction.

**Proof of the Theorem.** By hypothesis and by Theorem A(i) $G$ contains a proper normal subgroup $N$ such that every proper subgroup of $G/N$ is a Chernikov extension of a nilpotent subgroup of finite exponent. Thus $G/N$ satisfies one of (i), (ii) or (iii) of

Lemma 3.4. Assume that (i) and (iii) are not satisfied. Then $G/N$ satisfies (ii). Put $\overline{G} = G/N$. Then

$$\overline{G} = \bigcup_{i=1}^{\infty} \overline{T}_i,$$

where for each $i \geq 1$, $\overline{T}_i \in W(\overline{G})$ and $\overline{T}_i \leq \overline{T}_{i+1}$. Put

$$\overline{H} = \bigcup_{i=1}^{\infty} \overline{T}'_i.$$

It is easy to see that $\overline{H}$ is normal in $\overline{G}$ and $\overline{G}/\overline{H}$ is abelian since each $\overline{T}_i\overline{H}/\overline{H}$ is abelian. This implies that $\overline{G}/\overline{H} = 1$ and hence $\overline{G} = \overline{H}$ since $G$ is perfect. This completes the proof of the theorem.

**Proof of the Corollary.** By the theorem $G$ contains a proper normal subgroup $K$ such that every proper subgroup of $G/K$ is a Chernikov extension of a nilpotent subgroup of finite exponent and one of (i), (ii) or (iii) of the Theorem is satisfied. Assume that (ii) is satisfied. Without loss of generality $K = 1$. Then

$$G = \bigcup_{i=1}^{\infty} T_i,$$

where for each $i \geq 1$, $T_i \in W(G)$ and $T_i \leq T_{i+1}$. Also, $T_1T'_i = T_i$ for all $i \geq 1$, since $T_i/T'_i \cong C_{p^\infty}$. But this implies that $T_1 = T_i$ for all $i \geq 1$ and hence $G = T_1$ by Lemma 2.2 (iii) which is a contradiction.

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