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Groups with no infinite perfect subgroups and aspherical 2-complexes

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Abstract. The purpose of this paper is to generalize a theorem of J. F. Adams. He showed in [A] that if X is a subcomplex of an aspherical 2-complex and the fundamental group G of X has no non-trivial perfect subgroups, then X is aspherical. We weaken the hypothesis on G to "no infinite perfect subgroups."

1. Introduction

In [W], J. H. C. Whitehead, asked the following question: Is a subcomplex of an aspherical 2-complex aspherical?

A [G, 2]-complex X is a connected two-dimensional CW-complex with fundamental group $\pi_1 X \cong G$. If N is a subgroup of $\pi_1 X$, let X_N denote the covering of X corresponding to N. For any group G, let H_iG denote the ith homology of G with coefficients in the integers \mathbb{Z} . A group G is said to be perfect if the abelianization H_1G of G is trivial; G is superperfect if $H_1G = H_2G = 0$.

A [G, 2]-complex X is aspherical iff its second homotopy group $\pi_2 X$ vanishes. If X is a [G, 2]-complex which is a subcomplex of an aspherical 2-complex, then J. F. Adams showed in [A] that X is aspherical provided G has no non-trivial perfect subgroups. In this note we show that X is aspherical provided G is finitely presented and has no *infinite* perfect subgroups.

The idea of the proof is to show that if X is a [G, 2]-complex and G is a finitely presented group which has a finite, non-trivial, normal, superperfect subgroup P such that Q = G/P has cohomological dimension 1 or 2, then the Hurewicz homomorphism $\pi_2 X \to H_2 X_P$ is non-trivial.

2. Basic definitions

If X is a connected 2-complex and N is a subgroup of $\pi_1 X$ then X is N-Cockcroft if the Hurewicz homomorphism $\pi_2 X = \pi_2(X_N) \to H_2(X_N)$ is trivial. The N-Cockcroft property has been extensively studied in [Bo, BD, BDS, D, GH, H].

Let N be a subgroup of G. Then we say that G is N-Cockcroft if there is a [G, 2]-complex X and an isomorphism $\varphi : G \to \pi_1 X$ such that X is φ N-Cockcroft.

The following is the main theorem of this paper.

2.1 THEOREM. Let P be a non-trivial, finite, superperfect, normal subgroup of a finitely presented group G such that Q = G/P has cohomological dimension 1 or 2. Then G is not P-Cockcroft.

Note that the theorem is false if Q = 1. In this case, G = P is finite and superperfect. Let G be the binary icosahedral group. In this case, G admits a presentation with 2 generators and 2 relators. The realization of this presentation as a [G, 2]-complex has $H_2X = 0 = H_1X$, so X is P-Cockcroft.

If G is a group, the maximal perfect subgroup PG of G is defined as the normal subgroup of G generated by all perfect subgroups; it is also the intersection of the (transfinite) derived series of G.

2.2 COROLLARY. Let G be a finitely presented group with maximal perfect subgroup PG finite. Then any [G, 2]-complex X which is the subcomplex of an aspherical 2-complex is aspherical.

Proof. If G is finite, the result is well known (see [BD]). Hence we will assume that Q is infinite. If the [G, 2]-complex X is a subcomplex of an aspherical 2-complex and X is not aspherical, then by the main theorem of [BDS], we see that there must exist a superperfect, normal, non-trivial subgroup P of G such that G is P-Cockcroft and the quotient Q has $\operatorname{cd} Q \leq 2$. The group Q is infinite, so the cohomological dimension of Q is 1 or 2. But the maximal perfect subgroup of G is finite, so P is infinite. The theorem then says that G cannot be P-Cockcroft. Thus X must be aspherical. \square

3. Two lemmas

In this section we will prove two lemmas preliminary to giving a proof of the theorem.

Let G be a group and let \mathbb{C} be a projective $\mathbb{Z}G$ -resolution of the trivial $\mathbb{Z}G$ -module \mathbb{Z} . To each integer $i \geq 0$ we have an associated kernel $K_i = \ker \left\{ \partial_i : C_i \to C_{i-1} \right\}$ $(C_{-1} = \mathbb{Z})$. For any [G, 2]-complex X, let \tilde{X} be the universal covering of X. Then $C_*\tilde{X}$, the cellular chain complex of \tilde{X} , can be thought of as a partial resolution (of length two) of free left $\mathbb{Z}G$ -modules. For any [G, 2]-complex X, the kernel $K_1 = \ker \left\{ \partial_1 : C_1\tilde{X} \to C_0\tilde{X} \right\}$ is called the relation module determined by X.

For any left $\mathbb{Z}G$ -module M, we let M^G denote the subgroup of elements fixed by the action of G; we let $M_G = \mathbb{Z} \otimes_{\mathbb{Z}G} M = M/IG \cdot M$ (IG is the augmentation ideal in $\mathbb{Z}G$) be M with the G-action killed.

3.1 LEMMA. If P is a finite, normal subgroup of a group G and Q = G/P, then $H^i(G, \mathbb{Z}G) \cong H^i(G, \mathbb{Z}Q) \cong H^i(Q, \mathbb{Z}Q)$ for all i > 0. The first isomorphism is induced by $\mathbb{Z}G \to \mathbb{Z}Q$ and the second by $G \to Q$.

Proof. Because P is finite, we have $H^{j}(P, \mathbb{Z}G) = 0$ for j > 0. By using the Lyndon-Hochschield-Serre spectral sequence, we see that $H^{i}(G, \mathbb{Z}G) \cong H^{i}(Q, \mathbb{Z}G^{P})$ for i > 0. But clearly $\mathbb{Z}G^{P} \cong \bigoplus_{a \in Q} (\mathbb{Z}P)_{a}^{P} \cong \bigoplus_{a \in Q} (\mathbb{Z})_{a} \cong \mathbb{Z}Q$ as a $\mathbb{Z}Q$ -module. \square

3.2 LEMMA. Let X be a [G, 2]-complex and suppose P is a superperfect, normal subgroup of $\pi_1 X$ such that the Hurewicz map from $\pi_2 X = \pi_2 X_P \to H_2 X_P$ is trivial (i.e., G is P-Cockcroft with respect to X). Let $K_1 = \ker \left\{ \partial_1 : C_1 \widetilde{X} \to C_0 \widetilde{X} \right\}$ be the relation module determined by X, where \widetilde{X} is the universal covering of X. Then $\mathbb{Z} \otimes_{\mathbb{Z}P} K_1 = \ker \left\{ \partial_1(X_P) : C_1(X_P) \to C_0(X_P) \right\} \cong \mathbb{Z} \otimes_{\mathbb{Z}P} C_2 \widetilde{X}$ is a relation module for $Q = (\pi_1 X)/P$. Furthermore, the surjection $G \to Q$ induces an isomorphism $H^2(G, \mathbb{Z} \otimes_{\mathbb{Z}P} K_1) \cong H^2(Q, \mathbb{Z} \otimes_{\mathbb{Z}P} K_1)$.

Proof. Because P is a subgroup of $\pi_1 X$ we have $C_i X_P \cong \mathbb{Z} \otimes_{\mathbb{Z}P} C_i \tilde{X}$. That P is superperfect and G is P-Cockcroft with respect to X implies that

$$0 \to C_2 X_P \to C_1 X_P \to C_0 X_P \to \mathbb{Z} \to 0$$

is an exact sequence of free $\mathbb{Z}Q$ -modules (a free resolution of the trivial module \mathbb{Z}). Tensoring the exact sequence (of $\mathbb{Z}G$ -modules) $0 \to \pi_2 X \to C_2 \widetilde{X} \to K_1 \to 0$ with $\mathbb{Z} \otimes_{\mathbb{Z}P}$ and using the fact that X is P-Cockcroft, we see that $\mathbb{Z} \otimes_{\mathbb{Z}P} K_1 \cong C_2 X_P$. The isomorphism $H^2(G, \mathbb{Z} \otimes_{\mathbb{Z}P} K_1) \cong H^2(Q, \mathbb{Z} \otimes_{\mathbb{Z}P} K_1)$ follows from the LHS

$$1 \rightarrow P \rightarrow G \rightarrow Q \rightarrow 1$$

spectral sequence for the extension

together with the facts that P is superperfect and that $\mathbb{Z} \otimes_{\mathbb{Z}P} K_1$ is a trivial $\mathbb{Z}P$ -module. \square

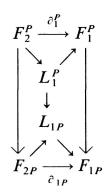
4. Proof of Theorem 2.1

From now on we assume that X is a [G, 2]-complex with fundamental group equal to G. We let P be a finite, superperfect, normal subgroup of G so that the Hurewicz map $\pi_2 X \to H_2 X_P$ is trivial. We let Q = G/P have cohomological dimension 1 or 2 and K_1 be the relation module determined by X. The proof by contradiction is given in a series of steps as follows.

STEP 1 is devoted to the proof of the following claim. Let p be the order of the finite group P and consider the inclusion $K_1^P \to \mathbb{Z} \otimes_{\mathbb{Z}P} K_1 = K_{1P}$.

CLAIM. If P is superperfect, then the image of K_1^P inside $\mathbb{Z} \otimes_{\mathbb{Z}P} K_1$ is $p \cdot \mathbb{Z} \otimes_{\mathbb{Z}P} K_1$.

Proof of the Claim. Let $F_2 \to F_1 \to \mathbb{Z}P \to \mathbb{Z} \to 0$ be a partial resolution of \mathbb{Z} over $\mathbb{Z}P$ by finitely generated free modules. Let L_1 denote the kernel of the map $\partial_1: F_1 \to \mathbb{Z}P$. Then the following diagram commutes:



The group P is finite implies that the vertical arrows are monomorphisms. The two outer vertical arrows are clearly multiplication by p because the modules are free. The group P is perfect implies that ∂_{1P} and ∂_{1}^{P} are epimorphisms and hence $L_{1P} = F_{1P}$ and $L_{1}^{P} = F_{1}^{P}$. Thus the interior vertical arrow has image which is multiplication by p. Now one uses Schanuel's lemma and a simple argument to show that the same is true of $K_{1}^{P} \to K_{1P}$. This completes the proof of the claim.

Hence the $\mathbb{Z}Q$ -module $A = \mathbb{Z} \otimes_{\mathbb{Z}P} K_1/K_1^P = \mathbb{Z} \otimes_{\mathbb{Z}P} K_1/p \cdot \mathbb{Z} \otimes_P K_1$. If we write $\mathbb{Z} \otimes_{\mathbb{Z}P} K_1 \cong \mathbb{Z}Q^{\alpha}$ ($= \mathbb{Z} \otimes_{\mathbb{Z}P} C_2 \tilde{X}$; this follows from lemma 3.2), then $A \cong \mathbb{Z}_p Q^{\alpha}$.

STEP 2. The following diagram is commutative, with top and vertical sequences exact:

$$\downarrow \qquad \qquad \downarrow \qquad \qquad \qquad \downarrow \qquad \qquad \qquad \downarrow \qquad \qquad \qquad \downarrow \qquad \qquad \downarrow \qquad \qquad \downarrow \qquad \qquad \downarrow \qquad$$

The horizontal maps f and f' are induced by $K_1 \to \mathbb{Z} \otimes_{\mathbb{Z}P} K_1$ and $K_1^P \to \mathbb{Z} \otimes_{\mathbb{Z}P} K_1$, respectively. By using a dimension shifting argument one shows that $H^2(P, K_1) \cong \mathbb{Z}_p$ has trivial $\mathbb{Z}Q$ -action. The fact that $p \cdot A = 0$ shows that $p \cdot H^2(Q, A) = 0$ also. The vertical sequences come from the LHS-spectral sequence. The left-most vertical sequence is exact, because $\mathrm{cd}\ Q \le 2$ and $H^1(P, K_1) = 0$ (this is a consequence of the finiteness of P). The fact that $H^2(P, \mathbb{Z} \otimes_{\mathbb{Z}P} K_1) = 0$ follows because P is superperfect and $\mathbb{Z} \otimes_{\mathbb{Z}P} K_1$ is a trivial $\mathbb{Z}P$ -module. We observe that the map f' is an isomorphism modulo torsion; that is to say, the kernel and the cokernel of f' are torsion groups. The group $H^3(Q, K_1^P) = 0$ because Q is two dimensional. By lemma 3.2, $\mathbb{Z} \otimes_{\mathbb{Z}P} K_1$ is a free $\mathbb{Z}Q$ -module, so f is an isomorphism, by lemma 3.1.

STEP 3. Let M be any $\mathbb{Z}G$ -module and $\rho(M): M \to \mathbb{Z} \otimes_{\mathbb{Z}P} M$ be the natural surjection. We will show that $\rho(K_1): K_1 \to \mathbb{Z} \otimes_{\mathbb{Z}P} K_1$ induces a split epimorphism

$$f: H^2(G, K_1) \to H^2(G, \mathbb{Z} \otimes_{\mathbb{Z}P} K_1).$$

We will show that there is a map $s: H^2(G, \mathbb{Z} \otimes_{\mathbb{Z}P} K_1) \to H^2(G, K_1)$ such that fs is an isomorphism.

Now $H^2(G, C_2\tilde{X}) \cong H^2(G, \mathbb{Z} \otimes_{\mathbb{Z}P} K_1)$, by lemma 3.1; the isomorphism is induced by $\rho(K_1) \partial_2$, where $\partial_2 : \mathbb{Z}G^{\alpha} = C_2\tilde{X} \to K_1$. This last follows because $\rho(K_1)\partial_2 = (1 \otimes \partial_2)\rho(C_2\tilde{X})$. The map $1 \otimes \partial_2$ is an isomorphism because G is P-Cockcroft and $\rho(C_2\tilde{X})$ induces an isomorphism on $H^2(G, -)$ by lemma 3.1. Thus the map ∂_2 induces a map $g: H^2(G, C_2\tilde{X}) \to H^2(G, K_1)$ whose composite gf is induced by the natural map $\mathbb{Z}G^{\alpha} \to \mathbb{Z}Q^{\alpha}$. Thus gf is an isomorphism, again by 3.1. Hence f is a split epimorphism and the map g can be chosen as $g = \partial_{2*}(\rho(K_1) \partial_2)^{-1}$.

STEP 4. We will show that, if $i: H^2(G, K_1^P) \to H^2(G, K_1)$ is the map in diagram 4.1, then im s = im i.

First we observe that, by definition, im $s = \text{im } \partial_{2*}$. Let $K_2 = \text{ker } \partial_2$ and consider the long exact sequence arising from the short exact sequence $0 \to K_2 \to C_2 \tilde{X} \to K_1 \to 0$;

$$\cdots \to H^2(G, C_2 \widetilde{X}) \xrightarrow{\ell_2 *} H^2(G, K_1) \to H^3(G, K_2) \to H^3(G, C_2 \widetilde{X}) = 0.$$

The group $H^3(G, C_2 \tilde{X}) = 0$ by 3.1 and the fact that cd $Q \le 2$ (3.2).

The commutativity of the diagram below (where we identify $H^3(P, K_2)$ with $H^2(P, K_1)$) shows that im $i = \text{im } \partial_{2*} = \text{im } s$:

$$H^{2}(G, K_{1}^{P})$$

$$\downarrow i$$

$$H^{2}(G, C_{2}\tilde{X}) \xrightarrow{\partial_{2}*} H^{2}(G, K_{1}) \longrightarrow H^{3}(G, K_{2}) \longrightarrow 0$$

$$\downarrow h \qquad \qquad \downarrow \cong$$

$$H^{2}(P, K_{1})^{Q} \longrightarrow H^{3}(P, K_{2})^{Q}.$$

$$(4.2)$$

STEP 5. We show that $\mathbb{Z}_p \otimes H^2(Q, \mathbb{Z}Q) = 0$.

The map fi (see 4.1) is an isomorphism because $\ker f \cap \operatorname{im} i = \ker f \cap \operatorname{im} s = 0$. This implies $f' = j^{-1}fi$ is an isomorphism. Thus, $H^2(Q, A) = 0$ and hence $\mathbb{Z}_p \otimes H^2(Q, \mathbb{Z}Q) = H^2(Q, \mathbb{Z}_pQ) = 0$.

STEP 6. The contradiction.

Case 1 (Q is free). The same proof above works (by simply reducing the dimension of the cohomology groups and the kernels by one in 4.1 and 4.2) to show that $\mathbb{Z}_p \otimes H^1(Q, \mathbb{Z}Q) = 0$. But this is impossible because $H^1(Q, \mathbb{Z}Q)$ is known to be free abelian and non-trivial [Sw, corollary 3.7]. Thus, G is P-Cockcroft and Q free leads to a contradiction.

Case 2: (cd Q = 2). Because P is finite and cd Q = 2 we have that $\mathbb{Z}_p \otimes H^2(Q, \mathbb{Z}Q) = 0$ by step 5.

Because G is finitely presented, so is Q. We observe that ([BE], theorem 5.2) Q is a free product of duality groups of dimension 1 or 2. Let R be one of the factors, and define $D = H^2(Q, \mathbb{Z}Q)$ and $E = H^2(R, \mathbb{Z}R)$. Let q be any prime divisor of p. The fact that $\mathbb{Z}_p \otimes D = 0$ implies that $\mathbb{Z}_q \otimes D = 0$. This in turn implies that $\mathbb{Z}_q \otimes E = 0$. If R is a duality group of dimension 2, we have, for any $\mathbb{Z}_q Q$ -module M, $H^2(R, M) \cong \mathbb{Z} \otimes_{\mathbb{Z}R} (M \otimes D)$. But because M is a \mathbb{Z}_q -module, we have $M \otimes D \cong \mathbb{Z}_q \otimes M \otimes D = 0$. Hence, the cohomological dimension of $R \leq 1$ over the ring \mathbb{Z}_q . This, together with the fact that R is torsion-free, shows that cd R = 1. Hence R is free and so Q is free. This brings us back to case 1. Hence no such group G can be P-Cockcroft. This finishes the proof of Theorem 2.1. \square

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