

8. OUTER AUTOMORPHISMS OF GROUPS OF TYPE F

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$$\chi_1(G)(ht^{vq}) = \left(\sum_{n \geq 0} \sum_{i=0}^{vq-1} (-1)^n A(\text{trace}([\tilde{f}_n][f_n^i])), - (q/r)v \sum_{i=0}^{r-1} L(f^i) \right)$$

and

$$\chi_1(G; \mathbf{Q})(ht^{vq}) = \left(0, - (q/r)v \sum_{i=0}^{r-1} L(f^i) \right) = (q/r)v \sum_{i=0}^{r-1} L(f^i) \{t\}$$

where $h \in \text{Fix}(\theta) \cap h_0^{-vq/r} Z(H)$. $\square$

Similarly, one can read off formulae for $\tilde{X}_1(G)$ from Theorem 6.14 and the rational version from Theorem 6.16.

8. OUTER AUTOMORPHISMS OF GROUPS OF TYPE $\mathcal{F}$

In this section we apply the preceding theory to prove the following theorem which relates the algebraic topology of an automorphism $\theta: H \rightarrow H$ of a group H of type $\mathcal{F}$ such that θ has finite order in $\text{Out}(H)$ to the fixed group of θ .

THEOREM 8.1. *Let H be a group of type $\mathcal{F}$ which has the Weak Bass Property over $\mathbf{Q}$. Suppose that $\theta: H \rightarrow H$ is an automorphism whose order in $\text{Out}(H)$ is $r \geq 1$. If the sum of the Lefschetz numbers $\sum_{i=0}^{r-1} L(\theta^i)$ is non-zero then $Z(H) \cap \text{Fix}(\theta) = (1)$.*

Before proving this we note that the quantity $\sum_{i=0}^{r-1} L(\theta^i)$ appearing above has the following interpretation:

PROPOSITION 8.2. $\sum_{i=0}^{r-1} L(\theta^i)$ is r times the Euler characteristic of the θ -invariant part of the homology of H , i.e.,

$$\sum_{i=0}^{r-1} L(\theta^i) = r \sum_{j \geq 0} (-1)^j \text{rank ker}(\text{id} - \theta_j: H_j(H) \rightarrow H_j(H)).$$

Proof. By elementary linear algebra, for any square complex matrix A with $A^r = I$ we have $\text{trace}(\sum_{i=0}^{r-1} A^i) = r \dim \ker(I - A)$. The conclusion easily follows. $\square$

Proof of Theorem 8.1. Let G be the semidirect product $G = H \rtimes_\theta T$ where T is infinite cyclic. By Lemma 8.7, below, G also has the WBP over $\mathbf{Q}$. Applying Theorem 7.11 to G , we have that $\chi_1(G; \mathbf{Q}) \neq 0$. By

Theorem 5.4, $Z(G)$ is infinite cyclic. By Corollary 7.9 there is an exact sequence $1 \rightarrow Z(H) \cap \text{Fix}(\theta) \rightarrow Z(G) \xrightarrow{P_*} q\mathbb{Z} \rightarrow 1$ where the period of θ , q , is positive. It follows that $Z(H) \cap \text{Fix}(\theta) = (1)$. $\square$

If $\chi(H) \neq 0$ then $Z(H) = (1)$ by Proposition 2.4 and consequently $Z(H) \cap \text{Fix}(\theta) = (1)$ in this case. If $\chi(H) = L(\theta^0) = 0$ then $\sum_{i=0}^{r-1} L(\theta^i) = \sum_{i=1}^{r-1} L(\theta^i)$. These observations yield the following corollaries of Theorem 8.1:

COROLLARY 8.3. *Let H be a group of type $\mathcal{F}$ which has the WBP over $\mathbf{Q}$. Suppose that $\theta: H \rightarrow H$ is an automorphism of order 2 in $\text{Out}(H)$. If $L(\theta) \neq 0$ then $Z(H) \cap \text{Fix}(\theta) = (1)$. $\square$*

COROLLARY 8.4. *Let H be a group of type $\mathcal{F}$ which has the WBP over $\mathbf{Q}$. Suppose $Z(H) \neq (1)$, the automorphism $\theta: H \rightarrow H$ has finite order r in $\text{Out}(H)$ and the restriction of θ to $Z(H)$ is the identity. Then $\sum_{i=1}^{r-1} L(\theta^i) = 0$.*

Proof. Since the restriction of θ to $Z(H)$ is the identity, $Z(H) \cap \text{Fix}(\theta) = Z(H) \neq (1)$. $\square$

An automorphism which has finite order in $\text{Out}(H)$ may have infinite order in $\text{Aut}(H)$. If θ has finite order in $\text{Aut}(H)$, the Weak Bass Property hypothesis can be dispensed with in Theorem 8.1 and Corollary 8.3:

PROPOSITION 8.5. *Let H be a group of type $\mathcal{F}$. Suppose that $\theta: H \rightarrow H$ has finite order in $\text{Aut}(H)$ and $L(\theta) \neq 0$. Then $Z(H) \cap \text{Fix}(\theta) = (1)$.*

Proof. Let $\omega \in Z(H) \cap \text{Fix}(\theta)$. We use the terminology of [Br]. Let Z be a finite $K(H, 1)$. Choose an essential fixed point, v , of $f: Z \rightarrow Z$ (inducing θ) as the basepoint of Z . There is a homotopy $K: f \simeq f$ such that $K(v, \cdot)$ represents ω . The fixed point v is K -related to some fixed point u of f [Br, p. 92]. Hence, for some $s > 0$, v is J -related to v , where J is the s -fold concatenation $K \star \cdots \star K$. Then there exists $\sigma \in H$ such that $\omega^s = \sigma\theta(\sigma^{-1})$; compare [G]. As in the proof of Proposition 7.7, we get $\omega^{rs} = \prod_{i=0}^{r-1} \theta^i(\sigma\theta(\sigma^{-1})) = 1$, so $\omega = 1$. $\square$

Note that $\sum_{i=1}^{r-1} L(\theta^i) \neq 0$ implies one of the $L(\theta^i)$'s is non-zero. Since $\text{Fix}(\theta) \subset \text{Fix}(\theta^i)$ for $i \geq 0$, we recover Theorem 8.1 (but without the Bass Conjecture hypothesis) in the special case where θ has finite order in $\text{Aut}(H)$.

The remainder of this section is devoted to the proof of Lemma 8.7 used above.

LEMMA 8.6. *Suppose that the group H has the WBP over $\mathbf{Q}$. Let T be an infinite cyclic group. Then the product group $H \times T$ also has the WBP over $\mathbf{Q}$.*

Proof. Let $G = H \times T$. Identify H with $H \times \{1\} \subset G$. We use the notation of §5. By Schafer's theorem [Sch, p. 224] applied to the normal subgroup $H \subset G$, the image of $T_0: K_0(\mathbf{Q}G) \rightarrow HH_0(\mathbf{Q}G)$ lies in $HH_0(\mathbf{Q}G)_H$. Let $p: G \rightarrow H$ be the projection homomorphism. There is a commutative diagram:

$$\begin{array}{ccccc} K_0(\mathbf{Q}G) & \xrightarrow{T_0} & HH_0(\mathbf{Q}G)_H & \xrightarrow{\varepsilon_*} & \mathbf{Q} \\ p_* \downarrow & & p_* \downarrow & & \parallel \\ K_0(\mathbf{Q}H) & \xrightarrow{T_0} & HH_0(\mathbf{Q}H) & \xrightarrow{\varepsilon_*} & \mathbf{Q} \end{array}$$

Write $HH_0(\mathbf{Q}G)_H = HH_0(\mathbf{Q}G)_{C(1)} \oplus HH_0(\mathbf{Q}G)''_H$ where $HH_0(\mathbf{Q}G)''_H$ is the direct sum of the $HH_0(\mathbf{Q}G)_{C(g)}$'s over $C(g) \in c(H) - \{C(1)\}$; also, $HH_0(\mathbf{Q}H) = HH_0(\mathbf{Q}H)_{C(1)} \oplus HH_0(\mathbf{Q}H)'$. By hypothesis, H has the WBP over $\mathbf{Q}$, i.e. the composite

$$K_0(\mathbf{Q}H) \xrightarrow{T_0} HH_0(\mathbf{Q}H) \rightarrow HH_0(\mathbf{Q}H)' \xrightarrow{\varepsilon_*} \mathbf{Q}$$

is zero. Since $p_*(HH_0(\mathbf{Q}G)_{C(1)}) \subset HH_0(\mathbf{Q}H)_{C(1)}$ and $p_*(HH_0(\mathbf{Q}G)''_H) \subset HH_0(\mathbf{Q}H)'$, the conclusion follows. $\square$

LEMMA 8.7. *Suppose that the group H has the WBP over $\mathbf{Q}$ and that $\theta: H \rightarrow H$ is an automorphism whose image in the group of outer automorphisms of H has finite order. Then the semidirect product $H \rtimes_\theta T$ also has the WBP over $\mathbf{Q}$.*

Proof. Let $G = H \rtimes_\theta T \equiv \langle H, t \mid tht^{-1} = \theta(h) \text{ for } h \in H \rangle$. Let n be the order of θ in the group outer automorphisms of H . Then the subgroup G' of G generated by H and t^n is isomorphic to $H \times T$; furthermore, G' is normal and of finite index, n , in G . There is a "transfer" homomorphism $\text{trans}: HH_0(\mathbf{Q}G) \rightarrow HH_0(\mathbf{Q}G')$ defined as follows. Given $g \in G$, we can write $gt^i = t^{\sigma(i)}g_i$ for $i = 0, \dots, n-1$ where $g_i \in G'$ and σ is a permutation of $\{0, \dots, n-1\}$. Let $\text{Fix}(\sigma) = \{i \mid \sigma(i) = i\}$. Then $\text{trans}(C(g)) = \sum_{i \in \text{Fix}(\sigma)} C(g_i)$. Observe that if $g \in G'$ then $\text{Fix}(\sigma) = \{0, \dots, n-1\}$

because G' is normal in G . In particular, $\varepsilon_*(\text{trans}(C(g))) = n$ if $g \in G'$. There is a commutative diagram:

$$\begin{array}{ccc} K_0(\mathbf{Q}G) & \xrightarrow{T_0} & HH_0(\mathbf{Q}G) \\ \text{res} \downarrow & & \text{trans} \downarrow \\ K_0(\mathbf{Q}G') & \xrightarrow{T_0} & HH_0(\mathbf{Q}G') \end{array}$$

where $\text{res}: K_0(\mathbf{Q}G) \rightarrow K_0(\mathbf{Q}G')$ is obtained by regarding a projective $\mathbf{Q}G$ module as a projective $\mathbf{Q}G'$ module; see [Bass] for details concerning the finite index transfer.

Recall that $HH_0(\mathbf{Q}G) = HH_0(\mathbf{Q}G)_H \oplus HH_0(\mathbf{Q}G)'_H$ where $HH_0(\mathbf{Q}G)'_H$ is the direct sum of the summands $HH_0(\mathbf{Q}G)_{C(g)}$ corresponding to the conjugacy classes not represented by elements of H . By Schafer's theorem [Sch, p. 224] applied to the normal subgroup $H \subset G$, the image of $T_0: K_0(\mathbf{Q}G) \rightarrow HH_0(\mathbf{Q}G)$ lies in $HH_0(\mathbf{Q}G)_H$. Thus we can replace $HH_0(\mathbf{Q}G)$ with $HH_0(\mathbf{Q}G)_H$ in the above diagram and obtain the commutative diagram:

$$\begin{array}{ccccc} K_0(\mathbf{Q}G) & \xrightarrow{T_0} & HH_0(\mathbf{Q}G)_H & \xrightarrow{\varepsilon_*} & \mathbf{Q} \\ \text{res} \downarrow & & \text{trans} \downarrow & & \times n \downarrow \\ K_0(\mathbf{Q}G') & \xrightarrow{T_0} & HH_0(\mathbf{Q}G') & \xrightarrow{\varepsilon_*} & \mathbf{Q} \end{array}$$

(the right square commutes because $H \subset G'$ and because of the observation made above). Write $HH_0(\mathbf{Q}G)_H = HH_0(\mathbf{Q}G)_{C(1)} \oplus HH_0(\mathbf{Q}G)''_H$ where $HH_0(\mathbf{Q}G)''_H$ is the direct sum of the $HH_0(\mathbf{Q}G)_{C(g)}$'s over $C(g) \in c(H) - \{C(1)\}$; also, $HH_0(\mathbf{Q}G') = HH_0(\mathbf{Q}G')_{C(1)} \oplus HH_0(\mathbf{Q}G')'$. Then $\text{trans}(HH_0(\mathbf{Q}G)_{C(1)}) \subset HH_0(\mathbf{Q}G')_{C(1)}$ and $\text{trans}(HH_0(\mathbf{Q}G)''_H) \subset HH_0(\mathbf{Q}G')'$. By Lemma 8.6, G' has the WBP over $\mathbf{Q}$, i.e. the composite $K_0(\mathbf{Q}G') \xrightarrow{T_0} HH_0(\mathbf{Q}G') \rightarrow HH_0(\mathbf{Q}G')' \xrightarrow{\varepsilon_*} \mathbf{Q}$ is zero. The conclusion follows from the above diagram. $\square$

9. TRACE FORMULAE FOR HOMOLOGICAL INTERSECTIONS

The goal of this section is to prove a "trace formula" (Theorem 9.13) for the homological intersection of the graph of a map $F: M \times Y \rightarrow M$ with the graph of the projection map $p: M \times Y \rightarrow M$ where Y is a closed oriented manifold and M is a compact oriented manifold. This result will be applied in §10 to complete the proof of Theorem 1.1.