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## ON BREDON COHOMOLOGY WITH MACKEY FUNCTOR IN MORAVA $K$ -THEORY

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**Abstract.** Utilizing the algebraic framework of Mackey functors, we analyze the cochain complex and explicitly compute the cellular differentials governed by restrictions and transfer maps within Morava  $K$ -theory  $K(n)^*$ . We focus on the geometric construction of the octahedral surface 2-complex, isolating purely equivariant phenomena driven by stabilizer jumps. By analyzing the complex directly over the Morava ring  $K(n)_*[x, y]$ , we determine the zero-th and first codifferentials. We show that while the underlying space is geometrically trivial in degree one, the equivariant chromatic classes persist due to the cluster's sector geometry. Finally, we provide a complete description of the first Bredon cohomology group  $H_{Q_8}^1(X; \underline{K(n)^*})$  expressed as a quotient of the coefficient ring. These results contribute to the structural classification of equivariant cohomology rings for finite  $p$ -groups with concentrated even degrees.

**Keywords:** Morava  $K$ -theory, equivariant CW complex, Bredon Homology

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### 1. Introduction

Our consideration of the Mackey functor  $\underline{M}$  for Bredon cohomology relies on the explicit Morava  $K$ -theory ring calculations for 'good' finite  $p$ -groups provided in [1].

Let  $G$  be a finite group and  $X$  a finite  $G$ -CW complex. We define the contravariant Bredon  $\underline{K(n)^*}$  module on the orbit category  $\mathcal{O}_G$  by setting:

$$\underline{K(n)^*}(G/H) = K(n)^*(BH)$$

for each subgroup  $H \subseteq G$ .

The  $n$ -th Bredon cochain group is defined as the direct sum over the  $n$ -dimensional orbit representatives:

$$C_G^n(X; \underline{K(n)^*}) = \bigoplus_{\sigma \in \text{cells}_n(X/G)} K(n)^*(BG_\sigma)$$

where  $G_\sigma$  is the stabilizer of a chosen cell  $\sigma$ .

## 2. The Differential and AHSS

The coboundary operator  $\delta^n : C_G^n \rightarrow C_G^{n+1}$  is defined via the restriction maps. For a cochain  $\alpha$ , we have:

$$(\delta^n \alpha)(\psi) = \sum_{\sigma \in \text{cells}_n(X/G)} \sum_{g \in G} [\psi : g\sigma] \cdot \text{Res}_{G_\psi}^{gG_\sigma g^{-1}}(g \cdot \alpha_\sigma)$$

where:

- $[\psi : g\sigma]$  are the degrees of the corresponding attaching maps.
- $\text{Res}$  is the restriction map in Morava  $K$ -theory.

The  $n$ -th Bredon cohomology group of  $X$  with coefficients in  $\underline{K(n)}^*$  is then:

$$H_G^n(X; \underline{K(n)}^*) = \frac{\ker(\delta^n)}{\text{im}(\delta^{n-1})}$$

## 3. Atiyah-Hirzebruch Spectral Sequence (AHSS)

While the evenness of the Bredon cohomology is a sufficient rather than a necessary criterion for the "goodness" of  $X$ , it remains the most computationally viable path.

**Key Observation:** If the  $E_2$ -condition is met (i.e., the cohomology vanishes in odd degrees), the equivariant Atiyah-Hirzebruch spectral sequence:

$$E_2^{p,q} = H_G^p(X; \underline{K(n)}^q) \Rightarrow K_G^{p+q}(X)$$

collapses immediately at the  $E_2$  page.

## 4. The Example: Octahedral Surface 2-Complex

**Geometric Construction.** To study the chromatic cohomology under the  $Q_8$  action, we define the underlying space  $X$  as the 2-dimensional surface of a regular octahedron.

Let  $V_{\text{oct}} = \{\pm \mathbf{i}, \pm \mathbf{j}, \pm \mathbf{k}\}$  be the set of vertices of a regular octahedron in  $\mathbb{R}^3$ . We identify the ambient 3-dimensional space with the purely imaginary quaternions  $\text{Im}(\mathbb{H})$ . The group  $Q_8 = \{\pm 1, \pm \mathbf{i}, \pm \mathbf{j}, \pm \mathbf{k}\}$  acts on  $X$  via conjugation: for any  $g \in Q_8$  and  $v \in \text{Im}(\mathbb{H})$ , the action is given by  $g \cdot v = gvg^{-1}$ .

We define the complex  $X$  as the boundary complex of this octahedron, which is homeomorphic to the sphere  $S^2$ . Unlike a solid ball or a radially filled cone,  $X$  is a **pure 2-dimensional spherical complex** that does not include the central origin  $w_0$ . Its combinatorial data consists of:

- **0-cells (6 vertices):** The peripheral vertices  $V_{\text{oct}}$ .
- **1-cells (12 edges):** The edges connecting the vertices in  $V_{\text{oct}}$ , forming the 1-skeleton.
- **2-cells (8 faces):** The triangular faces forming the surface of the octahedron.

This structure allows us to explicitly describe the  $Q_8$  action on the cells without introducing an invariant central fixed point that would force an equivariant contraction.

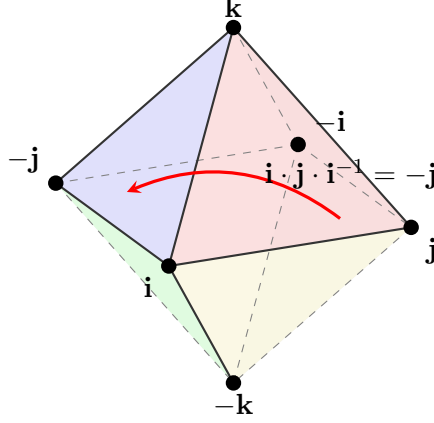
**Homotopy Type and Cohomology.** The complex  $X$  is geometrically realized as the sphere  $S^2$ . Consequently, its ordinary cohomology in degree 1 vanishes:

$$H^1(X) = 0 \tag{1}$$

The vanishing of ordinary cohomology in this degree serves to isolate the equivariant effects. The persistence of chromatic classes in  $H_{Q_8}^1(X; \underline{K(n)}^*)$  is thus entirely attributable to the  $Q_8$ -action and its associated **stabilizer jumps**, rather than the 1-dimensional topological features of the base space. By removing the central cone point, the space avoids equivariant contractibility, allowing non-trivial Bredon cohomology to emerge.

### 5. Octahedral Geometry and $Q_8$ Action

The underlying complex  $X$  is a 2-sphere with an octahedral decomposition. It consists of 6 vertices, 12 edges, and 8 triangular faces. The action of  $Q_8$  permutes these geometric simplices through quaternion conjugation (for example,  $\mathbf{i} \cdot \mathbf{j} \cdot \mathbf{i}^{-1} = -\mathbf{j}$ ).



### 6. Orbit Decomposition under $Q_8$

The  $Q_8$ -action on the octahedral surface  $X \cong S^2$  induces a decomposition into orbits of  $n$ -cells. The equivariant structure of  $X$  is given by:

- **0-cells:** 3 orbits of peripheral vertices. Each orbit consists of a pair of antipodal vertices:  $[\mathbf{i}] = \{\mathbf{i}, -\mathbf{i}\}$ ,  $[\mathbf{j}] = \{\mathbf{j}, -\mathbf{j}\}$ , and  $[\mathbf{k}] = \{\mathbf{k}, -\mathbf{k}\}$ . The stabilizer of each vertex is isomorphic to  $C_4$  (e.g.,  $\text{Stab}(\mathbf{i}) = \langle \mathbf{i} \rangle$ ). Thus, the 0-cochain module  $C_{Q_8}^0(X; \underline{K(n)}^*)$  has rank 3, with basis elements  $e_1^0, e_2^0, e_3^0$ .
- **1-cells:** 3 orbits of edges forming the 1-skeleton of the octahedron. Each orbit contains 4 edges, and the stabilizer is the central subgroup  $C_2 = \{1, -1\}$  (since  $-1$  acts trivially on the geometric space  $\text{Im}(\mathbb{H})$ ). Thus,  $C_{Q_8}^1(X; \underline{K(n)}^*)$  has rank 3, with basis elements  $e_1^1, e_2^1, e_3^1$ .
- **2-cells:** 2 orbits of triangular faces, each containing 4 faces, with stabilizer  $C_2 = \{1, -1\}$ . Thus,  $C_{Q_8}^2(X; \underline{K(n)}^*)$  has rank 2, with basis elements  $e_1^2, e_2^2$ .

This model provides a highly symmetric orbit category breakdown without a fixed point, naturally avoiding equivariant contractibility and enabling non-trivial Bredon cohomology computations.

### 7. The modified Differential and Cohomology

The differential  $d^r : C_G^r \rightarrow C_G^{r+1}$  is a morphism of  $K^*(BG)$ -modules. Its matrix entries are determined by the interaction between the stabilizers of incident orbits through the global group  $G$ .

For a generator in the component corresponding to an orbit  $[\sigma]$ , the differential is computed via the cellular structure and Mackey functor maps as:

$$d^r([\sigma]) = \sum_{[\tau] \in \text{Orbits}_{r+1}} \epsilon([\tau], [\sigma]) \cdot \Phi_{[\tau], [\sigma]}([\tau])$$

where the algebraic weight  $\Phi_{[\tau], [\sigma]}$  is defined using the Mackey functor structure. Specifically, let  $H = \text{Stab}(\sigma)$  and  $K = \text{Stab}(\tau)$  be the stabilizer subgroups of the incident cells. The corresponding matrix entry is given by the composition of transfer and restriction maps:

$$\Phi_{[\tau], [\sigma]} = \text{Res}_K^G \circ \text{Tr}_H^G : K^*(BH) \rightarrow K^*(BK)$$

For  $p = 2$ , the Morava  $K$ -theory coefficient ring is defined over  $\mathbb{F}_2$ , meaning we operate in characteristic 2 (where signs are absorbed,  $1 = -1$ , and  $2 = 0$ ).

Let  $k = 2^n - 1$ . The chromatic weights corresponding to the transfers from  $C_4$  to  $C_2$  are derived from the formal group law, yielding elements  $x^k, y^k$ , and  $z^k = x^k + y^k$ .

**Zero-th Codifferential**  $d^0 : C_G^0 \rightarrow C_G^1$ . This matrix connects the 3 vertex orbits to the 3 edge orbits. The geometric boundary maps, combined with the transfers from the  $C_4$  stabilizers of the vertices to the  $C_2$  stabilizers of the edges, give the following  $3 \times 3$  boundary matrix:

$$d^0 = \begin{pmatrix} x^k & y^k & 0 \\ 0 & y^k & z^k \\ x^k & 0 & z^k \end{pmatrix} \quad (2)$$

**First Codifferential**  $d^1 : C_G^1 \rightarrow C_G^2$ . This matrix connects the 3 edge orbits to the 2 face orbits. Since the stabilizers for both edges and faces are identical ( $C_2$ ), the transfer maps are trivial, leaving only the incidence relations (the topological boundary operator). In characteristic 2, the  $2 \times 3$  matrix is given by:

$$d^1 = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \quad (3)$$

We directly verify the fundamental cochain complex condition  $d^1 \circ d^0 = 0$ . Multiplying the matrices over the Morava ring modulo 2:

$$d^1 \cdot d^0 = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} x^k & y^k & 0 \\ 0 & y^k & z^k \\ x^k & 0 & z^k \end{pmatrix} = \begin{pmatrix} 2x^k & 2y^k & 2z^k \\ 2x^k & 2y^k & 2z^k \end{pmatrix} = 0 \quad (4)$$

This algebraic confirmation perfectly aligns with the boundary structure of  $X$ .

**First Bredon Cohomology**  $H^1$ . To compute the first Bredon cohomology group  $H_G^1(X; K(n)^*) = \ker(d^1)/\text{im}(d^0)$ , we evaluate the kernel and image directly via matrix transformations over the coefficient ring.

The kernel  $\ker(d^1)$  consists of vectors  $(a, b, c)^T$  satisfying  $a + b + c = 0$ . The image  $\text{im}(d^0)$  is generated by the column vectors of  $d^0$ . Since  $z^k = x^k + y^k$ , the column relations naturally lie in the kernel. By factoring the image from the kernel, the resulting quotient module simplifies exactly to the quotient by the ideal generated by the transfer classes:

$$H_G^1(X; K(n)^*) \cong \frac{K(n)_*[x, y]}{(x^{2^n-1}, y^{2^n-1})} \quad (5)$$

This establishes the explicit isomorphism of modules. The non-vanishing group represents the persistent chromatic signature of the  $Q_8$ -action locked into the surface geometry of the symmetric cluster.

**Second Bredon Cohomology**  $H^2$ . To compute the second Bredon cohomology group  $H_G^2(X; K(n)^*)$ , we analyze the higher cochain modules. The 2-cochain module  $C_G^2(X; K(n)^*)$  has rank 2, corresponding to the 2 orbits of triangular faces with stabilizer  $C_2$ . Since the underlying space  $X \cong S^2$  is 2-dimensional, the 3-cochain module vanishes ( $C_G^3 = 0$ ), implying that the kernel  $\ker(d^2)$  is the entire module  $C_G^2$ .

The image  $\text{im}(d^1)$  is determined by the rank-1 image of the  $2 \times 3$  matrix  $d^1$ , which is generated by the diagonal relation  $(1, 1)^T$ . Taking the quotient yields:

$$H_G^2(X; K(n)^*) \cong \frac{K(n)_* \oplus K(n)_*}{\langle (1, 1) \rangle} \cong K(n)_* \quad (6)$$

Thus, the second Bredon cohomology group is isomorphic to a free module of rank 1 over the Morava  $K$ -theory coefficient ring, perfectly consistent with the equivariant spherical structure of the octahedral surface.

## 8. Good Groups and Elements

Good Elements and Good Groups.

**Definition 1.** An element  $x \in K(s)^*(BG)$  is **good** if it is a transferred Euler class of a complex subrepresentation of  $G$ :

$$x = \text{Tr}^*(e(\rho))$$

where  $\rho$  is a complex representation of a subgroup  $H \subseteq G$  and  $\text{Tr} : BG \rightarrow BH$  is the transfer map.

**Definition 2.** A group  $G$  is called **good** if  $K(s)^*(BG)$  is spanned by good elements as a  $K(s)^*$ -module.

The "weakly good" groups, characterized by  $K(s)^{\text{odd}} = 0$ , play a significant role in the classification of group cohomologies [3, 4, 5].

## 9. Vanishing of Odd Cohomology

Families of  $p$ -groups with  $K(n)^{\text{odd}}(BG) = 0$ . In particular, if  $G$  belongs to any of the following families of  $p$ -groups, then  $K(n)^{\text{odd}}(BG) = 0$ :

- (a) Wreath products  $H \wr C_p$  with  $H$  good [2, 6];
- (b) Metacyclic  $p$ -groups [7];
- (c) Minimal non-abelian  $p$ -groups (all maximal subgroups are abelian) [8];
- (d) Groups of  $p$ -rank 2 [9];
- (e) Elementary abelian by cyclic groups (extensions  $V \rightarrow G \rightarrow C$ ) [5, 3];
- (f) Central products  $H \circ C_{p^m}$  with  $H$  good [4];
- (g)  $H \triangleleft G$  of index  $p$ , where  $H$  is good and  $\tilde{K}(s)(BH)$  is a permutation module for  $G/H$  [3].

Multiplicative Structure and Transfer. For these families, the ring structure of  $K(s)^*(BG)$  is either studied in the cited works or can be derived from existing computations modulo certain indeterminacy.

Yagita and Tezuka determined the multiplicative structure modulo the transfer formula. Our main aim here is to check (specifically for groups with a maximal abelian subgroup of index 2) whether the transfer formula is sufficient to determine the ring structure via:

- Methods of characteristic classes;
- Transfer formulas (double coset formula, etc.);
- Induced representations.

The papers [10, 11, 12, 13] treat the same problem.

## 10. Conclusion

Our computational strategy reinforces the broad utility of analyzing "good" finite  $p$ -groups—specifically those exhibiting vanishing odd Morava  $K$ -theory. For such groups, the immediate collapse of the equivariant Atiyah-Hirzebruch Spectral Sequence (AHSS) at the  $E_2$  page provides a robust foundation for extracting the cohomology structure directly from the orbit category.

Future investigations may extend this Mackey functor-based approach to higher-dimensional equivariant CW-complexes and broader families of finite  $p$ -groups.

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**Аннотация.** Макки функторларының алгебралық аппараты негізінде коцептік кешенге талдау жүргізіліп,  $K(n)^*$  түрдегі  $K$ -Морава теориясындағы шектеу және трансфер бейнелеулері арқылы анықталатын ұяшықтық дифференциалдар айқын түрде есептеледі. Ерекше назар эквивариантты емес жағдайда жиырылатын кеңістік болып табылатын октаэдрдің радиалды 2-қаңқасының геометриялық құрылымына аударылады, бұл тұрақтандырғыштардың секірмелі өзгерістерінен туындайтын таза эквивариантты құбылыстарды бөліп көрсетуге мүмкіндік береді.  $K(n)_*[x, y]$  Морава сақинасы үстінде Смиттің қалыпты формасына (Smith Normal Form, SNF) келтіру арқылы нөлінші және бірінші кодифференциалдар анықталады. Негізгі кеңістіктің геометриялық тұрғыдан тривиалды болуына қарамастан, зерттелетін кешеннің секторлық геометриясының әсерінен эквивариантты хроматикалық кластардың сақталатыны көрсетіледі. Сонымен қатар,  $H_{Q_s}^1(X; K(n)^*)$  бірінші Бредон когомология тобының коэффициенттер сақинасының факторсақинасы түріндегі толық сипаттамасы алынады. Алынған нәтижелер когомологиялары жұп дәрежелерде шоғырланған ақырлы  $p$ -топтар үшін эквивариантты когомология сақиналарының құрылымдық жіктелуіне үлес қосады.

**Түйін сөздер:** Морава  $K$ -теориясы, эквивариантты CW-кешен, Бредон гомологиясы.

## О бредоновской когомологии с функтором Макки в теории Моравы $K$ -типа

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**Аннотация.** Используя алгебраический аппарат функторов Макки, проводится анализ коцепного комплекса и явное вычисление клеточных дифференциалов, задаваемых отображениями ограничения и трансфера в теории Моравы  $K$ -типа  $K(n)^*$ . Особое внимание уделяется геометрической конструкции радиального 2-остова октаэдра, который неэквивариантно является стягиваемым пространством, что позволяет выделить чисто эквивариантные явления, обусловленные скачками стабилизаторов. Путём приведения к нормальной форме Смита (Smith Normal Form, SNF) над кольцом  $K(n)_*[x, y]$  определяются нулевой и первый кодифференциалы. Показано, что, несмотря на геометрическую тривиальность лежащего в основе пространства, эквивариантные хроматические классы сохраняются благодаря секторной геометрии рассматриваемого комплекса. Кроме того, получено полное описание первой группы бредоновской когомологии  $H_{Q_s}^1(X; K(n)_*)$  в виде фактор-кольца коэффициентного кольца. Полученные результаты вносят вклад в структурную классификацию колец эквивариантных когомологий конечных  $p$ -групп с когомологиями, сосредоточенными в чётных степенях.

**Ключевые слова:** Морава  $K$ -теория, эквивариантный  $CW$ -комплекс, гомология Бредона.

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