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Generators, Relations and Coverings of $^2B_2(K)$ *

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Introduction

R.Steinberg[1] has given a system of generators and relations of simple connected Chevalley groups, and constructed the universal covering of the group.

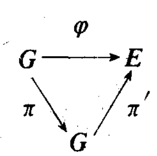
Using BN-pair technique, C.W.Curtis [5] and J,Grover [6] have also constructed the covering groups for more general groups such as the twisted groups over a field except the groups of type $^2A_{2n}$. On the other hand, Liu Chen [9] has generalized the results to the simple groups of Lie type with rank more than 1 but the group of type $^2F_4$.

In this note, we generalize the method of Steinberg to the twisted Chevalley groups of type $^2B_2$ with rank 1, and give some results on Schur mutiplier.

Notice: We adopt the notations and the results of [8] without any exposition.

I Preliminaries

A central extension of a group G is a couple $(\pi, \widetilde{G})$, where $\widetilde{G}$ is a group, π is a homorphism of $\widetilde{G}$ onto G and $\ker\pi \subseteq$ center of $\widetilde{G}$. Furthermore, a central extension $(\pi, \widetilde{G})$ is universal if for any central extension (π', E) of G, there exists a unique homorphism $\varphi: \widetilde{G} \to E$ such that $\pi'\varphi = \pi$. i.e. the following diagram is commutative:



We abbreviate universal central extension by u.c.e.

A group G is perfect if $G = DG$, where DG is the commtator subgroup of G.

If $(\pi, \widetilde{G})$ is a u.c.e of a prefect group G then we call the kenerl of π the Schur multiplier of G.

(1.1) If $(\pi, \widetilde{G})$ is a central extension of a group G which covers all others, i.e. for any central extension (π', E) of G, there exists a hormorphism $\varphi: \widetilde{G} \to E$ such that $\pi'\varphi = \pi$ and $\widetilde{G} = D\widetilde{G}$ then $(\pi, \widetilde{G})$ is a u.c.e of G.

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We assume that field K is a perfect field of characteristic 2 and that K admits an automorphism $t \to t^{\theta}$ such that $2\theta^2 = 1$. Let $\Phi = \{\pm a, \pm b; \pm(a+b), \pm(2a+b)\}$ be a root system of type B_2 and $S = \{a, b, a+b, 2a+b\}$ be an equivalence class in Φ, then ${}^2B_2(K)$ consists of the following elements:

$$X_S(t,u) = x_a(t^{\theta}) x_b(t) x_{a+b}(t^{\theta+1}+u) x_{2a+b}(u^{2\theta})$$

$$X_{-S}(t,u) = x_{-a}(t^{\theta}) x_{-b}(t) x_{-(a+b)}(t^{\theta+1}+u) x_{-(2a+b)}(u^{2\theta})$$

for any $t, u \in K$.

$$X_R(t_1, u_1) X_R(t_2, u_2) = X_R(t_1+t_2, u_1+u_2+t_1^{\theta} t_2) \qquad (1.2)$$

where $t_i, u_i \in K$ $(i=1,2)$ and $R = \pm S$.

We write $n_S = n_a n_{a+b}$ where $n_r = x_r(1) x_{-r}(-1) x_r(1)$ for any $r \in \Phi$.

$$n_S \in {}^2B_2(K) \qquad (1.3)$$

Since $w_a w_{a+b} = w_a w_b w_a w_b$ is an element of length 4 in Weyl group W, and then it maps all the positive roots to negative roots.

Let $H^1 = \langle h_S(\lambda) \mid \lambda \in K^* \rangle$ (where $h_S(\lambda) = h_a(\lambda) h_b(\lambda^{2\theta})$);

$$N^1 = \langle n_S, H^1 \rangle; \quad U^1 = \langle X_S(t,u) \mid t, u \in K \rangle; \quad B^1 = U^1 H^1, \qquad (1.4)$$

then K^1, N^1, U^1, B^1 are subgroups of ${}^2B_2(K)$ and ${}^2B_2(K)$ is a group with a splits BN-pair of rank 1. Thus, N^1/H^1 is isomorphic to the cyclic group of order 2.

We suppose that $n_s(\lambda) = h_s(\lambda) n_s$ and choose a 4-dimensional representation of $B_2(K)$.

$$x_a(t) = e + t(e_{12} + e_{43}); \qquad x_b(t) = e + te_{24};$$

$$x_{a+b}(t) = e + t(e_{14} + e_{23}); \quad x_{2a+b}(t) = e + te_{13},$$

here e is the identity matrix and e_{ij} are matrix units.

Since ${}^2B_2(K)$ has a Bruhat decomposition, a simple calculation shows that

$$n_S(\lambda) = X_S^{-1}(\lambda^{2\theta}(t^{2\theta+1}+u^{2\theta}), \lambda^{2\theta} u) X_{-S}(t,u) X_S(\lambda^{2\theta} u^{2\theta}, \lambda t^{\theta} + \lambda^{2\theta+1} u^{2\theta+1}) \qquad (1.5)$$

where $\lambda^{-1} = f(t,u) = t^{2\theta+1} + t^{\theta} u + u^{2\theta}$ for any $t, u \in K$ and $t \neq 0$ or $u \neq 0$.

$$h_s(\lambda) X_{\pm S}(t,u) h_S(\lambda)^{-1} = X_{\pm S}(\lambda^{\pm(4\theta-2)} t, \lambda^{\pm 2\theta} u) \qquad (1.6)$$

$$X_R(t,u)^{-1} = X_R(t, u + t^{\theta+1}) \quad (R = \pm S) \qquad (1.7)$$

$$n_S(\lambda) = n_S(\lambda)^{-1} \qquad (1.8)$$

$$n_S(\lambda) X_{\pm S}(t,u) n_s(\lambda)^{-1} = X_{\mp S}(\lambda^{\mp(4\theta-2)} t, \lambda^{\mp 2\theta} u) \qquad (1.9)$$

$$n_S(\lambda^{-1}) = X_{-S}(\lambda^{2\theta}(t^{2\theta+1}+u^{2\theta}), \lambda^{2\theta} u) X_S(t,u) X_{-S}(\lambda^{2\theta} u^{2\theta}, \lambda t^{\theta}) \qquad (1.10)$$

where $\lambda^{-1} = f(t,u)$.

$$n_S(v) n_S(\lambda) n_S(v)^{-1} = n_S(v^2 \lambda^{-1}) \qquad (1.11)$$

$$n_S(v) h_S(\lambda) n_S(v)^{-1} = h_S(v^2 \lambda^{-1}) h_S(v^2)^{-1} \qquad (1.12)$$

Ⅱ The Main Theorems

Definition 2.1 Suppose that $\widetilde{G}$ is a group generated by the collection of symbols $\{\widetilde{X}_R(t,u)\,|\,t,u)\in k, R=\pm S\}$ subjecte to the following relations, taken from the corresponding group ${}^2B_2(K)$.

(A) $\widetilde{X}_S(t_1,u_1)\widetilde{X}_S(t_2,u_2)=\widetilde{X}_S(t_1+t_2,u_1+u_2+t_1^\theta t_2)$ $\quad (t_i,u_i\in K\ ,\ i=1,2)$

(B) $\widetilde{n}_S(\lambda)\widetilde{X}_S(t,u)\widetilde{n}_S(\lambda)^{-1}=\widetilde{X}_{-S}(\lambda^{-4\theta+2}t,\lambda^{-2\theta}u)$,

where $\widetilde{n}_S(\lambda)$ has the same expression as $n_S(\lambda)$ in (1.5).

If G also satisfies the following relation

(C) $h_S(\lambda_1)h_s(l_2)=\widetilde{h}_S(\lambda_1\lambda_2)$, $\quad \lambda_1,\lambda_2\in K^*$,

Where $\widetilde{h}_S(\lambda)=\widetilde{n}_S(\lambda)\widetilde{n}_S(1)$ then we use G instead of $\widetilde{G}$.

Let $n_S=n_S(1)$ then the properties (1.2), (1.6)-(1.12) also hold with $\widetilde{x}$ (lies in $\widetilde{G}$) in place of x (lies in ${}^2B_2(K)$)

In order to prove the main theorem, we introduce the following lemma.

Lemma 2.2 let K be a field and $|K|>2$ then $\widetilde{G}=D\widetilde{G}$.

Proof $[\widetilde{h}_S(\lambda),\widetilde{X}_S(t,u)]=\widetilde{X}_S((\lambda^{4\theta-2}+1)t,\ (\lambda^{2\theta}+1)u+(\lambda^{2-2\theta}+1)t^{\theta+1})$, for any $t,u\in K$, there exists a $\lambda\in K^*$ such that $\lambda^{4\theta-2}+1\neq 0$, $\lambda^{2\theta}+1\neq 0$ since $|K|>2$. Hence, $\widetilde{G}=D\widetilde{G}$.

Theorem 2.3 (i) $(\pi,\widetilde{G})$ is a central extension of group ${}^2B_2(K)$ where π is the natural homorphism ;

(ii) G is isomorphic to ${}^2B_2(K)$, denoted by $G={}^2B_2(K)$.

Proof (i) (a) There is a homorphism $\pi,\widetilde{G}\to{}^2B_2(K)$ such that

$$\pi(\widetilde{X}_R(t,u))=X_R(t,u),$$

for any t,u, K and $R=\pm S$.

Let $C(\widetilde{G})$ be the center of $\widetilde{G}$, we shall show that $\ker\pi\subset C(\widetilde{G})$.

As usual, let $\widetilde{U}^1=\langle X^4{}_S(t,u)\,|\,t,u\in K\rangle$ then $\pi:\widetilde{U}^1\to U^1$ is obviously an isomorphism.

(b) Let

$$\widetilde{H}^1=\langle\widetilde{h}_S(\lambda)\,|\,\lambda\in K^*\rangle,\ \widetilde{N}^1=\langle\widetilde{n}_S(\lambda)\,|\,\lambda\in K^*\rangle,\ \widetilde{B}^1=\widetilde{U}^1\widetilde{H}^1,$$

then H^1 is in the normalizer of $\widetilde{U}^1$, also a normal subgroup of $\widetilde{N}^1$ and $\widetilde{N}^1/\widetilde{H}^1=N^1/H^1$.

(c) We now show that $\widetilde{B}^1\cup\widetilde{B}^1\widetilde{n}_S\widetilde{B}^1$ is a subgroup of $\widetilde{G}$. It is sufficent to show that

$$\widetilde{n}_S\widetilde{B}^1\widetilde{n}_S\subseteq\widetilde{B}^1\cup\widetilde{B}^1\widetilde{n}_s\widetilde{B}^1.$$

Since

$$\widetilde{n}_S\widetilde{B}^1\widetilde{n}_S=\widetilde{n}_S\widetilde{U}^1\widetilde{n}_S^{-1}\widetilde{n}_S\widetilde{H}^1\widetilde{n}_S.$$

It follows from relation (B) that

$$\widetilde{X}_{-S}(t,u)\in\widetilde{B}^1\widetilde{n}_S\widetilde{B}^1,$$

then

$$\widetilde{n}_S\widetilde{U}^1\widetilde{n}_S^{-1}\subset\widetilde{B}^1\widetilde{n}_S\widetilde{B}^1.$$

Hence, $\widetilde{B}^1\cup\widetilde{B}^1\widetilde{n}_S\widetilde{B}^1$ is a subgroup of $\widetilde{G}$.

(d) It is evident that $\widetilde{G}=\widetilde{B}^1\cup\widetilde{B}^1\widetilde{n}_S\widetilde{B}^1$ since $\widetilde{G}$ is generated by $\widetilde{B}^1$ and $\widetilde{N}^1$ which are contained in $\widetilde{B}^1\cup\widetilde{B}^1\widetilde{n}_S\widetilde{B}^1$.

(e) We show that each element of $\widetilde{G}$ has a unique expression of the form

$$\widetilde{g}=\widetilde{u}'\,\widetilde{h}\widetilde{n}_S\widetilde{u} \qquad \text{or} \qquad \widetilde{g}=\widetilde{u}'\,\widetilde{h}$$

with $\widetilde{u},\widetilde{u}'\in U^1$ and $\widetilde{h}\in\widetilde{H}^1$.

Suppose that

$$\widetilde{u}_1'\widetilde{h}_1\widetilde{h}_S\widetilde{u}_1=\widetilde{u}_2'\widetilde{h}_2\widetilde{n}_S\widetilde{u}_2 \quad \text{or} \quad \widetilde{u}_1'\widetilde{h}_1=\widetilde{u}_2'\widetilde{h}_2.$$

Applying π on both sides of the equations, then, by (a) and the uniquenesss of expression in ${}^2B_2(K)$, we have

$$\widetilde{u}_1'=\widetilde{u}_2',\ \widetilde{u}_1=\widetilde{u}_2 \quad \text{and} \quad \widetilde{h}_1=\widetilde{h}_2.$$

(f) We consider finally the kernel of π.

Let $\widetilde{u}'\widetilde{h}\widetilde{n}_S\widetilde{u}$ be in ker π, then $\pi(\widetilde{u}')\pi(\widetilde{h})\pi(\widetilde{n}_S)\pi(\widetilde{u})=1$.

It follows a contradiction that

$$\pi(\widetilde{n}_S)=n_S=1.$$

Now, suppose that $\widetilde{u}'h\in\ker\pi$, then $\pi(\widetilde{u}')\pi(h)=1$.

By (a), $\widetilde{u}=1$, hence, $\ker\pi\subset\widetilde{H}^1$.

Let $\widetilde{h}=\prod_{i=1}^{n}\widetilde{h}_S(\lambda_i)\in\ker\pi$, where $\lambda_i\in K^*(i=1,2,\cdots,n)$, then

$$\widetilde{h}\widetilde{X}_S(t,u)\widetilde{h}^{-1}=\widetilde{X}_S\Big(\big(\prod_{i=1}^{n}\lambda_i\big)^{4\theta-2}t,\ \big(\prod_{i=1}^{n}\lambda_i\big)^{2\theta}u\Big).$$

Applying π, we have

$$\widetilde{X}_S(t,u)=\widetilde{X}_S\Big(\big(\prod_{i=1}^{n}\lambda_i\big)^{4\theta-2}t,\quad \big(\prod_{i=1}^{n}\lambda_i\big)^{2\theta}u\Big),$$

hence

$$\prod_{i=1}^{n}\lambda_i=1$$

and so $\widetilde{h}$ commutes with $\widetilde{X}_S(t,u)$.

Similarly, we obtain that $\widetilde{h}$ commutes with $\widetilde{X}_{-S}(t,u)$, therefore, $\widetilde{h}$ must be contained in $C(\widetilde{G})$ since $\widetilde{X}_R(t,u)$ $(R=\pm S)$ generate the group $\widetilde{G}$. Thus, the kernel of π belongs to $C(\widetilde{G})$.

(ii) It follows immediately from the relation (C) that

$$\widetilde{h}\in\ker\pi\Leftrightarrow\widetilde{h}=\widetilde{h}(1)=1,$$

then G is isomorphic to ${}^2B_2(k)$.

From now on, we can identify the abstract group G with group ${}^2B_2(k)$, and we have

Theorem 2.4 If K is an extension of finite field $GF(2^5)$ then $(\pi,\widetilde{G})$ is a u.c.e of G.

Proof We need only to show that for any central extension (ψ, E) of G, there exists a homorphism $\varphi: \widetilde{G} \to E$ such that $\psi\varphi = \pi$.

Define $\varphi\widetilde{X}_R(t,u) \in \psi^{-1}(X_R(t,u)$ for any $t, u \in K$ and $R = \pm S$, so that

(1) $[\varphi\widetilde{h}_S(\lambda), \varphi\widetilde{X}_S(t,u)] = \varphi\widetilde{X}_S((\lambda^{4\theta-2}+1)t, (\lambda^{2\theta}+1)u + (\lambda^{2-2\theta}+1)t^{\theta+1})$.

Note that this choice is not circular since the commutator $[x,y]$ with $x, y \in E$ depends only on the classes mod $C(E)$ to which x and y belong, where $C(E)$ is the center of E.

(2) $\varphi\widetilde{h}\varphi\widetilde{X}_S(t,u)\varphi\widetilde{h}^{-1} = \varphi(\widetilde{h}\widetilde{X}_S(t,u)\widetilde{h}^{-1})$,

for any $\widetilde{h} = \prod_{i=1}^{n} \widetilde{h}_S(\lambda_i)$ in $\widetilde{H}^1$, where $\lambda_i \in K$ $(i = 1, 2, \cdots, n)$

Conjugating (1) by $\varphi\widetilde{h}$, we obtain

$$[\varphi\widetilde{h}_S(\lambda), \varphi\widetilde{X}_S(\prod_{i=1}^{n}\lambda_i^{4\theta-2}t, \prod_{i=1}^{n}\lambda_i^{2\theta}u)$$
$$= \varphi\widetilde{h}\varphi\widetilde{X}_S((\lambda^{4\theta-2}+1)t, (\lambda^{2\theta}+1)u + (\lambda^{2-2\theta}+1)t^{\theta+1})\varphi\widetilde{h}^{-1}$$
$$= \varphi\widetilde{X}_S((\lambda^{4\theta-2}+1)\prod_{i=1}^{n}\lambda_i^{4\theta-2}t, (\lambda^{2\theta}+1)\prod_{i=1}^{n}\lambda_i^{2\theta}u + (\lambda^{2-2\theta}+1)\prod_{i=1}^{n}\lambda_i^{2\theta}t^{\theta+1})$$

Since $|K| \geqslant 2^5$, there exists $\lambda \in K^*$ such that

$$\lambda^{4\theta-2}+1 \neq 0 \qquad \text{and} \qquad \lambda^{2\theta}+1 \neq 0$$

so we can easily obtain (2).

Similarly we have

(3) $\varphi\widetilde{n}\varphi\widetilde{X}_S(t,u)\varphi\widetilde{n}^{-1} = \varphi(\widetilde{n}\widetilde{X}_S(t,u)\widetilde{n}^{-1})$,

for any $\widetilde{n} \in \widetilde{N}$, hence φ preserves the relation (B).

(4) Let

$$[\varphi\widetilde{X}_S(t_1,u_1), \varphi\widetilde{X}_S(t_2,u_2)] = f(t_1,t_2,u_1,u_2)\varphi\widetilde{X}_S(0, t_1^{\theta}t_2 + t_1t_2^{\theta}) \qquad (*)$$

then $f(t_1,t_2,u_1,u_2) = 1$.

It follows exactly as in Theorem 10 of [2] that

(a) $f(0,0,u_1,u_2) = 1$ and

$$\varphi\widetilde{X}_S(0,u_1)\varphi\widetilde{X}_S(0,u_2) = \varphi\widetilde{X}_S(0, u_1+u_2).$$

Conjugating $(*)$ by $\varphi h_S(\lambda)$ $(\lambda \in K^*)$, we have

(b) $f(t_1,t_2,u_1,u_2) = f(\lambda^{4\theta-2}t_1, \lambda^{4\theta-2}t_2, \lambda^{2\theta}u_1, \lambda^{2\theta}u_2)$.

Considering $[\widetilde{X}_S(t_1,u_1)\widetilde{X}_S(t_2',u_2'), \widetilde{X}_S(t_2,u_2)]$, we have

(c) $f(t_1+t_1', t_2, u_1+u_1'+t_1^{\theta}t_1', u_2)$

$$= f(t_1,t_2,u_1,u_2)f(t_1',t_2,u_1',u_2)\cdot f(t_1,0,u_1,t_1'^{\theta}t_2+t_1't_2^{\theta}).$$

Similarly,

$$f(t_1, t_2+t_2', u_1, u_2+u_2'+t_2^{\theta}t_2')$$
$$= f(t_1,t_2,u_1,u_2)f(t_1,t_2',u_1,u_2')\cdot f(t_2,0,u_2,t_1^{\theta}t_2+t_1t_2^{\theta}).$$

(d) $f(t_1,0,u_1,u_2)f(t_1',0,u_1',u_2) = f(t_1+t_1',0,u_1+u_1'+t_1^{\theta}t_1',u_2)$.

$$f(t_1, 0, u_1, u_2) f(t_1, 0, u_1, u_2') = f(t_1, 0, u_1, u_2 + u_2').$$

(e) $f(t_1, 0, u_1, u_2) = 1$.

By the assumption of field K, there exists a $v \in K^*$ such that

$$\begin{cases} v^{\theta+1} + (1-v)^{\theta+1} + (v(1-v))^{\theta+1} \neq 0 \\ v^{2-2\theta} + (1-v)^{2-2\theta} + (v(1-v))^{2-2\theta} \neq 0 \\ v(1-v) \neq 0 \\ 1 + v(1-v) \neq 0 . \end{cases}$$

This is possible since

$$v^{\theta+1} + (1-v)^{\theta+1} + (v(1-v))^{\theta+1} = ((1-v)v^{\theta} - 1)(v \cdot v^{\theta} - (1-v)),$$
$$v^{2-2\theta} + (1-v)^{2-2\theta} + (v(1-v))^{2-2\theta} = (v^{\theta} - v^2)^2 / v^{2\theta}(1-v)^{2\theta},$$

and at most 17 elements values of v are to be avoided.

Similarly, we can show

(f) $f(t_1, t_2, u_1, u_2) = 1$.

(5) $\varphi \widetilde{X}_S(t_1, u_1) \varphi \widetilde{X}_S(0, u_2) = \varphi \widetilde{X}_S(t_1, u_1 + u_2)$.

Suppose that

$$x = \varphi \widetilde{X}_S(t_1, u_1) \varphi \widetilde{X}_S(0, u_2) \varphi \widetilde{X}_S(t_1, u_1 + u_2)^{-1},$$

then x is in the center of E since $\psi(x) = 1$.

Hence

$$\begin{aligned} x &= \varphi h_S(\lambda) x \varphi h_S(\lambda)^{-1} \\ &= \varphi \widetilde{X}_S(\lambda_1 t_1, \lambda_2 u_1 + \lambda_1^{\theta} t_1^{\theta+1}) \varphi \widetilde{X}_S(0, \lambda_2 u_2) \varphi \widetilde{X}_S(\lambda_1 t_1, \lambda_2(u_1 + u_2) + \lambda_1^{\theta} t_1^{\theta+1})^{-1} \cdot x \end{aligned}$$

where $\lambda_1 = \lambda^{4\theta-2} + 1$ and $\lambda_2 = \lambda^{2\theta} + 1$.

Thus,

$$\varphi \widetilde{X}_S(\lambda_1 t_1, \lambda_2 u_1 + \lambda_1^{\theta} t_1^{\theta+1}) \varphi \widetilde{X}_S(0, \lambda_2 u_2) = \varphi \widetilde{X}_S(\lambda_1 t_1, \lambda_2(u_1 + u_2) + \lambda_1^{\theta} t_1^{\theta+1}).$$

By (4) and (5), we have

(6) $\varphi \widetilde{X}_S(t_1, u_1) \varphi \widetilde{X}_S(t_2, u_2) = \varphi \widetilde{X}_S(t_1 + t_2, u_1 + u_2 + t_1^{\theta} t_2)$,

then φ preserves the relation (A), thus we complete the proof.

Lemma 2.5. We assume that K is an algebraic extension of prime field $GF(2)$, let $h(t,u) = h_S(t) h_S(u) h_S(t,u)^{-1}$ then $h(t,u) = 1$. In another words, (A) and (B) suffice to define G abstractly.

Proof: Arguing as in Lemma 39 of [2], we then have

(i) If t, u generated a cyclic subgroup of K^* then $h(t,u) = h(u,t)$.

(ii) If $h(t,u) = h(u,t)$ then $h(t, u^2) = 1$.

Since K is a perfect field of characteristic 2, then the elements in K^* are square.

Fof any $t, u \in K^*$, we denote the smallest subfield containing t, u of K as F, then F^* is a cyclic subgroup of K^* generated by t and u. Therefore,

Corollary 2.6. If the field K is an algebraic extension of field $GF(2^5)$, then the Schur multiplier of ${}^2B_2(K)$ is trivial.

Remark If the field is finite then the group ${}^2B_2(K)$ is Suzuki group and the consequence which we just procured coincides with the corresponding result in [7].

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${}^2B_2(K)$ 的生成元、关系式和覆盖

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摘 要

本文用生成元、关系式构造了任意域K上扭 Chevalley 单群 ${}^2B_2(K)$ 的泛中心扩张.(域$K=GF(2^3)$除外) 当域K为$GF(2^5)$的代数扩域时，证明了 ${}^2B_2(K)$ 的Schur 乘子是平凡的.