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A NOTE ON THE ORTHOGONAL GROUP OF A QUADRATIC MODULE OF RANK TWO OVER A COMMUTATIVE RING

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Let A be an arbitrary commutaive ring with the identity element. This note will give an elementary property on the orthogonal group of a non-degenerate quadartic A-module of rank two. Throughout this paper, we will assume that (V, q) is a non-degenerate quadratic A-module such that V is a finitely generated projective A-module and $[V_{\mathfrak{m}}: A_{\mathfrak{m}}]=2$ for all maximal ideal $\mathfrak{m}$ of A. The Cilfford algebra $\mathrm{C}(V, q)$ is a quadratic extension of $\mathrm{C}_0(V, q)$, the set of homogeneous elements of degree 0 in $\mathrm{C}(V, q)$, and $\mathrm{C}_0(V, q)$ is a commutative and separable quadratic extension of A (cf. [3], [4]). Set $B=\mathrm{C}_0(V, q)$. B is a Galois extension of A with a Galois group $G=\{I, \tau\}$, and τ is the unique A-algrbra automorphism of B such that the fixed subring of B is A ([4], [5]). By [3], V is an invertible B-bilmodule, and (V, ϕ), $\phi: V\times V\rightarrow B$; $\phi(x, y)=xy$ in $\mathrm{C}(V, q)$ for $x, y\in V$, is a non-degenerate hermitian B-module ((2.4) in [3]). We denote by $\mathrm{I}(A)$ the set of idempotents in A, which is an abelian group with respect to the product $*$; $e*e'=e+e'-2ee'$ for $e, e'\in \mathrm{I}(A)$. Then, by [1], the group Aut (B/A) of all A-algebra automorphisms of B is $\{e\tau+(1-e)I;\ e\in I(A)\}$, and is isomorphic to $\mathrm{I}(A)$ by the isomorphism μ: $\mathrm{I}(A)\rightarrow \mathrm{Aut}\ (B/A)$; $e \rightsquigarrow \mu =e\tau+(1-e)I$. Let $O(V, q)$ be the orthogonal group of (V, q), i.e. $O(V, q)=\{\rho\in \mathrm{Hom}_A(V, V);\ q(\rho v))=q(v)$ and $\rho(V)=V\}$. For any $\rho\in O(V, q)$, ρ is extended to an A-algebra automorphism $\tilde{\rho}$ of $\mathrm{C}(V, q)$ which induces an automorphism of B. Accordingly, there exists a group homorphism η: $O(V, q)\rightarrow \mathrm{I}(A)$; $\rho \rightsquigarrow \mu^{-1}(\rho\,|\,B)$. We put $O^+(V, q)=\{\rho\in O(V, q);\ \rho\,|\,B=I\}$ and $O^-(V, q)=\{\rho\in O(V, q);\ \tilde{\rho}\,|\,B\neq I\}$.

REMARK 1. Let V be a free A-module with the basis $\{u, v\}$, $V=Au\oplus Av$. For $\rho\in O(V, q)$, let $\rho=\begin{pmatrix} a & b \\ c & d \end{pmatrix}$ denote the matrix of ρ with respect to the basis $\{u, v\}$. Then $(\det \rho)^2=1$. If ρ is in $O^+(V, q)$ then $\det\rho=1$. If $\tilde{\rho}\,|\,B=\tau$ then $\det\rho=-1$.

Proof. Since $\mathrm{C}(V, q)=A\oplus Auv\oplus Au\oplus Av$ and $B=A\oplus Auv$, we have $\tilde{\rho}(uv)=(au+bv)(cu+dv)=\mathrm{B}_q(cu, bv)+acq(u)+bdq(v)+(\det\rho)uv$. Since $(uv)^2=\mathrm{B}_q(u, v)uv-q(u)q(v)$, we have $B=\mathrm{C}^+(V, q)=(A, \mathrm{B}_q(u, v), -1)$ and $\tau(uv)=\mathrm{B}_q(u, v)$

$-uv$ (cf. Proposition 3 in [2]). If $\tilde{\rho}|B=I$ then $\det \rho=1$ and $B_q(cu, bv)+acq(u)+bdq(v)=0$. If $\tilde{\rho}|B=\tau$ then $\det \rho=-1$ and $(cb-1)B_q(u, v)+acq(u)+bdq(v)=0$.

Let N: $U(B)\to U(A)$ be a group homomorphism of the unit group of B to the unit group of A defined by $N(b)=b\tau(b)$.

Proposition 1. *$O^+(V, q)$ is an abelian group, and is isomorphic to Ker N.*

Proof. Since $C(V, q)=B\oplus V$ and V is an invertible B-bimodule, if ρ is in $O^+(V, q)$, then $\tilde{\rho}|B=I$, and $\tilde{\rho}|V=\rho$ induces an isometry of the hermitian B-module (V, ϕ) onto itself, hence there exists an element b in $U(B)$ such that $\rho(v)=bv$ for all $v\in V$. Accordingly, $\phi(x, y)=\phi(\rho(x), \rho(y))=\phi(bx, by)=b\tau(b)\phi(x, y)=N(b)\phi(x, y)$, and we have $N(b)=1$, since B is generated by $\phi(V, V)$. The correspondence $\rho \rightsquigarrow b$ is a group monomorphism of $O^+(V. q)$ to Ker N. Conversely, for any b in Ker N, it is easily obtained that b induces an isometry of (V, q) onto itself. Therefore, $O^+(V, q)\approx$ Ker N.

Corollary 1. *$O(V, q)=\bigcup_{\tilde{\rho}_e|B=\mu_e\in \mathrm{Aut}(B/A)} \rho_e\circ O^+(V, q)$ and the following sequence is exact;*

$$(1)\longrightarrow \operatorname{Ker} N \longrightarrow O(V, q)\xrightarrow{\eta} I(A).$$

Proposition 2. *Let ρ_0 be an element in $O^-(V, q)$ such that $\tilde{\rho}_0|B=\tau$. Then, there extst α in A such that $\rho_0^2=\alpha I$ and $\alpha^2=1$. For every $\rho\in O^-(V, q)$ such that $\tilde{\rho}|B=\tau$, we have $\rho^2=\rho_0^2=\alpha I$.*

Proof. Let ρ_0 be an element in $O^-(V, q)$ such that $\tilde{\rho}_0|B=\tau$, ρ_0^2 is in $O^+(V, q)$, hence there is α in Ker N such that $\rho_0^2(v)=\alpha v$ for all $v\in V$. Since $\alpha\rho_0(v)=\rho_0^3(v)=\rho_0(\alpha v)=\tau(\alpha)\rho_0(v)$ for all $v\in V$ and V is faithful over B, we have that $\tau(\alpha)=\alpha$ is in $B^\tau=A$ and $\alpha^2=N(\alpha)=1$. For any $\rho\in O^-(V, q)$ such that $\tilde{\rho}|B=\tau$, $\rho\circ\rho_0^{-1}$ is in $O^+(V, q)$, and so there exists b in Ker N such that $\rho(v)=b\rho_0(v)$ for all $v\in V$. Accordingly, we have $\rho^2=b\rho_0 b\rho_0=b\tau(b)\rho_0^2=\rho_0^2$.

Corollary 2. *If A has no idempotents other than 0 and 1, and if $O(V, q)\neq O^+(V, q)$, then there exists α in $U(A)\cap$ Ker N suvh that $\rho^2=\alpha I$ for every ρ in $O^-(V, q)$. Furthermore, if 2 is invertible in A, then $\alpha=1$.*

Proof. We assume that A has no idempotents other than 0 and 1, $\frac{1}{2}$ is in A, and $O^-(V, q)\neq\phi$. Since $\mathrm{Aut}(B/A)=G=\{I, \tau\}$, there exists α in A such that $\alpha^2=1$ and $\rho^2=\alpha I$ for every $\rho\in O^-(V, q)$. $\frac{1+\alpha}{2}$ becomes an idepotent in A. Therefore, $\frac{1+\alpha}{2}$ is 1 or 0, that is, α is 1 or -1. We will show $\alpha=1$. Assume $\alpha=-1$. For any maximal ideal $\mathfrak{m}$ of A, we consider the localization $(V_{\mathfrak{m}}, q_{\mathfrak{m}})$

$=A_{\mathfrak{m}}u\oplus A_{\mathfrak{m}}v$, and the induced isometry ρ on $(V_{\mathfrak{m}}, q_{\mathfrak{m}})$ for $\rho\in O^{-}(V, q)$. Let $\rho=\begin{pmatrix} a & b \\ c & d \end{pmatrix}$ denote the matrix of ρ with respect to the basis u, v. For the fact that $\det \rho=ad-bc=-1$ and $\begin{pmatrix} a & b \\ d & c \end{pmatrix}^2=\begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$, we obtain that $a(a+d)=-2$ and $b=c=0$, and so $\rho(u)=au$ and $a^2=-1$. Accordingly, $q_{\mathfrak{m}}(u)=q_{\mathfrak{m}}(\rho(u))=q_{\mathfrak{m}}(au)=a^2q_{\mathfrak{m}}(u)=-q_{\mathfrak{m}}(u)$. Since we can chose u such that $q_{\mathfrak{m}}(u)\neq 0$, this is a contradiction. Consequently, $\alpha=1$.

Proposition 3. *Let A be a commutative ring such that A has no idempotents other than* 0 *and* 1, 2 *is invertible in A. If $O(V, q)\neq O^{+}(V, q)$, then for every $\rho\in O^{-}(V, q)$, there exists an invertible A-submodule U of V such that $\rho|U=-I$, $\rho|U^{\perp}=I$ and $V=U\oplus(U)^{\perp}$.*

Proof. If ρ is in $O^{-}(V, q)$, by Corollary 2, $\rho^2=\mathrm{I}$, hence we have that $\frac{I-\rho}{2}$ and $\frac{I+\rho}{2}$ are idempotents and $I=\frac{I-\rho}{2}+\frac{I+\rho}{2}$. Since $\tilde{\rho}|B=\tau$, we have $\rho\neq I$, hence $\frac{I-\rho}{2}$ is neither 0 nor I. This mention is held for the localization with respect to every maximal ideal of A. Therefore, $U=\frac{I-\rho}{2}(V)$ and $U'=\frac{I+\rho}{2}(V)$ are finitely generated projective A-modules of rank one, and we can check that U and U' are mutually orthogonal, $V=U\oplus U'$ and $U'=U^{\perp}$. Since $\rho\circ\frac{I-\rho}{2}=-\left(\frac{I-\rho}{2}\right)$ and $\rho\circ\frac{I+\rho}{2}=\frac{I+\rho}{2}$, we have $\rho|U=-I$, $\rho|U'=\rho|U^{\perp}=I$ and $V=U\oplus U^{\perp}$.

REMARK 2. Let A be as Proposition 3. If we call such an isometry in Proposition 3 a symmetry of (V, q), then $O(V, q)$ is an abelian group having no symmetries, or every element of $O(V, q)$ is a product of one or two symmetries.

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