MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 5/1984

Brauergruppen über Körpern

29.1. bis 4.2.1984

Die Tagung wurde von Herrn M. Knus (Zürich) und Herrn W. Scharlau (Münster) geleitet. Der Initiator der Tagung war Herr P. Draxl, der leider mitten in den Vorbereitungen im Oktober 1983 starb. Auf seinen Einsatz und sein Organisationstalent ist der Erfolg dieser Tagung ganz wesentlich zurückzuführen.

Ein Schwerpunktthema auf der Tagung bildeten die Resultate von Merkur'ev und deren Konsequenzen, die die Erkenntnisse über die Struktur der Brauergruppe eines Körpers entscheidend vorangetrieben haben. In weiteren Vorträgen wurden Querverbindungen z.B. mit der Theorie der quadratischen Formen und der algebraischen Geometrie aufgezeigt, so daß sich eine sehr gute Übersicht über den aktuellen Stand der Forschung ergab.

Vortragsauszüge

B. FEIN: Henselian Valued Skew Fields

Peter Draxl, one of the original organizers of this conference, died in October, 1983. In this talk we report on some results he obtained shortly before his death. Let K be a field having a

Henselian valuation v and let D be a skew field, $Z(D) = K$, $(D:K) < \infty$. Let char $\overline{K} = p$. The main result of our talk is the following extension of Ostrowski's classical result for fields: $(D:K) = e(D/K)f(D/K)p^b$ for some $b \geq 0$. In the course of proving this, Draxl also obtains the following striking result: Suppose $\overline{D} = \overline{K}$, and $p \nmid (D:K)$. Let m be the exponent of $v(D^*)/v(K^*)$. Then K contains a primitive m-th root of unity, D is isomorphic to a tensor product of cyclic algebras each having index dividing m, and $(D:K) = e(D/K)$.

S. ROSSET: <u>General crossed products and degrees of such</u>

Given a field K, an action of a group G on it and $\alpha \in H^2(G,K^*)$ one constructs the crossed product $K \rtimes_\alpha G$ in the usual way. The main question here is: do free modules over $K \rtimes_\alpha G$ have unique rank? In char. 0 this can be proved (by methods of rings of operators) for the following important special case: Let Γ be an extension $\underline{\alpha} : 1 \to A \to \Gamma \to G \to 1$ with A torsion free abelian. Let $S = kA \setminus \{0\} \subset k\Gamma$; classical localization $S^{-1}k\Gamma$ exists and is isomorphic to $K \rtimes_{\underline{\underline{\alpha}}} G$, where $K = k(A)$ (fraction field of kA) and $\underline{\underline{\alpha}}$ is $\underline{\alpha}$ mapped into $H^2(G,K^*)$. Then: unique rank holds for this case. As an application I proved a generalized <u>Gottlieb theorem</u>: If X is a finite aspherical polyhedron and $\Gamma = \pi_1(X)$ has a nontrivial normal abelian subgroup then $\chi(X) = 0$. This is done using the facts that (for $k = \mathbb{C}$) $S^{-1}\mathbb{C}\Gamma \otimes_{\mathbb{C}A} \mathbb{C} = 0$ and $S^{-1}\mathbb{C}\Gamma$ is flat over $\mathbb{C}\Gamma$. This flatness is generally not true for non-commutative localization but holds for classical (Öre type) localization.

In a second part of the talk I discussed Euler characteristics of modules over group rings of virtually polycyclic groups and some conjectures concerning their denominators.

M. SCHACHER: Applications of the classification of simple groups to Brauer groups

Suppose k is a field which is finitely generated over the rational numbers, $k \subsetneq L$, $[L:k] < \infty$. We consider the alternate conjectures

(1) $B(L/k) \neq 0$

(2) $B(L/k)$ is infinite.

Then (1) and (2) are equivalent, and both are equivalent to

(3) If G is a finite simple group, $H \subset G$ a maximal subgroup, then for some prime $p \mid o(G)$ there is an element $g \in G$ of order p^a with no conjugate of g in H .

The proof of (1) and (2) is accomplished by verifying (3) against the list of simple groups. As an added consequence we get: for some prime $p \mid [L:k]$, $B(L/k)_p$ contains infinitely many cyclic classes. It is not known if $B(L/k)$ is generated by cyclic algebras even when k contains m-th roots of unity, $m = [L:k]$.

H. OPOLKA: Cyclotomic splitting fields

Notation: k is a field, $\bar{k}$ a separabel algebraic closure of k , p a prime number $\neq$ char(k) and - for technical reasons - $p \neq 2$, ξ_{p^i} a primitive root of unity of order p^i in $\bar{k}$, $k^p =$ $k(\{\xi_{p^i}, i = 1,2,3,\ldots\})$. The condition that for all finite extensions K/k , $K \subset k^p$, every central simple K-algebra of p-power exponent has a splitting field $E \subset k^p$ is shown to be equivalent to the vanishing of $H^3(Gal(\bar{k}/K, \mathbb{Z}_p)$ for all finite K/k , $K \subset k^p$, and also equivalent to a solvability condition for central embedding problems. This can be used to give a new characterization of fields with strict cohomological dimension 2 in terms of Brauer groups. Finally we give an application to the Hasse norm theorem.

J. SONN: Arithmetic questions arising from Brauer groups and division algebras.

1. Class groups of global fields

Theorem: Given a global field F and a finite abelian group G of order prime to char(F), there exists a finite extension of F whose class group has a direct summand isomorphic to G. This is actually a corollary of a sharper result on unramified extensions, which in the case G cyclic of prime power order is used in the determination of the structure of the Brauer group of a rational function field over a global field.

2. Admissibility

Let K be a field, G a finite group. G is called K-admissible iff there exists a finite-dimensional K-central division algebra D which is a crossed product for G. If G is $\mathbb{Q}$-admissible then G is "Sylow-metacyclic", i.e. all its Sylow-subgroups are metacyclic (Schacher).

Theorem: The converse is true for solvable groups.

For unsolvable groups, there is a reduction to an explicit list of "almost" simple groups. Another fact: Let K,L be finite Galois extensions of $\mathbb{Q}$. If the K-admissible groups coincide with the L-admissible groups, then K = L.

M. KNEBUSCH: Specialization and generic splitting of quadratic forms

In this talk I explained some facts about specialization of quadratic forms with good reduction and also with bad reduction and about generic splitting of quadratic forms, needed for Arason's proof of Merkurjev's theorem (cf. below). All these facts are contained in my papers "Specialization of quadratic and symmetric bilinear forms, and a norm theorem", Acta arithmetica 24 (1973), and "Generic splitting of quadratic forms I", Proc. London Math. Soc. 33 (1976).

J.K. ARASON: Merkurjev's Theorem without K-theory

Merkurjev's Theorem that for a field F of characteristic $\neq 2$ the mapping $K_2F/2K_2F \to H^2(F, \mathbb{Z}/2\mathbb{Z})$ is an isomorphism can also be stated as the Clifford invariant $I^2F/I^3F \to H^2(F, \mathbb{Z}/2\mathbb{Z})$ being an isomorphism. Here I^nF is the n-th power of the fundamental ideal IF of the Witt ring $W(F)$ of quadratic forms over F. In this talk we describe a proof of Merkurjev's Theorem which only uses the theory of quadratic forms. The method is to show that certain statements concerning the injectivity or surjectivity of the Clifford invariant go up from a ground field F to the generic splitting field of certain quadratic forms over F. This is then used on some "generic forms". The general case is then proven by specialization arguments.

D.E. HAILE: A cohomological approach to the theory of orders over a discrete valuation ring

I use a cohomology theory (developed in collaboration with R. Larson and M. Sweedler) to investigate a class of orders (in central simple algebras) over a discrete valuation ring R. The class contains (up to a suitable notion of equivalence) all maximal R-orders. The theory elucidates the connection between the set of maximal R-orders and the Brauer group $B(R)$, providing in some cases a classification of the orbits of the action of $B(R)$ on the set (of suitable classes) of maximal R-orders.

M. VAN DEN BERGH: Index relations in division algebras over function fields of curves

1. Algebraic elements. The cases of genus 0,1 (v.d. Bergh-van Geel)

Let k be a field, C a curve defined over k, $K = k(C)$ its function field. We consider the following problem: If D is a division algebra finite dim. over its center, what can be said of the maximal (commutative) k-algebraic elements in D. Does D contain a k-alg. splitting field. In the case K is rational over k answers to these questions follow from Faddeev's theory. For those fields a weaker form of the Hasse principle holds, namely if D is everywhere unramified it must be a constant extension (i.e. $D = h \otimes_k K$, $\overline{h} \in Br(k)$). We proved the following results

1) $g_K = 0$: the weak Hasse principle holds
2) $g_K = 1$, K contains a rational point, say $x \in C$, then all D, which are everywhere unramified and such that $D_x \cong M_n(K_x)$, contain k-algebraic splitting fields.

The first result is slightly more general than Faddeev's. However the method used in the proof is different. Both 1) and 2) follow from a non-commutative version of Riemann-Roch.

2. The algebraic index of D (v.d. Bergh).

In higher genus I obtained the following quantitative results. I define the algebraic index $a(D)$ as the g.c.d. of the degrees of the algebraic splitting fields of D. $a(D)$ is to some extent determined by local information, so it is natural to restrict to the unramified case. Under the same assumptions as in (1.2) the following results are obtained. ($P(D)$ = period of D, $i(D)$ its index):

(1) $a(D) \mid P(D)^{\deg}$

(2) If $Br(k) = 0$ then $a(D) \mid g \cdot ! \, P(D)^g$

(3) If $k = \mathbb{C}((t))$ then if for all $1 \leq i \leq 2g : i \nmid P(D)$, $P(D) = a(D)$.

P. STEINER: Brauer groups of rational function fields

By the Auslander-Brumer-Faddeev theorem, the calculation of $Br(\mathbb{C}(t_1,\ldots,t_n))$ reduces to that of character groups $\chi(K)$ of function fields K . If X is a smooth algebraic variety with function field K , one has an exact sequence

$$0 \to H^1(X, \mathbb{Q}/\mathbb{Z}) \to \chi(K) \to Div(X) \otimes_{\mathbb{Z}} \mathbb{Q}/\mathbb{Z} \xrightarrow{c} H^2(X, \mathbb{Q}/\mathbb{Z}) ,$$

where c is the first Chern class. For a good choice of X , this sequence splits and one gets an isomorphism

$$Br(\mathbb{C}(t_1,\ldots,t_n)) \cong \bigoplus_i \{H^1(X_i, \mathbb{Q}/\mathbb{Z}) \oplus Div_0(X_i) \otimes_{\mathbb{Z}} \mathbb{Q}/\mathbb{Z}\} .$$

One can then prove that $Br(\mathbb{C}(t_1,\ldots,t_n))$ is divisible and that its abstract isomorphy class is independant of n for $n \geq 2$.

W. SCHELTER: Generic matrices over the integers

We answer the question of Procesi: Is the kernel of the homomorphism $\mathbb{Z}\{X_1,\ldots,X_m\} \to \mathbb{Z}/p\mathbb{Z}\{X_1,\ldots,X_m\}$ $p\mathbb{Z}\{X\}$? Here $\{X_i\}$ are generic matrices. The following polynomial

$$F = \sum_{\sigma \in S_4} (-1)^{\sigma} X_{\sigma 1} Y X_{\sigma 2} X_{\sigma 3} X_{\sigma 4}$$

is central in char 2 but not char 0 . Thus $[F, X_1] = G$ is in the kernel. We have computed a basis for the lattice $\mathbb{Z}\{X\}$ which contains G . The rank in degree $(1,2,1,1,1)$ is 192 in char 0 and 191 in char 2 . The above central F is however a polynomial in the traces and determinants in char 2 . This adds evidence to the conjecture that all invariants in char p are generated by the coefficients of the characteristic polynomial.

F. VAN OYSTAEYEN: Graded Methods in Brauer Group Theory

A. Splitting by Clifford Systems

If an R_e-algebra contains a Clifford system R over R_e for the group G then there is a natural action of G on A such that $A^G = Z_A(R) = \{a \in A ; ar = ra \ \forall r \in R\}$. This entails "dual crossed product" results for Azumaya algebras; also in char $= p \neq 0$.

B. Generalized Chase-Rosenberg Sequences:

If an Azumaya algebra, or more precisely a relative Azumaya algebra A contains a Galois extension S of R then A is R-strongly graded over S , i.e. $A = \bigoplus_{\sigma \in G} A_\sigma$, $A_e = S$, $Q_k(A_\sigma A_\tau) = A_{\sigma\tau}$; from this one derives the long exact sequence:

$$1 \to H^1(S/R , UQ_k) \to Pic(R,k) \to H^P(S/R,(Pic,k)) \to$$
$$\to H^2(S/R , UQ_k) \to Br\ (S/R,k) \to H^1(S/R,(Pic,k)) \to$$
$$\to H^3(S/R , UQ_k) .$$

(v. Oystaeyen for Galois cohomology; Caenepeel, Verschoren for Amitsur cohomology)

C. Brauer Groups of Projective Curves and Varieties.

$Br(Proj\ R) = Br(R,k_t)$, where k_t is the localization associated to the set of primes in $Proj(R)$ within $Spec(R)$. If $\dim(Proj\ R) \leq 2$, $\beta^g(\Gamma_*(\tilde{R})) = Br(Proj(R))$. If $X = Proj(R)$ is a projective curve, $\tilde{X}$ its normalization, then we have an exact sequence

$$0 \to BrX \to Br\tilde{X} \oplus Br(V) \to Br(\tilde{V}) ,$$ leading to

$$0 \to BrX \to \beta^g(\bar{R}) \oplus (\bigoplus_{P \in V} Br\ \mathbb{k}_x(P) \to \bigoplus_{Q \in \tilde{V}} Br\ \mathbb{k}_{\bar{x}}\ (Q))$$

(v. Oystaeyen, Verschoren)

D. SALTMAN: The Brauer group of a local ring.

I presented a proof of the following theorem of Merkuriev: Let k be a field, R a local k-algebra and F the residue field of R. Then the map $Br(R) \to Br(F)$ is surjective on the prime to 2 part. The proof is performed by first proving the following. Let p be an odd prime and ρ a primitive p^n-th root of one. If F is a field and $F_n = F(\rho)$, then the map Cor: $Br(F_n) \to Br(F)$ is surjective on the subgroups annihilated by p^n.

J. RITTER: Representations of Local Skew Fields

In connection with the so-called Local Langlands conjecture the following question is raised: What are the finite quotients, or also the finite subquotients, H of D^* ? Here D is a central-simple division algebra over some finite extension field of the p-adic rationals. In order to motivate this questioning firstly the efforts are described that have been made with regard to a verification of the conjecture; and secondly, in the outstanding case when p is the index of D, it is pointed at certain groups arising from Galois representation theory which might be natural candidates for the H of above. These are the character groups $G_\chi = G_K/\ker \chi$ belonging to the non-monomial p-dimensional characters χ of the absolute Galois group G_K of K, which can very well be described, and in terms of which the character χ can be presented as a linear combination of monomial characters, what, as a consequence, implies the possibility of tackling the computation of the Artin root number of χ.

D. KANEVSKY: Some remarks on Brauer equivalences for cubic surfaces

Some examples of very elementar calculations of Brauer equivalences for certain cubic surfaces V over local and global fields K (without using of a cohomological group $H^1(\mathrm{Gal}(\bar{K}/K), \mathrm{Pic}V \otimes \bar{K}))$ are given. Also some questions of Manin on universal, Brauer and R-equivalences for V, posed in his book "Cubic forms", are answered.

A. PFISTER: Quadratic Forms and Brauer Groups of Some Function Fields

For a function field F of transcendence degree 2 over $\mathbb{R}$ the u-invariant for quadratic forms over F satisfies $u(F) \leq 6$, and one would like to prove $u(F) \leq 4$. This is the case iff the so-called period-index problem has a positive answer for a certain subgroup $B_{2t}(F)$ of the Brauer group $B(F)$. $B(F)$ contains a cohomology group $H^1(C_o)$ where C_o is the Jacobian of F/K for an intermediate field $\mathbb{R} \subset K \subset F$, $tr(K/\mathbb{R}) = 1$. $H^1(C_o)$ is essentially known by work of Ogg-Šafarevič, but the period-index problem is solved only in special cases.

J.P. TIGNOL: Abelian splitting fields of universal division algebras

(joint work with S. Amitsur)

Let's say a finite group G splits a simple algebra A if A has a splitting field which is a Galois extension of its center with Galois group isomorphic to G.

Amitsur has proved that if a group G splits a universal division algebra $UD(k,n)$ of degree n, then every simple k-algebra of degree n is split by some subgroup of G. This theorem is combined with a detailed analysis of the splitting group of division algebras of iterated Laurent power series rings over algebraically closed

fields to yield the following result: If G splits a universal division algebra $UD(k,p^n)$, then the order of G is divisible by $p^{\beta(n)}$, where $\beta(n) = \sum_{m\geq 1} \{\frac{1}{2}[\frac{n}{m}]\} = \frac{1}{2} n \log n + O(n)$.
(For any real number r, $\{r\}$ and $[r]$ denote the integers which are closest to r and such that $[r] \leq r \leq \{r\}$.)

G. AYOUB: <u>Anneaux de Witt sur les surfaces affines réelles</u>

Si A est une $\mathbb{R}$-algèbre affine de dimension 1, le groupe de Witt $W(A)$ est de type fini.
Si A est une $\mathbb{R}$-algèbre affine normale de dimension 2, le groupe de Witt $W(A)$ est toujours de type fini.
Enfin, si $\mathrm{Pic}\,\bar{A}/\mathrm{Pic}\,A$ est de type fini ($\bar{A}$ étant la normalisée de A), alors $W(A)$ est de type fini. Même si A n'est pas normale.
Si $A = \mathbb{R}[X,Y,Z]/(X^2-Z^2f(Y))$, $f(Y)$ ne contenant pas de facteurs carrés, $\mathrm{Pic}\,\bar{A}/\mathrm{Pic}\,A$ n'est pas de type fini et $W(A)$ ne l'est pas non plus.

J.-L. COLLIOT-THELENE: <u>Another theorem of Mercur'ev.</u>

I reported on Mercur'ev's partial solution of a problem raised by Brumer and Rosen:
If k is a field, p a prime, and $2\cdot Br(k)_{(p)} \neq 0$ (with $A_{(p)}$ = p-primary torsion), then $Br(k)_{(p)} \supset \mathbb{Q}_p/\mathbb{Z}_p$.
Merkur'ev has proved this conjecture under the assumption $[k(\mu_p):k] \leq 3$. The proof uses the theorem of Mercur'ev-Suslin to produce a non-trivial cyclic algebra of degree p^n; if $\mu_p \subset k$, one then discusses whether $H^1(k,\mathbb{Q}_p/\mathbb{Z}_p)$ is divisible or not. In the first case, the non-trivial cyclic algebra gives a non-zero map $H^1(k,\mathbb{Q}_p/\mathbb{Z}_p) \to Br\,k$. In the second case, $H^1(k,\mathbb{Q}_p/\mathbb{Z}_p)$ non-divisible, gives an infinite cyclic tower by means of roots of

unity, which again produces an infinitely divisible element in Br k. In the case $\mu_p \not\subset k$, one uses a particular subgroup of $H^1(L,\mathbb{Q}_p/\mathbb{Z}_p)$ instead of $H^1(k,\mathbb{Q}_p/\mathbb{Z}_p)$.

J.-J. SANSUC: Variétés stablement rationnelles non rationnelles

(joint work with Beauville, Colliot-Thélène, Swinnerton-Dyer)

Le problème de Zariski est le suivant: soit F/k une extension de corps de degré de transcendance d; on suppose $F(u_1,\ldots,u_m) \simeq k(v_1,\ldots,v_{m+d})$; a-t-on $F \simeq k(t_1,\ldots,t_d)$?

En termes géométriques: soit X/k une varieté intègre; on suppose $X \times \mathbb{P}^m_k$ k-rationnelle; a-t-on X k-rationnelle?

La réponse est oui pour $d = 1$ et k quelconque (Lüroth), pour $d = 2$ et k algébriquement clos (Castelnuovo). Nous montrons que la réponse est non pour $d = 2$ et k quelconque (e.g. $k = \mathbb{Q}$) et pour $d = 3$ et $k = \mathbb{C}$. Les examples sont la surface $y^2+3z^2 = x^3-2$ pour $k = \mathbb{Q}$ et la "threefold" $y^2-a(t)z^2 = P(t,x)$ pour $k = \mathbb{C}$ avec: $a = \mathrm{disc}_x P$, la courbe C definie par $P(t,x) = 0$ dans $\mathbb{P}^2$ est lisse de genre $g \geq 3$.

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Gefördert durch
DFG Deutsche Forschungsgemeinschaft