COHOMOLOGY IN THE FINITE TOPOLOGY AND BRAUER GROUPS

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An exact sequence relating $\text{Br}(X)$, the Brauer group of a regular scheme of dimension $\leq 2$, and Amitsur cohomology (obtained as the cohomology of the sheaf of units on an appropriate Grothendieck topology) is derived by functorial methods. In order to do this we first show that any torsion element of $H^2(\mathcal{X}_{et}, G_m)$, i.e., $\text{Pic}(X)$, and $H^2(\mathcal{X}_{et}, G_m)$, i.e., $\text{Br}(X)$, is split by a finite, faithfully flat covering $Y \rightarrow X$. After proving a divisibility result for $\text{Pic}(X)$ under such coverings and some preliminary investigation of cohomology in the topology defined from such coverings, the exact sequence which is analogous to that of Chase and Rosenberg is obtained.

Let $X$ be a regular scheme with dim $X \leq 2$, i.e. $\mathcal{O}_y$ is a regular local ring for all $y \in X$. Grothendieck has then shown that the Brauer group of the scheme $X$, $\text{Br}(X)$, is isomorphic to $H^2(\mathcal{X}_{et}, G_m)$ where $\mathcal{X}_{et}$ is the etale site on $X$ [2]. On the other hand Chase and Rosenberg have given an exact sequence relating the kernel of $\text{Br}(R) \rightarrow \text{Br}(S)$ with $H^2(S/R, G_m)$ where $S$ is a finite, faithfully flat $R$-algebra [5]. This result suggests that the Brauer group of $X$, $X$ a regular Japanese scheme with dim $X \leq 2$, might be described by $H^2(\mathcal{X}_f, G_m)$ where $\mathcal{X}_f$, the finite site on $X$, is the one suggested by using coverings of the type giving the Chase-Rosenberg exact sequence. Surprisingly, $H^2(\mathcal{X}_f, G_m)$ turns out to be too large. The measure of the difference lies in $\text{Pic}(X)$. If $\text{Pic}(X)$ is torsion, then $H^2(\mathcal{X}_f, G_m)$ is the Brauer group of $X$.

Clearly we must first show that any Azumaya algebra on $X$ can be split by a finite, faithfully flat covering of $X$. This and some curious results on the behaviour of $\text{Pic}(X)$ constitute the major part of the first section. In the next section the cohomology groups, $H^n(\mathcal{X}_f, G_m)$, are investigated by spectral sequence arguments, and a sequence similar to the Chase-Rosenberg sequence is derived. The result mentioned above then follows immediately from this sequence and the splitting theorems of the first section. In a forthcoming paper most of these results will be extended to the $l$-primary component of $\text{Br}(X)$, $l$ a prime, for affine schemes $X$ of characteristic $l^*$. This accounts for the condition $\text{Sp}(l)$ introduced in the second section.

We have generally adopted the style of Artin's Grothendieck Topologies [1] since it seems to be more readily available than SGAA [2]. This makes no difference in the results since all of the topologies...
we will use are generated from pretopologies and the Cech cohomology groups in such topologies can be computed as in Artin's notes [2; Exp. I, 2.1.4 and Exp. V, 2.1, d)]. A general knowledge of sheaves of Azumaya algebras on schemes is assumed. For details the reader can consult Grothendieck's Bourbaki talk [9] which is a straightforward extension of the work of Auslander and Goldman in the affine case [3]. We have adopted Bourbaki's convention of calling central, separable algebras (in the language of Auslander-Goldman) Azumaya algebras.

In what follows all rings and schemes are noetherian. All rings have 1 and are commutative unless they are Azumaya algebras.

1. Some splitting theorems. We will be interested in the fpfp (faithfully flat of finite presentation), etale, Zariski, and finite topologies on (Sch), the category of schemes belonging to a fixed universe. They are generated from pretopologies [2; Exp. I, 2.1.2] where for \( X \in (\text{Sch}) \), \( \{ X_i \to X \}_{i \in I} \) is a covering family of \( X \) in the fpfp, etale, Zariski, or finite pretopology if (1) for all \( i \in I \), \( \varphi_i \) is resp. flat and locally of finite presentation, resp. etale [6; Exp. 1], resp. an open immersion, resp. finite, flat and (2) \( \bigcup_{i \in I} \varphi_i(X_i) = X \). Fixing a scheme \( X \) we get the fpfp, etale, Zariski, and finite sites on \( X \) denoted by \( X_{\text{fpfp}}, X_{\text{et}}, X_{\text{zar}}, \) and \( X_f \) respectively. They are formed by taking the full subcategory of \( (\text{Sch})/X \) such that the structure map satisfies condition (1) on the covering families in the respective pretopologies. The set of covering families of \( X \) will be denoted \( \text{Cov} X_* \) where \( * = \text{fpfp}, \text{et}, \text{Zar}, \) or \( f \) respectively. These sites are related by morphisms of sites \( X_{\text{fpfp}} \longrightarrow X_{\text{et}} \longrightarrow X_{\text{zar}} \) and \( X_{\text{fpfp}} \longrightarrow X_f \) for any \( X \in (\text{Sch}) \). The category of sheaves of abelian groups on these sites will be denoted by \( \mathcal{X}^* \) where \( * = \text{fpfp}, \text{et}, \text{Zar}, \) or \( f \).

Let \( X \) be a scheme, \( F \) a presheaf of abelian groups on the site \( X_* \) where \( * = \text{fpfp}, \text{et}, \text{Zar}, \) or \( f \). \( \check{H}^*(X_*, F) \) will denote the Cech cohomology of \( F \) on \( X_* \) and \( H^*_X(F) \) will be the presheaf on \( X_* \) given by \( H^*_X(F)(Y) = \check{H}^*(Y, F) \) for \( Y \in \text{Ob}X_* \). If \( F \subseteq X_*, H^*(X_*, F) \) will denote the cohomology (by derived functors) of \( F \) on the site \( X_* \), and \( H^*_X(F) \) will be the presheaf on \( X_* \) given by \( H^*_X(F)(Y) = H^*(Y_*, F) \) for \( Y \in \text{Ob}X_* \). If \( Y \) is a scheme over \( X \), faithfully flat quasi-compact descent theory shows that the functor of points of \( Y \) defines a sheaf in any of the above topologies [6; Exp. VIII].

**Lemma 1.1.** Let \( X \) be a scheme, \( X = X_1 \sqcup \cdots \sqcup X_n \) be a decomposition of \( X \) into connected components, \( i_j: X_j \to X, 1 \leq j \leq n, \) be the inclusion map. Given \( F_j \in \check{X}_{j*} \), let \( F = \bigoplus_{j=1}^n i_{j*} F_j \) where \( * \) is any of the above topologies. Then there is a natural isomorphism \( \bigoplus_{j=1}^n H^*(X_{j*}, F_j) \to \)
$H^m(X_*, F)$ for all $m$. Moreover if $F$ is representable, then $F = \bigoplus_{j=1}^r i_{j*}^* F$ in any of these topologies.

**Proof.** $X_*$ is noetherian with final object (of finite type in the language of [2]). Consequently $\bigoplus i_{j*} F_j$ defined as a presheaf is a sheaf and $\bigoplus H^m(X_*, i_{j*} F_j) \to H^m(X_*, F)$ is an isomorphism for all $m$ [1; Ê, 5]. Moreover for any $Y \to X$, $Y = \varphi^{-1}(X_i) \sqcup \cdots \sqcup \varphi^{-1}(X_n)$. Hence $X_* = X_{i_1} \times \cdots \times X_{i_n}$ and so $i_{j*}$ is exact, $1 \leq j \leq n$. Thus the Leray spectral sequence for $i_j$ collapses, and $H^m(X_*, F_\varphi) \to H^m(X_*, i_{j*} F'_j)$ is an isomorphism for all $m$.

Suppose $Y \to X$ represents $F$. Then $\varphi^{-1}(X_i)$ represents $i_j^* F$, and so $F = \bigoplus_{j=1}^r i_{j*}^* F$.

**Corollary 1.2.** Let $X$ be a scheme, $X = X_1 \sqcup \cdots \sqcup X_n$ be a decomposition of $X$ into connected components, $G_{m,X}$ be the sheaf of units on $X_*$. Then $\bigoplus_{i=1}^r H^m(X_{i*}, G_{m,X}) \to H^m(X_*, G_{m,X})$ is an isomorphism for all $m$.

Recall that an integral domain $R$ is Japanese if the normalization of $R$ in any finite extension of its quotient field is an $R$-module of finite type [7; 0, 23.1]. We extend this to schemes by calling a scheme $X$ Japanese if for every point $y \in X$, $\mathcal{O}_y/p_i$ is Japanese for all $p_i \in \text{Ass } (\mathcal{O}_y)$.

**Proposition 1.3.** Let $X$ be a regular, connected scheme with $\dim X \leq 2$.

1. If $X$ is Japanese, then $\{Y \to X \in \text{Cov } X_f | Y$ is normal and integral$\}$ is a cofinal subset of $\text{Cov } X_f$.

2. Let $\{X_i \xrightarrow{\varphi_i} X\}_{i \in I} \in \text{Cov } X_{et}$ be a finite set of etale maps with $X_i$ finite over the open subscheme $\varphi_i(X_i)$. Then there is $Y \to X \in \text{Cov } X_f$ and $\{U_i \to Y\}_{i \in I} \in \text{Cov } Y_{zar}$ which refines $\{X_i \times_X Y \to Y\}$.

**Proof.** (1) Let $Z \to X \in \text{Cov } X_f$, $\tilde{Z} \subset Z$ where $\tilde{Z}$ is one of the irreducible components of $Z$ given the reduced subscheme structure. Let $Y \to X$ be the normalization of $X$ in the function field of $\tilde{Z}$. Since $\tilde{Z}$ is finite over $X$, $\varphi$ factors through $\tilde{Z}$. Since $X$ is Japanese, $\varphi$ is finite and onto. To show that $\varphi$ is flat we may assume that $X = \text{Spec } R$, $R$ a regular local ring with $\dim R \leq 2$, and $Y = \text{Spec } S$ where $S$ is the normalization of $R$ in a finite extension field of the quotient field of $R$. But then $S$ is a Cohen-Macauley ring since it is normal and $\dim S \leq 2$. Hence $S$ is $R$-flat [7; 0, 17.3.5].

(2) Since $\varphi_i$ is etale $X_i$ is a regular scheme [6; Exp. I]. Moreover $V_i = \varphi_i(X_i)$ is an open set in $X$ since $\varphi_i$ is flat of finite presentation [8; 2.4.6]. Let $Y_i$ be the normalization of $X$ in the ring of regular
functions on $X_i$. $\varphi_i^*: Y_i \to X$ is finite since the ring of regular functions on $X_i$ is a finite product of finite separable extension fields of the function field of $X$. $\varphi'_i$ is flat and onto by the argument above. Now $\varphi_i^{-1}(V_i) = V_i \times Y_i$ is the normalization of $V_i$ in the ring of rational functions on $X_i$ where the fibred product is always over $X$. But $\varphi_i$ is finite over $V_i$. Hence $X_i$ is finite and normal over $V_i$ and so $X_i \cong V_i \times Y_i$.

Let $Y = \mathcal{X}_{i,1} Y_i$, $\varphi: Y \to X \in \text{Cov } X_f$ since $I$ is finite. Let $U_i = \varphi^{-1}(V_i) \times Y$. Then the section $V_i \times Y_i \xrightarrow{(\cong, p_2)} X_i \times Y_i$ induces a map $U_i = V_i \times Y \to X_i \times Y$ defined over $X$. Thus the Zariski covering $\{U_i\}$ of $Y$ refines the etale covering $\{X_i \times Y \to Y\}$.

Now suppose $X$ is a scheme with no embedded components, and let $y_1, \ldots, y_n$ be the generic points of the irreducible components of $X$. Then $R_x$, the sheaf of rational functions in the Zariski topology, can be identified with $\bigoplus_{i=1}^n i_x(*)$ where $i_X: \text{Spec } (O_{x_i}) \to X$ is the canonical map. Let $R_x^*$ be the subsheaf of units of $R_x$. There is an exact sequence of sheaves

$$0 \to G_m \xrightarrow{k} R_x^* \xrightarrow{} \text{Div}_x \to 0$$

where $G_m$ is the sheaf of units and $\text{Div}_x = \text{Cokernel } (k)$ is the sheaf of Cartier divisors on $X$ in the Zariski topology [12]. Since $O_{x_i}^*$ is a constant sheaf on the irreducible space $Y = \text{Spec } (O_{x_i})$, $H^i(Y_{zar}, O_{x_i}^*)$ vanishes for $i > 0$. In particular the long exact cohomology sequence for any open set $U \subseteq X$ give an exact sequence

$$(1.4) \quad 0 \to \Gamma(U, G_m) \to \Gamma(U, R_x^*) \to \Gamma(U, \text{Div}_x) \xrightarrow{\delta} \text{Pic } (U) \to 0$$

since $H^i(Y_{zar}, G_m) \cong \text{Pic } (U)$, the group of isomorphism classes of invertible $O_U$-modules.

**Theorem 1.5.** Let $X$ be a regular, Japanese scheme with $\dim X \leq 2$, $U$ an open subscheme of $\tilde{X}$, $\tilde{X} \to X \in \text{Cov } X_f$.

1. If $y \in H^i(U_{et}, G_m)$ is a torsion element, then there is $Y \to X \in \text{Cov } X_f$ and $\varphi: Y \to \tilde{X} \in \text{Mor } X_f$, such that $\varphi^*(y) = 0$ in $H^i(\varphi^{-1}(U)_{et}, G_m)$.

2. If $y \in H^i(U_{et}, G_m)$ and $n$ is any positive integer, then there are $Y \to X \in \text{Cov } X_f$, $\varphi: Y \to \tilde{X} \in \text{Mor } X_f$, and $\tilde{y} \in H^i(\varphi^{-1}(U)_{et}, G_m)$ such that $ny = \varphi^*(y)$.

**Proof.** Since $H^i(Y_{et}, G_m) \cong H^i(Y_{zar}, G_m) \cong \text{Pic } (Y)$ for any scheme
Y[2; Exp. IX, §3], (1) and (2) may be phrased in terms of Pic (X), Pic (Y), and Pic (U). Moreover we may assume that X and X are connected, X a normal, integral X-scheme.

(1) By (1.4) there is a Cartier divisor $D \in \Gamma(U, \text{Div}_X)$ such that $\delta(D) = y$ and $nD = (f)$, $f \in \Gamma(U, R^*_X)$, where $(f)$ denotes the Cartier divisor of the rational function $f$. $D$ is determined by a Zariski covering $\{U_i\}_i$ of $U$ and local equations $f_i \in \Gamma(U_i, R^*_X) = K^*$ such that $f_i \cdot f_i^{-1} \in \Gamma(U_i \cap U_j, G_m)$ where $K^*$ is the group of units in the function field $K$ of $X$. Moreover we may assume that $f_i \cdot f_i^{-1} \in \Gamma(U_i, G_m)$ for all $i$. Let $Y$ be the normalization of $X$ in $L = K(V_{\text{t}})$, $V_{\text{t}} = \varphi^{-1}(U)$, $g_i = \varphi^*(f_i) \in \Gamma(V_i, R^*_Y)$ and $g = \varphi^*(f) \in \Gamma(V, R^*_Y)$. Since $Y$ is integral, $\{V_i\}_i$ and $g_i$, define $\varphi^*(D) \in \Gamma(V, \text{Div}_Y)$. By construction there is $\overline{g} \in \Gamma(V, R^*_Y)$ with $\overline{g}^* = g$. But then the Cartier divisor $(\overline{g}^{-1}) + \varphi^*(D)$ has local equations $\overline{g}_i = g_i^{-1} \cdot g_i$ with $\overline{g}_i \in \Gamma(V_i, G_m)$. Since $Y$ is normal, $\overline{g}_i \in \Gamma(V_i, O_{V_i})$, and so $\delta((\overline{g}^{-1}) + \varphi^*(D)) = 0 = \varphi^*(\delta(D)) = \varphi^*(y)$. Finally the argument of Proposition 1.3 shows that $Y \rightarrow X \in \text{Cov } X_f$ as desired.

(2) Again we may assume that $X$ is a normal, integral $X$-scheme. Represent $y$ by a Cartier divisor $D \in \Gamma(U, \text{Div}_X)$ where $D$ is defined by local equations $f_i \in \Gamma(U_i, R^*_X) = K^*$, $\{U_i\}_i$, $1 \leq i \leq n$, a Zariski covering of $U$, such that $f_i \cdot f_i^{-1} \in \Gamma(U_i \cap U_j, G_m)$. Let $L = K(\sqrt[n]{\overline{f}_i})_{i=1,\ldots,n}$, $Y$ be the normalization of $X$ in $L$, $\varphi: Y \rightarrow X$, $V_i = \varphi^{-1}(U_i)$, $g_i = \varphi^*(f_i) \in \Gamma(V_i, R^*_Y)$ and $g = \varphi^*(f) \in \Gamma(V, R^*_Y)$. Since $Y$ is integral, $\{V_i\}_i$ and $g_i$ define $\varphi^*(D) \in \Gamma(V, \text{Div}_Y)$. By construction there is $\overline{g} \in \Gamma(V, R^*_Y)$ with $\overline{g}^* = g$. But then the Cartier divisor $(\overline{g}^{-1}) + \varphi^*(D)$ has local equations $\overline{g}_i = g_i^{-1} \cdot g_i$ with $\overline{g}_i \in \Gamma(V_i, G_m)$. Since $Y$ is normal, $\overline{g}_i \in \Gamma(V_i, O_{V_i})$, and so $\delta((\overline{g}^{-1}) + \varphi^*(D)) = 0 = \varphi^*(\delta(D)) = \varphi^*(y)$. Finally the argument of Proposition 1.3 shows that $Y \rightarrow X \in \text{Cov } X_f$ as desired.

The following result was pointed out by J. L. Verdier.

**Proposition 1.6.** Let $X$ be any scheme, $y$ a torsion element in $H^1(X_{et}, G_m)$. Then there is $Y \xrightarrow{\varphi} X \in \text{Cov } X_f$ such that $\varphi^*(y) = 0$ in $H^1(Y_{et}, G_m)$.

**Proof.** Let $L$ be the invertible $O_X$-module whose class in Pic ($X$) is $y$, $s \in \Gamma(X, L^{\otimes n})$ the global section defining the isomorphism $O_X \xrightarrow{\sim} L^{\otimes n}$. Then $R = \bigoplus_{s=0}^n L^{\otimes s}/(1 - s)(\bigoplus_{s=0}^n L^{\otimes s})$ is a coherent faithfully flat sheaf of $O_X$-algebras, and clearly $L \otimes_{O_X} R \cong R$ as sheaves of $R$-modules. Let $Y = \text{Spec } (R)$. Then $Y \rightarrow X \in \text{Cov } X_f$ and $\varphi^*(L) \cong O_Y$.

More surprising and much more interesting is the next splitting theorem for elements of $\text{Br } (X)$, the Brauer group of $X[9]$. 

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THEOREM 1.7. Let $X$ be a regular Japanese scheme with $\dim X \leq 2$, $y \in H^3(X_{et}, G_m)$. Then there is $\varphi: Y \to X \in \text{Cov}_X$ with $\varphi^*(y) = 0$ in $H^3(Y_{et}, G_m)$.

Proof. Grothendieck has shown that $\text{Br}(X) \subseteq H^2(X_{et}, G_m)$ and $\text{Br}(X)$ is torsion for any scheme $X[9]$. Moreover if $X$ is regular with $\dim X \leq 2$, then $\text{Br}(X) = H^2(X_{et}, G_m)[10]$. Thus we may assume that $X$ is connected and $n \cdot y = 0$ for some integer $n$. Since an Azumaya algebra can be split locally (in the Zariski topology) by finite etale coverings and $X$ is noetherian, we can find $\tilde{X} \to X$ and a finite Zariski covering $\{U_i\}$ of $\tilde{X}$ such that $(\bar{\varphi} | U_i)^*(y) = 0$ in $H^2(U_{i_{et}}, G_m)$ by Proposition 1.3. Thus it suffices to show that given $\tilde{X} \to X \in \text{Cov}_X$, $y \in H^2(X_{et}, G_m)$ an element of order $n$ and a Zariski covering $\{U_i\}$ of $\tilde{X}$ such that $y | U_i = 0$ in $H^2(U_{i_{et}}, G_m)$, then there is $Y \to X \in \text{Cov}_X$, $Y \to X \in \text{Cov}_X$, such that $\varphi^*(y) = 0$.

In the Leray spectral sequence for $\varepsilon: \tilde{X}_{et} \to \tilde{X}_{zar}, R\varepsilon_{et}(G_m) = 0$ since the Zariski topology contains enough coverings to split elements of Pic. Thus the exact sequence of low degree terms gives an exact sequence

$$0 \longrightarrow H^2(\tilde{X}_{zar}, G_m) \longrightarrow H^3(\tilde{X}_{et}, G_m) \longrightarrow \Gamma(\tilde{X}, R^2\varepsilon_{et}(G_m)).$$

Since $y$ is split by a Zariski covering of $\tilde{X}$, there is an element $z \in H^2(\tilde{X}_{zar}, G_m)$ of order $n$ with $j(z) = y$.

The spectral sequence $H^3(\tilde{X}_{zar}, H^3_{zar}(G_m)) \Rightarrow H^3(\tilde{X}_{zar}, G_m)$ gives an exact sequence

$$0 \longrightarrow H^3(\tilde{X}_{zar}, G_m) \longrightarrow H^3(\tilde{X}_{et}, G_m) \longrightarrow \Gamma(\tilde{X}, R^3\varepsilon_{et}(G_m)).$$

Since $y$ is split by a Zariski covering of $\tilde{X}$, there is an element $z \in H^2(\tilde{X}_{zar}, G_m)$ of order $n$ with $j(z) = y$.

The spectral sequence $H^3(\tilde{X}_{zar}, H^3_{zar}(G_m)) \Rightarrow H^3(\tilde{X}_{zar}, G_m)$ gives an exact sequence

$$0 \longrightarrow H^3(\tilde{X}_{zar}, G_m) \longrightarrow H^3(\tilde{X}_{et}, G_m) \longrightarrow \Gamma(\tilde{X}, R^3\varepsilon_{et}(G_m)).$$

Since $y$ is split by a Zariski covering of $\tilde{X}$, there is an element $z \in H^2(\tilde{X}_{zar}, G_m)$ of order $n$ with $j(z) = y$.

The spectral sequence $H^3(\tilde{X}_{zar}, H^3_{zar}(G_m)) \Rightarrow H^3(\tilde{X}_{zar}, G_m)$ gives an exact sequence

$$0 \longrightarrow H^3(\tilde{X}_{zar}, G_m) \longrightarrow H^3(\tilde{X}_{et}, G_m) \longrightarrow \Gamma(\tilde{X}, R^3\varepsilon_{et}(G_m)).$$

Since $y$ is split by a Zariski covering of $\tilde{X}$, there is an element $z \in H^2(\tilde{X}_{zar}, G_m)$ of order $n$ with $j(z) = y$.
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Let \( K \) be the function field of \( \bar{X} \), \( L = K(\sqrt[n]{\xi_{ij}}, \xi_{ij, j = n}) \) where \( \xi \) is a primitive \( m \)th root of unity, and \( n = p^r m, (m, p) = 1 \), if \( p = \text{char } K > 0 \), \( n = m \) otherwise. Let \( Y \) be the normalization of \( X \) in \( L \), \( \varphi: Y \to X \). The argument of Proposition 1.3 shows that \( \varphi \in \text{Cov } X \), and, of course, there is a morphism \( \psi: \hat{Y} \to \hat{X} \) of \( X \)-schemes. Since \( \psi^{-1}(V_i \cap V_j), G_m \) we may assume that the cohomology class \( z \in \check{H}^2(Y_{zar}, G_m) \) that we must split can be represented by \( \{v_{ijk}\} \) where \( v_{ijk} \in \Gamma(V_i \cap V_j \cap V_k, \mu_n) \) and \( \mu_n \) is the sheaf of \( n \)th roots of unity. Now \( Y \) has a global section of order \( m \) where \( n = p^r m, (m, p) = 1 \), if \( p = \text{char } L > 0 \) and \( m = n \) otherwise. Hence \( \mu_n \) is the constant sheaf \( \mathbb{Z}/m\mathbb{Z} \) on \( Y \) [6, Exp. XI, §6]. Since \( Y \) is irreducible and a constant sheaf on an irreducible space is flasque, \( H^2(Y_{zar}, \mu_n) = 0 \). The Cech cohomology spectral sequence then shows that \( H^2(Y_{zar}, \mu_n) = 0 \) and so \( z = 0 \) in \( \check{H}^2(Y_{zar}, G_m) \) as desired.

**Corollary 1.8.** Let \( A \) be an Azumaya algebra on \( X \), \( X \) a regular Japanese scheme with \( \dim X \leq 2 \). Then there is \( Y \to X \in \text{Cov } X \) and a locally free coherent \( O_Y \)-module \( F \) such that \( \varphi^*(A) \cong \text{End} \gamma(F) \).

**Remark.** Let \( X \) be a regular connected Japanese scheme with \( \dim X \leq 2 \), and let \( K \) be a finite extension of the field of rational functions on \( X \). The Japanese assumption on \( X \) was only used to show that the normalization of \( X \) in \( L \), a finite extension of \( K \) obtained by adjoining \( n \)th roots of elements in \( K \), was finite over \( X \). Thus without the Japanese assumption Theorems 1.5 and 1.7 hold for \( (n, p) = 1 \) where \( p = \text{char } K > 0 \) (\( n \) = order of \( y \) in Theorem 1.5, (1) and Theorem (1.7)) since in this case the above extensions are separable and (2) of Proposition 1.3 did not use the Japanese assumption.

2. Finite cohomology. This section is devoted to determining the structure of \( H^*(X_f, G_m) \). The results when combined with the splitting theorems of the previous section describe the relationship between \( \text{Br } (X) \) and \( H^2(X_f, G_m) \) for a regular Japanese scheme \( X \) with \( \dim X \leq 2 \).

**Theorem 2.1.** Let \( X \) be a connected scheme, \( Y \to X \in \text{Cov } X \). Then there are natural maps \( i_*: H^*(X_*, G_{m,x}) \to H^*(X_*, \varphi_* G_{m,y}) \) and \( N_*: H^*(X_*, \varphi_* G_{m,y}) \to H^*(X_*, G_{m,x}) \) for \( n \geq 0 \) such that \( N_* i_* \) is multiplication by \( \text{rk}_{\gamma}(\varphi_* \gamma) \) where \( * = \text{fppf, et, Zar, or } f \). Moreover \( H^*(X_f, G_m) \) is a torsion group for all \( n > 0 \).

**Proof.** Let \( * = \text{fppf} \). Then \( i_* \) comes from the natural inclusion \( G_{m,x} \to \varphi_* G_{m,y} \) where \( G_{m,x}, \varphi_* G_{m,y} \in \check{X}_{\text{fppf}} \).
Let $R$ be a ring, $S$ a finite $R$-algebra which is free as an $R$-module.
Define $N: S^* \to R^*$ where $R^*$, $S^*$ are the units of $R$, $S$ respectively by setting $N(u) = \det(L_u)$ where $L_u$ is the $R$-linear map of $S$ defined by left multiplication by the unit $u$. Since $L_u$ is an isomorphism, its determinant is a unit in $R$. The functorial properties of det show that $N$ is natural in $R$. Thus if $Y \to X$ is any finite faithfully flat morphism, then $\varphi_* \mathcal{O}_Y$ is a locally free coherent sheaf of $\mathcal{O}_X$-modules and $N$ extends to a morphism of sheaves $N: \varphi_*^\mathcal{O}_Y \to \varphi_*^\mathcal{O}_X$ [12; Lecture 10] which is natural with respect to base change of $X$. Thus it extends to a map $N: \varphi_* G_{m,Y} \to G_{m,X} \in \text{Mor } \mathcal{X}_{\text{fppf}}$ by commutativity of the diagram below for any $X_1 \to X_2 \in \text{Mor } \mathcal{X}_{\text{fppf}}$:

$$
\begin{array}{c}
\Gamma(Y \times X_2, G_{m,Y}) \\
\downarrow \downarrow
\end{array} \xrightarrow{N} \begin{array}{c}
\Gamma(X_2, G_{m,X}) \\
\Gamma(Y \times X_1, G_{m,X}) \\
\downarrow \downarrow
\end{array} \xrightarrow{N} \begin{array}{c}
\Gamma(X_1, G_{m,X}) \\
\end{array} .
$$

If $X$ is connected, then $\text{rank}_{\mathcal{O}_X}(\varphi_* (\mathcal{O}_Y))$ is a constant and for any $X_1 \to X_2 \in \text{Ob } \mathcal{X}_{\text{fppf}}$ the composite

$$
\begin{array}{c}
\Gamma(X_2, G_{m,X}) \\
\downarrow \downarrow
\end{array} \xrightarrow{i_*} \begin{array}{c}
\Gamma(Y \times X_2, G_{m,Y}) \\
\downarrow \downarrow
\end{array} \xrightarrow{N} \begin{array}{c}
\Gamma(X_1, G_{m,X}) \\
\end{array}
$$

sends $u$ to $u^m$ where $m = \text{rank}_{\mathcal{O}_{X_1}}((\varphi \times X_1)_* (\mathcal{O}_{Y \times X_1})) = \text{rank}_{\mathcal{O}_X}(\varphi_* \mathcal{O}_Y))$. Thus $N$ induces

$$
N_*: H^n(X_{\text{fppf}}, \varphi_* G_{m,Y}) \longrightarrow H^n(X_{\text{fppf}}, G_{m,X})
$$

for all $n \geq 0$ and by universality $N_* i_*$ is multiplication by $\text{rank}_{\mathcal{O}_X}(\varphi_* (\mathcal{O}_Y))$. The morphisms of sites $X_{\text{fppf}} \to X_*$ where $* = \text{et}$, Zar, or $j$ gives a map $N: \varphi_* G_{m,Y} \to G_{m,X} \in \text{Mor } \mathcal{X}_*$ which extends to $N_*: H^*(X_*, \varphi_* G_{m,Y}) \to H^*(X_*, G_{m,X})$ with the desired properties. In particular the kernel of $i_*$ is torsion.

Finally we must show that $H^n(X_f, G_m)$ is torsion for all $n > 0$. If $Y \to X \in \text{Cov } X_f$, then $\varphi^*: \mathcal{X}_f \to \mathcal{Y}_f$ is exact and left adjoint to $\varphi_*$. In particular

$$
H^n(Y_f, G_m) \longrightarrow H^n(Y_f, G_{m,X})
$$

is an isomorphism [1; II, 4.13] and so we will drop the subscript $X$ on $G_{m,X}$. We will use induction on $n$, $n \geq 1$, to show that for a scheme $X$, $H^n(X_f, G_m)$ is torsion. By Corollary 1.2 we may assume that $X$ is connected. Let $y \in H^n(X_f, G_m)$. There is $\varphi: Y \to X \in \text{Cov } X_f$ such that $\varphi^*(y) = 0$ in $H^n(Y_f, G_m)$ [1; II, 2.5]. Now the map $\varphi^*$ may be written as the composite

$$
H^n(X_f, G_{m,X}) \xrightarrow{t_*} H^n(X_f, \varphi_* G_{m,Y}) \xrightarrow{\delta_*} H^n(Y_f, G_{m,X})
$$
where $e_n$ is the edge homomorphism of the Leray spectral sequence for $\varphi: Y \to X$, $H^p(X_f, R^q\varphi_*(G_{m,Y})) \Rightarrow H^q(Y_f, G_{m,Y})$. By the above the kernel of $i_*$ is torsion and so it suffices to show that the kernel of $e_n$ is also torsion for $n \geq 1$. For $n = 1$, the exact sequence of low degree terms shows that $H^1(X_f, \varphi_*(G_{m,Y}))$ is a subgroup of $H^1(Y_f, G_{m,Y})$. For $n > 1$, any element in the kernel of $e_n$ is in $d_r((E)^\otimes r)$ for some $r$, $2 \leq r \leq n$. Hence it suffices to show that $H^n(X_f, R^i\varphi_*(G_m))$ is torsion for $1 \leq l \leq n - 1$ and $m \geq 0$.

In general $R^i\varphi_*(G_m)$ is the sheaf in $\mathcal{X}_f$ associated to the presheaf $\mathcal{X} \mapsto H^i(\mathcal{X} \times_X Y_f, G_{m,Y})$ for any $\mathcal{X} \in \text{Ob } X_f$ [1; II, 4.7], and so is torsion by the induction hypothesis. Hence, it is sufficient to show that $H^n(X_f, F)$ is torsion for any torsion sheaf $F \in \mathcal{X}_f$ and $m \geq 0$. Let $sF$ be the kernel of multiplication by $n$ on $F$. Then $\Gamma(X, \mathcal{F}) = 0$ since for any $\mathcal{X} \in \text{Ob } X_f$ and any element $y \in H^i(\mathcal{X} \times_X Y_f, G_m) = \text{Pic } (\mathcal{X} \times_X Y)$ there is a Zariski covering $\{U_i\}$ of $\mathcal{X}$ such that $y|_{U_i \times Y} = 0$ in $H^i(\mathcal{U}_i \times_Y Y_f, G_m)$ [12; Lecture 10]. Hence this map is injective.

We are now in a position to evaluate some of the cohomology groups of $G_m$ in the finite topology. If $G$ is a group or a presheaf on $X_*$ in some topology, let $G_1$ and $G(l)$ denote the subgroup or subpresheaf consisting of torsion elements and elements whose order is a power of $l$ respectively. For a fixed scheme $X$ we have morphisms of sites $X_{fppf} \to X_f$ and $X_{fppf} \to X_{et}$. Grothendieck has shown that $\varepsilon_*$ induces an isomorphism $H^*(X_*, G_m) \to H^*(X_{fppf}, G_m)$ for all $n \geq 0$ [11; Appendix]. This immediately extends the results of the previous section to equivalent results about $H^*(X_{fppf}, G_m), i = 0, 1, 2$.

The proof of the main theorem is based on the Kummer sequence

\begin{equation}
0 \to \mu_n \to G_m \xrightarrow{n} G_m \to 0
\end{equation}

where $n$ is the $n$th power map. Since taking $n$th roots of global units gives a finite faithfully flat extension, this is an exact sequence of sheaves in both $\mathcal{X}_f$ and $\mathcal{X}_{fppf}$. We will leave it to the context to

**Corollary 2.2.** Let $X$ be a scheme, $Y \to X \in \text{Cov } X_f$. Then the kernel of $H^i(X_{fppf}, G_m) \to H^i(Y_{fppf}, G_m)$ is torsion.

**Proof.** As in the proof above it is sufficient to show that the kernel of $H^i(X_{fppf}, \varphi_*(G_m)) \to H^i(Y_{fppf}, G_m)$ is torsion. But $\Gamma(X, R^i\varphi_*(G_m)) = 0$ since for any $\mathcal{X} \in \text{Ob } X_f$ and any element $y \in H^i(\mathcal{X} \times_X Y_{fppf}, G_m) = \text{Pic } (\mathcal{X} \times_X Y)$ there is a Zariski covering $\{U_i\}$ of $\mathcal{X}$ such that $y|_{U_i \times Y} = 0$ in $H^i(\mathcal{U}_i \times_Y Y_{fppf}, G_m)$ [12; Lecture 10]. Hence this map is injective.
determine in which topology $\mu_n$ and $G_m$ are sheaves.

**Definition.** A scheme $X$ satisfies $\text{Sp}(l)$ for some prime $l$ if for any $Y \in \text{Ob}X_f$ and $y \in H^1(Y_{\text{fppf}}, G_m)$, there is $\bar{y} \in \text{Ob}X_f$, $\bar{y} \xrightarrow{\varphi} Y \in \text{Mor} X_f$ and $\bar{y} \in H^1(\bar{Y}_{\text{fppf}}, G_m)$ with $\bar{y} = \varphi^*(y)$.

By Theorem 1.5 if $X$ is a regular Japanese scheme with $\dim X \leq 2$, then $X$ satisfies $\text{Sp}(l)$ for all primes $l$.

**Theorem 2.4.** Let $X$ be any scheme. Then $H^i(X_f, G_m) \cong \text{Pic}_l(X)$, and $R^i\tau_*(G_m)$ is torsion free. There are exact sequences

$$0 \rightarrow \text{Pic}_l(X) \rightarrow \text{Pic}(X) \rightarrow \Gamma(X, R^i\tau_*(G_m)) \rightarrow$$

$$H^i(X_f, G_m) \xrightarrow{\tau_*} F^iH^i(X_{\text{fppf}}, G_m) \rightarrow H^i(X_f, R^i\tau_*(G_m))$$

and

$$0 \rightarrow F^iH^i(X_{\text{fppf}}, G_m) \rightarrow H^i(X_{\text{fppf}}, G_m) \rightarrow \Gamma(X_f, R^i\tau_*(G_m)),$$

where $F^iH^i(X_{\text{fppf}}, G_m)$ is a torsion group. If Pic$(X)$ is torsion, then $\tau_*$ is injective. If $X$ satisfies $\text{Sp}(l)$, then $\Gamma(X, R^i\tau_*(G_m))$ is $l$-divisible and

$$\tau_*(l) : H^2(X_f, G_m)(l) \rightarrow (F^iH^2(X_{\text{fppf}}, G_m))(l)$$

is onto. If Pic$(X)$ is torsion, then $\tau_*(l)$ is an isomorphism.

**Proof.** For any $Y \rightarrow X \in \text{Ob}X_f$, the spectral sequence coming from $\tau: X_{\text{fppf}} \rightarrow X_f$ applied to the Kummer sequence gives a large diagram with exact columns coming from the low degree terms of the spectral sequences and all but the third row exact from the Kummer sequence:

$$
\begin{array}{ccc}
0 & 0 & 0 \\
& & \\
\Gamma(Y, G_m) & \longrightarrow & H^1(Y_f, \mu_n) \\
& & \downarrow \\
& & H^i(Y_f, G_m) \\
& & \longrightarrow \\
& & H^i(Y_f, G_m) \\
\end{array}
$$

$$
\begin{array}{ccc}
\Gamma(Y, G_m) & d^2 & \longrightarrow \\
& & \downarrow \\
& & H^1(Y_{\text{fppf}}, \mu_n) \\
& & \longrightarrow \\
& & H^i(Y_{\text{fppf}}, G_m) \\
& & \longrightarrow \\
& & H^i(Y_{\text{fppf}}, G_m) \\
\end{array}
$$

(2.5)

$$
\begin{array}{ccc}
\Gamma(Y, R^i\tau_*(\mu_n)) & \longrightarrow & \Gamma(Y, R^i\tau_*(G_m)) \\
& & \downarrow \\
& & H^3(Y_f, \mu_n) \\
& & \longrightarrow \\
& & H^3(Y_f, G_m) \\
& & \longrightarrow \\
& & H^3(Y_f, G_m) \\
& & \tau_* \\
& & \downarrow \\
& & F^iH^2(Y_{\text{fppf}}, \mu_n) \\
& & \downarrow \\
& & F^iH^2(Y_{\text{fppf}}, G_m) \\
& & \longrightarrow \\
& & F^iH^2(Y_{\text{fppf}}, G_m) \\
& & \longrightarrow \\
& & H^4(Y_f, R^i\tau_*(G_m)) \\
\end{array}
$$
The middle column suitably interpreted is the 6 term exact sequence of the theorem. By definition of the filtration on the spectral sequence,

\[ 0 \longrightarrow F^i H^i(Y_{\text{fppf}}, G_m) \longrightarrow H^i(Y_{\text{fppf}}, G_m) \longrightarrow E^2_{\infty} \cong \Gamma(Y_f, R^i \tau_* G_m) \]

is exact. By Corollary 2.2, \( F^i H^i(Y_{\text{fppf}}, G) \), which consists of these elements in \( H^i(Y_{\text{fppf}}, G_m) \) that are split by \( Y \rightarrow Y \in \text{Cov } Y_f \) for some \( Y \), is a torsion group. Moreover \( H^i(Y_{\text{fppf}}, G_m) \cong \text{Pic } (Y) \). Thus the

\[ 0 > F^i H^i(Y_{\text{fppf}}, G_m) > H^i(Y_{\text{fppf}}, G_m) > E^2_{\infty} \cong \Gamma(Y_f, R^i \tau_* G_m) \]

is exact. By Corollary 2.2, \( F^i H^i(Y_{\text{fppf}}, G) \), which consists of these elements in \( H^i(Y_{\text{fppf}}, G_m) \) that are split by \( Y \rightarrow Y \in \text{Cov } Y_f \) for some \( Y \), is a torsion group. Moreover \( F^i H^i(Y_{\text{fppf}}, G_m) \cong \text{Pic } (Y) \). Thus the naturality in \( Y \) of (2.5), Proposition 1.6, and Theorem 2.1 combine to show that \( H^i(X_f, G_m) \cong \text{Pic } (X) \) for any scheme \( X \).

In order to show that \( R^2 \tau^* (\mu_n) \) is torsion free, it is sufficient to show that \( R^2 \tau^* (\mu_n) \), the sheaf associated to \( Y \rightarrow H^i(Y_{\text{fppf}}, \mu_n) \) for \( Y \rightarrow X \in \text{Ob } X_f \), is 0 [1; II 4.7]. So given \( Y^0 \rightarrow Y \in \text{Cov } Y_f \) and \( \mu_n \in R^2 \tau^* (\mu_n) \), we have

\[ \phi^*(y) = 0 \text{ in } H^2(Y_{\text{fppf}}, \mu_n) \]

is exact. By Corollary 2.2, \( F^i H^i(Y_{\text{fppf}}, G) \), which consists of these elements in \( H^i(Y_{\text{fppf}}, G_m) \) that are split by \( Y \rightarrow Y \in \text{Cov } Y_f \) for some \( Y \), is a torsion group. Moreover \( F^i H^i(Y_{\text{fppf}}, G_m) \cong \text{Pic } (Y) \). Thus the naturality in \( Y \) of (2.5), Proposition 1.6, and Theorem 2.1 combine to show that \( H^0(X_f, G_m) \cong \text{Pic } (X) \) for any scheme \( X \).

Now suppose \( X \) satisfies \( \text{Sp } (l) \). If \( \Gamma(X, R^2 \tau^* (\mu_n)) \rightarrow \Gamma(X, R^2 \tau^* (G_m)) \)

is injective, then \( \Gamma(X, R^2 \tau^* (G_m)) \rightarrow \Gamma(X, R^2 \tau^* (G_m)) \) is onto. Thus it is sufficient to show that for any \( Y \rightarrow X \in \text{Cov } X_f \), \( y \in H^2(Y_{\text{fppf}}, \mu_n) \) such that \( j^*(y) = 0 \) in \( H^2(Y_{\text{fppf}}, G_m) \), there is \( \tilde{Y} \rightarrow X \in \text{Cov } X_f \) and \( \tilde{Y} \rightarrow Y \in \text{Mor } X_f \) such that \( \phi^*(y) = 0 \). Since \( j^*(y) = 0 \), there is \( z \in \text{Pic } (Y) \) such that \( d^i(z) = y \) where \( d^i: H^i(Y_{\text{fppf}}, G_m) \rightarrow H^i(Y_{\text{fppf}}, \mu_n) \) is the connecting homomorphism coming from (2.3). Since \( X \) satisfies \( \text{Sp } (l) \), there is \( \tilde{Y} \rightarrow X \in \text{Cov } X_f \), \( \tilde{Y} \rightarrow Y \in \text{Mor } X_f \), and \( \tilde{z} \in \text{Pic } (\tilde{Y}) \) such that \( l \cdot \tilde{z} = \phi^*(z) \).

But then \( \phi^*(y) = 0 \) since \( d^i(l \cdot \tilde{z}) = \phi^*(y) = 0 \).

Finally we must show that

\[ \tau^* (l): H^2(X_f, G_m)(l) \rightarrow (F^i H^i(X_{\text{fppf}}, G_m))(l) \]

is onto. First note that for any presheaf of sets \( F \) on \( X_f \), \( U \in \text{Ob } X_f \), and any element \( y \in H^2(F)(U) \), there is a covering \( V \rightarrow U \) and an element \( y \in F(V) \) which represents \( \phi^*(y) \) in \( H^2(F)(V) \). This may be seen by representing \( y \) by an element \( y^i \in F(V) \) such that \( p_i^*(y^i) = \phi^*(y) \). Then \( \phi^*(y) \) is represented by \( p_i^*(y) \in F(V \times V) \) where \( V \rightarrow U \) is a covering of \( U \) and \( p_i \) is the projection map onto the \( i \)th factor. Then \( \phi^*(y) \) is represented by \( p_i^*(y) \in F(V \times V) \) where \( V \rightarrow U \) is a covering of \( V \). Since \( p_i^*(y) = p_i^*(y) \), \( y \in F(V) \) represents \( \phi^*(y) \).

Now if \( H^2(X_f, R^2 \tau^* G_m)(l) = 0 \), then the exact long middle column of (2.5) shows that \( \tau^* (l) \) is onto. So suppose \( x \in H^2(X_f, R^2 \tau^* G_m) \) and \( l \cdot x =
0. Since $H^i(X_f, R^\tau_\alpha G_m) \cong \tilde{H}^i(X_f, R^\tau_\alpha G_m)$, there is $Y \rightarrow X \in \text{Cov} X_f$ and $y \in \Gamma(Y \times X_f, Y, R^\tau_\alpha G_m)$ satisfying the cocycle identity which represents $x$ in $H^i(X_f, R^\tau_\alpha G_m)$. Moreover we may choose $Y$ so that for some element $\tilde{y} \in \Gamma(Y, R^\tau_\alpha G_m)$ we have $p^*_x(\tilde{y}) - p^*_y(\tilde{y}) = l_y$. Since $R^\tau_\alpha G_m$ is the sheaf in $X_f$ coming from the presheaf $H^i_{\text{pro}}(G_m)$, the above remark and the observation that $H^i(F)$ is the sheaf associated to $F$ shows that there is $Y$, $\tilde{y} \in \text{Cov} X_f$ and $y \in \Gamma(Y, R^\tau_\alpha G_m)$ such that $\tilde{y}$ represents $\varphi^*(\tilde{y})$. Thus since $X$ satisfies $\text{Sp}(l)$, we may assume that there is $\tilde{y} \in \Gamma(Y, R^\tau_\alpha G_m)$ with $l\tilde{y} = \tilde{y}$ by taking a refinement in Cov $X_f$ of $Y ightarrow X$ if necessary. Altering the original Čech cocycle $y$ by the boundary $p^*_x(\tilde{y}) - p^*_y(\tilde{y})$ and denoting the resulting cocycle by $z \in \Gamma(Y \times X_f, R^\tau_\alpha G_m)$, we find that $lz = 0$. Since $R^\tau_\alpha G_m$ is torsion free, $z = 0$, and so $y = 0$.

**Corollary 2.5.** Let $X$ be a regular Japanese scheme with $\dim X \leq 2$. Then there is an exact sequence

$$0 \rightarrow \text{Pic}_r(X) \rightarrow \text{Pic}(X) \rightarrow \Gamma(X_f, R^\tau_\alpha G_m) \rightarrow H^i(X_f, G_m) \rightarrow \text{Br}(X) \rightarrow 0$$

where $\text{Br}(X)$ is the Brauer group of $X$ and $\Gamma(X_f, R^\tau_\alpha G_m)$ is a vector space over the rationals of dimension $= \dim (\text{Pic}(X) \otimes \mathbb{Q})$. In particular if $\text{Pic}_r(X) = \text{Pic}(X)$, then $H^i(X_f, G_m) \cong \text{Br}(X)$.

**Proof.** By Theorem 1.7 every element of $H^i(X_{\text{pro}}, G_m)$ can be split by a covering map of $X$ in $X_f$. Hence

$$\tau^*: H^i(X_f, G_m) = H^i(X_{\text{pro}}, G_m),$$

and by Grothendieck's result this is $\text{Br}(X)$. The dimension statement follows immediately since the other terms are torsion groups.

**Corollary 2.6** Let $X$ be a regular Japanese scheme with $\dim X \leq 2$. Then $H^i(X_{\text{pro}}, G_m) \cong \tilde{H}^i(X_{\text{pro}}, G_m)$.

**Proof.** The morphism $\tau: X_{\text{pro}} \rightarrow X_f$ induces a mapping of spectral sequences between Čech and sheaf cohomology:

$$[\tilde{H}^p(X_f, H^j_f(G_m))] \rightarrow H^p(X_f, G_m) \rightarrow [\tilde{H}^p(X_{\text{pro}}, H^j_{\text{pro}}(G_m))] \rightarrow H^p(X_{\text{pro}}, G_m).$$

The mapping between exact sequences of low degree terms gives

$$0 \rightarrow \tilde{H}^i(X_f, G_m) \rightarrow H^i(X_f, G_m) \rightarrow \tilde{H}^i(X_f, H^j_f(G_m)) \rightarrow H^i(X_{\text{pro}}, G_m) \rightarrow \tilde{H}^i(X_{\text{pro}}, H^j_{\text{pro}}(G_m)).$$
Moreover $H^j(G_m)(Y) = \text{Pic}_i(Y)$. If $x \in \tilde{H}^i(X_f, H^j(G_m))$, then it can be represented by $y \in \text{Pic}_i(Y \times_X Y)$ where $Y \to X \in \text{Cov} X_f$. Since $Y \times_X Y$ is finite over $X$, $y$ can be split by a Zariski covering of $X$ [12]. Thus $\tilde{\tau}_n(x) = 0$ and so $\tau_n$ factors through $\tilde{H}^i(X_{\text{Zar}}, G_m)$. Since $\tau_n$ is surjective, we get the desired conclusion.

**Remark.** The argument Bass uses to prove that $K^0(R)$ is a finitely generated abelian group for $R$ a finite $Z$-algebra [4; Theorem 18.6] may be copied to show that Pic $(R)$ is a finite group if $R$ is a finite $Z$-algebra.

**References**


Received April 2, 1971 and in revised form March 24, 1972. The preparation of this paper was partially supported by NSF Grant GP-8718. This work is an extension of some of the ideas in my thesis. I would like to thank G. P. Hochschild, my thesis advisor, for his patience and constant encouragement. I would also like to thank J. L. Verdier and H. Bass for their comments and suggestions during the preparation of this paper.

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