

Title

D. Zack Garza

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1 Sunday, August 30

Last of preliminaries. Upcoming: one-variable function fields and their valuation rings.

1.1 Polynomials Defining Regular Function Fields

Where's the curve: $f(x, y) = 0$.

Exercise 1.1.

Let R_1, R_2 be k -algebras that are also domains with fraction fields K_i . Show $R_1 \otimes_k R_2$ is a domain $\iff K_1 \otimes_k K_2$ is a domain.

Denominator-clearing argument.

Definition 1.0.1 (Geometrically Irreducible).

A polynomial of positive degree $f \in k[t_1, \dots, t_n]$ is *geometrically irreducible* if $f \in \bar{k}[t_1, \dots, t_n]$ is irreducible as a polynomial.

If $n = 1$ then f is geometrically irreducible \iff it's linear, i.e. of degree 1.

Let f be irreducible, then since polynomial rings are UFDs then $\langle f \rangle$ is a prime ideal (irreducibles generate principal ideals) and $k[t_1, \dots, t_n]/\langle f \rangle$ is a domain. Let K_f be the fraction field.

Exercise 1.2.

Easy:

- Above for $1 \leq i \leq n$ let x_i be the image of t_i in K_f . Show that $K_f = k(x_1, \dots, x_n)$.
- Show that if K/k is generated by x_1, \dots, x_n , then it is the fraction field of $k[t_1, \dots, t_n]/\mathfrak{p}$ for some prime ideal \mathfrak{p} (equivalently, a height 1 ideal).

Proposition 1.1(?).

Suppose that f is geometrically irreducible.

- a. The function field K/k is regular.
- b. For all ℓ/k , $f \in \ell[t_1, \dots, t_n]$ is irreducible.

In this case we say f is *absolutely irreducible* as a synonym for geometrically irreducible.

Proof.

By definition of geometric irreducibility, $\bar{k}[t_1, \dots, t_n]/\langle f \rangle = k[t_1, \dots, t_n]/\langle f \rangle \otimes_k \bar{k}$ is a domain.

The exercise shows that $K_f \otimes_k k$ is a domain, so K_f is regular.

It follows that for all ℓ/k , $K_f \otimes_k \ell$ is a domain, so $\ell[t_1, \dots, t_n]/\langle f \rangle$ is a domain. ■

Moral: geometrically irreducible polynomials are good sources of regular function fields.

Exercise 1.3.

Let k be a field, $d \in \mathbb{Z}^+$ such that $4 \nmid d$ and $p(x) \in k[x]$ be positive degree. Factor $p(x) = \prod_{i=1}^r (x - a_i)^{\ell_i}$ in $\bar{k}[x]$.

- a. Suppose that for some i , $d \nmid \ell_i$. Show that $f(x, y) := y^d - p(x) \in k[x, y]$ is geometrically irreducible. Conclude that $K_f := k[x, y]/\langle y^d - p(x) \rangle$ is a regular one-variable function field over k , and thus elliptic curves yield regular function fields.

Referred to as *hyperelliptic* or *superelliptic* function fields. Hint: use FT 9.21 or Lang's Algebra.

- b. What happens when $4 \mid d$?

Exercise 1.4 (Nice, Recommended).

Assume k is a field, if necessary assuming $\text{char}(k) \neq 2$.

- a. Let $f(x, y) = x^2 - y^2 - 1$ and show K_f is rational: $K_f = k(z)$.
- b. Let $f(x, y) = x^2 + y^2 - 1$. Show that K_f is again rational.
- c. Let $k = \mathbb{C}$ and $f(x, y) = x^2 + y^2 + 1$, K_f is rational.
- d. Let $k = \mathbb{R}$. For $f(x, y) = x^2 + y^2 + 1$, is K_f rational?

Example of a non-rational genus zero function field.

Question (converse): Can we always construct regular function fields using geometrically irreducible polynomials?

Answer: In several variables, no, since not every variety is birational to a hypersurface.

In one variable, yes:

Theorem 1.2 (Regular Function Fields in One Variable are Geometrically Irreducible).

Let K/k be a one variable function fields (finitely generated, transcendence degree one). Then

- If K/k is separable, then $K = k(x, y)$ for some $x, y \in K$.
- If K/k is regular (separable + constant subfield is k , so stronger) then $K \cong K_f$ for a geometrically irreducible $f \in k[x, y]$.

Proof .

Recall separable implies there exists a separating transcendence basis.

Proof of (a):

This means there exists a primitive element $x \in K$ such that $K/k(x)$ is finite and separable.

By the Primitive Element Corollary (FT 7.2), there exist a $y \in K$ such that $K = k(x, y)$.

Proof of (b):

Omitted for now, slightly technical. ■

Importance of last result: a regular function field on one variable corresponds to a nice geometrically irreducible polynomial f .

Note: the plane curve module may not be smooth, and in fact usually is not possible. I.e. $k[x, y]/\langle f \rangle$ is a one-dimensional noetherian domain, which need not be integrally closed.