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p-ADIC TEICHMÜLLER SPACE AND SIEGEL HALFSPACE

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In order to study the space $\mathfrak{M}_n$ of Mumford curves of genus n and the space $\mathfrak{A}_n$ of principally polarized abelian varieties which can be represented as analytic tori we introduce the p-adic Teichmüller space $\mathfrak{T}_n$ and the Teichmüller modular group Ψ_n as well the p-adic Siegel halfspace $\mathcal{H}_n$ and the Siegel modular group $\Gamma_n \cong PGL_n(\underset{\sim}{Z})$. One will arrive at the result that the orbit space $\mathfrak{T}_n$ mod Ψ_n is the space $\mathfrak{M}_n$ of Mumford curves and that the orbit space $\mathcal{H}_n$ mod Γ_n is the space $\mathfrak{A}_n$ of polarized abelian varieties.

In this paper, we will only describe the main points of the construction of the analytic space $\mathfrak{T}_n$ and the transformation group Ψ_n as well as the construction of the analytic space $\mathcal{H}_n$ and the transformation group Γ_n . A great deal of questions remain open.

1. Conjugacy classes of homomorphisms.

(1.1) Homomorphism classes. - Let X , Y be groups, let A be a subgroup of the group Aut X of automorphisms of X and B a subgroup of Aut Y .

Denote by (X , Y) the set of all group homomorphisms $\zeta : X \to Y$. A acts on (X , Y) by composition of mappings from right :

$$X \xrightarrow{\alpha} X \xrightarrow{\zeta} Y .$$

If $\alpha \in A$, $\zeta \in (X , Y)$, then $\zeta \circ \alpha \in (X , Y)$. The set of equivalence classes ζA will be denoted by ${}_A[Y , X)$.

The group B acts on (X , Y) by composition of mappings from left :

$$X \xrightarrow{\zeta} Y \xrightarrow{\beta} Y .$$

If $\beta \in B$, $\zeta \in (X , Y)$, then $\beta \circ \zeta \in (X , Y)$. The set of equivalence classes $\beta\zeta$ will be denoted by $(X , Y]_B$.

For $\alpha \in A$, $\beta \in B$, $\zeta \in (X , Y)$, we have

$$(\beta \circ \zeta) \circ \alpha = \beta \circ (\zeta \circ \alpha)$$

because composition of mappings is associative. Therefore A (resp. B) acts canonically on $(X , Y]_B$ (resp. $[X , Y)_B$) .

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Obviously, $(X , Y]_B \mod A = {}_A[X , Y) \mod B$.

We denote this set by ${}_A[X , Y]_B$. Its elements are the double cosets $B\zeta A$.

One gets a canonical commutative diagram

$$\begin{array}{ccccc} & & (X , Y) & & \\ & \swarrow & & \searrow & \\ (X , Y]_B & & & & {}_A[X , Y) \\ & \searrow & & \swarrow & \\ & & {}_A[X , Y]_B & & \end{array}$$

where each arrow denotes the canonical equivalence class mapping.

(1.2) Isotropy groups. – We consider the following isotropy groups :

$$\mathfrak{J}_A(\zeta) := \{\alpha \in A ; \quad \zeta \circ \alpha = \zeta\}$$

$$\mathfrak{J}_B(\zeta) := \{\beta \in B ; \quad \beta \circ \zeta = \zeta\}$$

$$\mathfrak{J}_A(B\zeta) := \{\alpha \in A ; \quad B\zeta \circ \alpha = B\zeta\}$$

$$\mathfrak{J}_B(\zeta A) := \{\beta \in B ; \quad \beta \circ \zeta A = \zeta A\} .$$

PROPOSITION 1. – $\mathfrak{J}_A(\zeta)$ is a normal subgroup of $\mathfrak{J}_A(B\zeta)$. $\mathfrak{J}_B(\zeta)$ is a normal subgroup of $\mathfrak{J}_B(\zeta A)$ and

$$\mathfrak{J}_A(B\zeta)/\mathfrak{J}_A(\zeta) \cong \mathfrak{J}_B(\zeta A)/\mathfrak{J}_B(\zeta) .$$

Proof.

1° Let $\alpha_0 \in \mathfrak{J}_A(\zeta)$, $\alpha \in \mathfrak{J}_A(B\zeta)$. Then there is a $\beta \in B$ such that $\zeta \circ \alpha = \beta \circ \zeta$. Now $\zeta \circ \alpha_0 = \zeta$ and

$$\zeta \circ \alpha \circ \alpha_0 \circ \alpha^{-1} = \beta \circ \zeta \circ \alpha_0 \circ \alpha^{-1} = \beta \circ \zeta \circ \alpha^{-1} = \zeta \circ \alpha \circ \alpha^{-1} = \zeta$$

which shows that $\alpha\alpha_0\alpha^{-1} \in \mathfrak{J}_A(\zeta)$. Thus $\mathfrak{J}_A(\zeta)$ is a normal subgroup of $\mathfrak{J}_A(B\zeta)$.

2° Let $\beta_0 \in \mathfrak{J}_B(\zeta)$, $\beta \in \mathfrak{J}_B(\zeta A)$. Then there is a $\alpha \in A$ such that $\beta \circ \zeta = \zeta \circ \alpha$. Now $\beta_0 \circ \zeta = \zeta$ and

$$\beta^{-1} \beta_0 \beta\zeta = \beta^{-1} \beta_0 \zeta\alpha = \beta^{-1} \zeta\alpha = \beta^{-1} \beta\zeta = \zeta$$

which shows that $\beta^{-1} \beta_0 \beta \in \mathfrak{J}_B(\zeta)$. Thus $\mathfrak{J}_B(\zeta)$ is a normal subgroup of $\mathfrak{J}_B(\zeta A)$.

3° It is an easy exercice to show that the mapping which associates to $\alpha \in \mathfrak{J}_A(B\zeta)$ the residue class $\overline{\beta}$ in $\mathfrak{J}_B(\zeta A)/\mathfrak{J}_B(\zeta)$ of a $\beta \in B$ which satisfies $\zeta\alpha = \beta \circ \zeta$ induces an isomorphism $\mathfrak{J}_A(B\zeta)/\mathfrak{J}_A(\zeta)$ on to $\mathfrak{J}_B(\zeta A)/\mathfrak{J}_B(\zeta)$.

(1.3) Schottky groups. - Let now K be an algebraically closed field together with a non-trivial complete ultrametric valuation. Let E_n be a non-abelian free group of rank $n \geq 2$ together with a fixed basis $e_1, \dots, e_n$.

We consider $PSL_2(K) = \{\pm \begin{pmatrix} a & b \\ c & d \end{pmatrix} ; a, b, c, d \in K ; ad - bc = 1\}$ as a K-algebraic group. Denote by tr^2 the regular function on $PSL_2(K)$ which has the value $(a+d)^2$ at the point $\pm \begin{pmatrix} a & b \\ c & d \end{pmatrix}$. An element $\pm \begin{pmatrix} a & b \\ c & d \end{pmatrix}$ of $PSL_2(K)$ is called hyperbolic if $|tr^2 \begin{pmatrix} a & b \\ c & d \end{pmatrix}| = |a+d|^2 > 1$. The set $(E_n, PSL_2(K))$ of all group homomorphisms $\zeta : E_n \to PSL_2(K)$ will be identified with the n-fold product $PSL_2^n(K) = PSL_2(K) \times \dots \times PSL_2(K)$ of $PSL_2(K)$: any $w = (w_1, \dots, w_n) \in PSL_2^n(K)$ determines a unique homomorphism $\zeta_w : E_n \to PSL_2(K)$ which satisfies $\zeta_w(e_i) = w_i$ for all i.

The action of $\operatorname{Aut} E_n$ on $(E_n, PSL_2(K))$ when it is identified with $PSL_2^n(K)$ can be described as follows : let $\alpha \in \operatorname{Aut} E_n$, $\alpha(e_i)$ is a reduced word in the letter $e_1, \dots, e_n$: we substitute w_j for e_j and obtain an element w_i' for each i. Then

$$(w_1, \dots, w_n) \times \alpha = (w_1', \dots, w_n') .$$

This explicit description shows that α is a biregular transformation of the K-algebraic space $PSL_2^n(K)$.

Definition. - A homomorphism $\zeta : E_n \to PSL_2(K)$ is called Schottky homomorphism, if $\zeta(e)$ is hyperbolic for any $e \in E_n$, $e \neq 1$.

Denote by $\mathbb{S}_n$ the set of Schottky homomorphisms. As a subset of $PSL_2^n(K)$ it is given by infinitely many inequalities. More precisely : we fix $e \in E_n$, and consider the mapping $\zeta \to \zeta(e)$. It is a regular mapping $\Phi_e : PSL_2^n(K) \to PSL_2^n(K)$ and $f_e = tr^2 \Phi_e$ is a regular function on $PSL_2^n(K)$. Then

$$\mathbb{S}_n = \{w \in PSL_2^n(K) ; |f_e(w)| > 1 \text{ for all } e \in E_n, e \neq 1\} .$$

One can give explicit expressions for the mapping Φ_e and the function f_e. e is determined by the finite sequence $\varepsilon(1), \dots, \varepsilon(r)$ with $\varepsilon(i) \in \{\pm 1, \dots, \pm n\}$ and $\varepsilon(i+1) \neq -\varepsilon(i)$ such that

$$e = \prod_{i=1}^{r} e_{\varepsilon(i)} \quad \text{with} \quad e_{-i} = e_i^{-1} .$$

Let

$$\Phi_e\left(\pm \begin{pmatrix} a_1 & b_1 \\ c_1 & d_1 \end{pmatrix}, \dots, \pm \begin{pmatrix} a_n & b_n \\ c_n & d_n \end{pmatrix}\right) = \pm \begin{pmatrix} x_{11} & x_{12} \\ x_{21} & x_{22} \end{pmatrix} ,$$

we will give expression for $x_{k\ell}$ as polynomials in $a_1, \dots, d_n$.

$N_{k\ell}$:= set of all sequences $s = ((i_1, j_1), (i_2, j_2), \dots, (i_r, j_r))$ such that $i_{\nu+1} = j_\nu$ for all ν and $i_\nu, j_\nu \in \{1, 2\}$. For any such s, we consider the product

$$x(s) := x^{(1)}_{i_1 j_1} \cdots x^{(r)}_{i_r j_r}$$

with

$$x^{(\nu)}_{i_\nu j_\nu} := \begin{cases} a_{\varepsilon(i)} \, ; & (i_\nu , j_\nu) = (1 , 1) \\ b_{\varepsilon(i)} \, ; & (i_\nu , j_\nu) = (1 , 2) \\ c_{\varepsilon(i)} \, ; & (i_\nu , j_\nu) = (2 , 1) \\ d_{\varepsilon(i)} \, ; & (i_\nu , j_\nu) = (2 , 2) \end{cases}$$

with $a_{-i} = + d_i$, $b_{-i} = - b_i$, $c_{-i} = - c_i$, $d_{-i} = a_i$. Then

$$x_{11} = \textstyle\sum_{s \in N_{11}} x(s)$$

$$x_{12} = \textstyle\sum_{s \in N_{12}} x(s)$$

$$x_{21} = \textstyle\sum_{s \in N_{21}} x(s)$$

$$x_{22} = \textstyle\sum_{s \in N_{12}} x(s) \; .$$

The proof readily follows by induction on r .

We consider homomorphism classes as in §(1.1) for $A = \mathrm{Aut}\, E_n$, B = group of inner automorphisms of $PSL_2(K) \cong PSL_2(K)$. The set $\bar{\mathbb{S}}_n = {}_{\mathrm{Aut}E_n}[\mathbb{S}_n)$ of classes $\zeta \circ \mathrm{Aut}\, E_n$ with $\zeta \in \mathbb{S}_n$ is just simply the set of Schottky subgroups of $PSL_2(K)$ of rank n (see [1], chap.ter I, (1.6)). Because if $\zeta \in \mathbb{S}_n$, $\alpha \in \mathrm{Aut}\, E_n$, then the image $\mathrm{Im}(\zeta \circ \alpha)$ does not depend on α .

If, on the other hand, Γ is a Schottky subgroup of $PSL_2(K)$ of rank n , then by definition there is a $\zeta \in \mathbb{S}_n$ such that $\mathrm{Im}\, \zeta = \Gamma$. If $\zeta' \in \mathbb{S}_n$ also satisfies $\mathrm{Im}\, \zeta' = \Gamma$, then we note that $(\zeta|\Gamma)^{-1} : \Gamma \longrightarrow E_n$ is a group homomorphism and $\alpha = (\zeta|\Gamma)^{-1} \circ \zeta' \in \mathrm{Aut}\, E_n$ and $\zeta \circ \alpha = \zeta'$.

2. Hyperbolic fractional linear transformations.

(2.1). Let $\underset{\sim}{P} = K \cup \{\infty\}$ be the projective line over K and $\underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P} = \{(x , y) \in \underset{\sim}{P} \times \underset{\sim}{P} : \; x \neq y\}$ be the complement of the diagonal in the product $\underset{\sim}{P} \times \underset{\sim}{P}$.

In order to determine the regular functions on $\underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P}$, we introduce the following affine charts :

$$U_{11} = \{(x\ ,\ y) \in \underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P}\ ;\quad x \neq \infty\ ,\quad y \neq \infty\}$$

$$U_{12} = \{(x\ ,\ y) \in \underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P}\ ;\quad x \neq \infty\ ,\quad y \neq 0\}$$

$$U_{21} = \{(x\ ,\ y) \in \underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P}\ ;\quad x \neq 0\ ,\quad y \neq \infty\}$$

$$U_{22} = \{(x\ ,\ y) \in \underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P}\ ;\quad x \neq 0\ ,\quad y \neq 0\}\ .$$

The algebras $\mathcal{O}(U_{ij})$ of regular functions on U_{ij} are the following

$$\mathcal{O}(U_{11}) = K[x\ ,\ y\ ,\ \frac{1}{x-y}]$$

$$\mathcal{O}(U_{12}) = K[x\ ,\ \frac{1}{y}\ ,\ \frac{1}{1-\frac{x}{y}}]$$

$$\mathcal{O}(U_{21}) = K[\frac{1}{x}\ ,\ y\ ,\ \frac{1}{1-\frac{y}{x}}]$$

$$\mathcal{O}(U_{22}) = K[\frac{1}{x}\ ,\ \frac{1}{y}\ ,\ \frac{1}{\frac{1}{x}-\frac{1}{y}}]\ .$$

PROPOSITION 2. – $\mathcal{O}(\underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P}) = K[\frac{1}{x-y}\ ,\ \frac{x}{x-y}\ ,\ \frac{xy}{x-y}]$.

Proof. – The functions

$$\frac{1}{x-y} = \frac{\frac{1}{y}}{\frac{x}{y}-1} = \frac{\frac{1}{x}}{1-\frac{y}{x}} = \frac{\frac{1}{x}\times\frac{1}{y}}{\frac{1}{y}-\frac{1}{x}}$$

$$\frac{x}{x-y} = \frac{\frac{x}{y}}{\frac{x}{y}-1} = \frac{1}{1-\frac{y}{x}} = \frac{\frac{1}{y}}{\frac{1}{y}-\frac{1}{x}}$$

$$\frac{xy}{x-y} = \frac{x}{\frac{x}{y}-1} = \frac{y}{1-\frac{y}{x}} = \frac{1}{\frac{1}{y}-\frac{1}{x}}$$

are clearly regular on each U_{ij} and are thus regular on $\underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P}$. Therefore the K-algebra $K[\frac{1}{x-y}\ ,\ \frac{x}{x-y}\ ,\ \frac{xy}{x-y}]$ generated by $\frac{1}{x-y}\ ,\ \frac{x}{x-y}\ ,\ \frac{xy}{x-y}$ is a subalgebra of $\mathcal{O}(\underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P})$. Let now f be a regular function on $\underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P}$.

Let f have a representation $f = g(x\ ,\ y)/(x-y)^n$ with a polynomial $g(x\ ,\ y) \in K[x\ ,\ y]$ in the variables x , y . Let

$$g(x\ ,\ y) = \sum_{\nu,\mu} g_{\nu\mu}\, x^{\nu}\, y^{\mu}\ .$$

Then

$$f = \sum g_{\nu\mu} \frac{x^{\nu}\, y^{\mu}}{(x-y)^n} = \sum g_{\nu\mu} \frac{x^{\nu}\, y^{\mu-n}}{(\frac{x}{y}-1)^n}$$

which shows that $f \in \mathcal{O}(U_{12}) = K[x , 1/y , 1/(1 - x/y)]$ if, and only if, $g_{\nu\mu} = 0$ whenever $\mu > n$.

In the same way, one proves that $f \in \mathcal{O}(U_{21})$ if, and only if, $g_{\nu\mu} = 0$ whenever $\nu > n$. But if $n \geqslant \nu \geqslant \mu$, then

$$\frac{x^\nu y^\mu}{(x-y)^n} = \left(\frac{xy}{x-y}\right)^\mu \times \left(\frac{x}{x-y}\right)^{\nu-\mu} \times \left(\frac{1}{x-y}\right)^{n-\nu},$$

which shows that $\dfrac{x^\nu y^\mu}{(x-y)^n} \in K\left[\frac{1}{x-y}, \frac{x}{x-y}, \frac{xy}{x-y}\right]$.

If $n \geqslant \mu \geqslant \nu$, then

$$\frac{x^\nu y^\mu}{(x-y)^n} = \left(\frac{xy}{x-y}\right)^\nu \times \left(\frac{y}{x-y}\right)^{\mu-\nu} \times \left(\frac{1}{x-y}\right)^{n-\mu}.$$

As $\dfrac{y}{x-y} = \dfrac{x}{x-y} - 1$, we obtain also

$$\frac{x^\nu y^\mu}{(x-y)^n} \in K\left[\frac{1}{x-y}, \frac{x}{x-y}, \frac{xy}{x-y}\right].$$

As g is a linear combination of functions in $K\left[\frac{1}{x-y}, \frac{x}{x-y}, \frac{xy}{x-y}\right]$, it is also in this algebra, which proves

$$\mathcal{O}(\underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P}) \subseteq K\left[\frac{1}{x-y}, \frac{x}{x-y}, \frac{xy}{x-y}\right].$$

(2.2). Let $SL_2(K) = \{\begin{pmatrix} a & b \\ c & d\end{pmatrix} ; a, b, c, d \in K ; ad - bc = 1\}$ and $K_* = K - \{0\}$. We consider the mapping

$$\pi : K_* \times (\underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P}) \longrightarrow SL_2(K)$$

given by

$$\pi(\tau, x, y) = \begin{pmatrix} a(\tau, x, y), & b(\tau, x, y) \\ c(\tau, x, y), & d(\tau, x, y)\end{pmatrix}$$

$$a(\tau, x, y) = \frac{\tau^{-1} x - \tau y}{x - y}$$

$$b(\tau, x, y) = \frac{(\tau - \tau^{-1})xy}{x - y}$$

$$c(\tau, x, y) = \frac{\tau^{-1} - \tau}{x - y}$$

$$d(\tau, x, y) = \frac{\tau x - \tau^{-1} y}{x - y}$$

$$a(\tau, x, y)\, d(\tau, x, y) = \frac{x^2 + y^2 - (\tau^{-2} + \tau^2)xy}{(x-y)^2}$$

$$= \frac{(x-y)^2 - (\tau^{-2} - 2 + \tau^2)xy}{(x-y)^2}$$

$$= 1 - \frac{(\tau^{-1} - \tau)^2\, xy}{(x-y)^2}$$

$$= 1 + b(\tau, x, y)\, c(\tau, x, y)$$

which shows that indeed $\pi(\tau, x, y) \in SL_2(K)$.

Properties of π :

$$\pi(-\tau, x, y) = -\pi(\tau, x, y)$$

$$\pi(\tau^{-1}, y, x) = +\pi(\tau, x, y)$$

$$\pi(\tau, x, y) \times \pi(\tau^{-1}, x, y) = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$\pi(\tau_1, x, y) \times \pi(\tau_2, x, y) = \pi(\tau_1 \tau_2, x, y)$$

$$\pi(1, x, y) = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$\pi(-1, x, y) = \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix} .$$

If $\tau, \tau' \neq \pm 1$, then $\pi(\tau, x, y) = \pi(\tau', x', y')$ if, and only if, either $\tau = \tau'$, $x' = x$, $y' = y$ or if $\tau' = +\tau^{-1}$, $y' = x$, $x' = y$.

Let $\sigma = \begin{pmatrix} a_0 & b_0 \\ c_0 & d_0 \end{pmatrix} \in SL_2(K)$. σ acts on $\underset{\sim}{P}$ by $\sigma(x) = \dfrac{a_0 x + b_0}{c_0 x + d_0}$.

Then

$$\pi(\tau, \sigma(x), \sigma(y)) = \sigma\pi(\tau, x, y)\, \sigma^{-1}$$

$$\pi(\tau, x, y)(x) = x , \quad \pi(\tau, x, y)(y) = y$$

$$\pi(K_* \times (\underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P})) = \{\begin{pmatrix} a & b \\ c & d \end{pmatrix} \in SL_2(K) \;;\; a + d \neq \pm 2\} \cup \{\pm \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\}$$

The trace $\operatorname{tr} \pi(\tau, x, y) = \tau + \tau^{-1}$.

π is a morphism of K-algebraic spaces,

π induce a 2-sheeted unramified covering,

from $(K - \{0, 1, -1\}) \times (\underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P})$ onto the affine subdomain $SL_2'(K) = \{\begin{pmatrix} a & b \\ c & d \end{pmatrix} \in SL_2(K) \;;\; (a + d)^2 \neq 4\}$ of non-parabolic matrices.

Let

$$\mathcal{O}_1 = \mathcal{O}(K - \{0 , 1 , -1\} \times (\underset{\sim}{P} \times \underset{\sim}{P} - \underset{\sim}{P})) = K[\tau , \tau^{-1} , \frac{1}{\tau-1} , \frac{1}{\tau+1} , \frac{1}{x-y} , \frac{x}{x-y} , \frac{xy}{x-y}]$$

and

$$\mathcal{O}_2 = \mathcal{O}(SL_2'(K)) = K[a , b , c , d , \frac{1}{a + d - 2} , \frac{1}{a + d + 2}]/(ad - bc - 1) .$$

The mapping π induces a K-algebra homomorphism

$$\pi_* : \mathcal{O}_2 \longrightarrow \mathcal{O}_1$$

which is injective.

PROPOSITION 3. – $\mathcal{O}_1$ <u>is a free</u> $\mathcal{O}_2$<u>-module, generated by</u> 1 <u>and</u> τ .

<u>Proof.</u> – Let M be the $\mathcal{O}_2$-module, generated by 1 and τ . One has $\tau \notin \mathcal{O}_2$, as for any polynomial $f(\tau , x , y) \in \mathcal{O}_2$, we have the condition $f(\tau,x,y)=f(\tau^{-1},y,x)$.

Now $\tau + \tau^{-1} = a + d$ and $\tau^2 - (a + d)\tau + 1 = 0$ which shows that τ is quadratic over $\mathcal{O}_2$. Thus $\tau^2 \in M$ and more generally all powers τ^i of τ , $i \in \underset{\sim}{Z}$, are in M .

Thus M is a $\mathcal{O}_2$-algebra.

$$\frac{(\tau - \tau^{-1})}{(a + d - 2)(a + d + 2)} = \frac{\tau - \tau^{-1}}{(\tau + \tau^{-1}) - 4} = \frac{1}{\tau - \tau^{-1}} \in M$$

$$\frac{\tau(1 - \tau^{-1})}{\tau - \tau^{-1}} = \frac{1}{1 + \tau^{-1}} \in M$$

$$\frac{\tau(1 + \tau^{-1})}{\tau - \tau^{-1}} = \frac{1}{1 - \tau^{-1}} \in M$$

$$\frac{1}{x - y} = \frac{c}{\tau^{-1} - \tau} \in M$$

$$\frac{xy}{x - y} = \frac{b}{\tau^{-1} - \tau} \in M$$

$$\frac{x}{x - y} = \frac{a - \tau}{\tau^{-1} - \tau} \in M .$$

This shows that $M = \mathcal{O}_1$.

(2.3). Let $SL_2^{hb}(K) = \{\begin{pmatrix} a & b \\ c & d \end{pmatrix} \in SL_2(K) ; |a + d| > 1\}$ be the subdomain of $SL_2(K)$ of hyperbolic matrices and

$$Hb(K) := \{(\tau , x , y) \in K_* \times (\underset{\sim}{P} \times \underset{\sim}{P}) - \underset{\sim}{P} | 0 < |\tau| < 1\} .$$

Then π induces an analytic mapping

$$\pi' : Hb(K) \longrightarrow SL_2^{hb}(K) .$$

PROPOSITION 4. – π' <u>is bianalytic</u>.

LEMMA. – <u>There exists a power series</u> $\tau(s) \in \underset{\sim}{Z}[[s]]$ <u>such that</u> $\tau(s) + \frac{1}{\tau(s)} = \frac{1}{s}$.

<u>Proof</u>. – Define $\tau_0 = 0$, $\tau_1 = 1$ and, for $k \geqslant 1$,

$$\tau_{k+1} := - \sum_{i=1}^{k-1} (-1)^i \tau_i \tau_{k-i} \in \underset{\sim}{Z} .$$

Then $\tau(s) := \sum_{i=1}^{\infty} \tau_i s^i$ satisfies the equation $\tau(s) + \frac{1}{\tau(s)} = s^{-1}$.

One gets $\tau_i = 0$ if i is even and $\tau_i > 0$ if i is odd and

$$\tau(s) = s + s^3 + 2s^5 + 5s^7 + 14s^9 + 42s^{11} + 132s^{13} + 429s^{15} + \dots$$

Another way to prove this lemma : you remark that $\tau(s)$ satisfies a quadratic equation :

$$\tau(s)^2 - \frac{1}{s} \tau(s) + 1 = 0 .$$

Thus if char $K \neq 2$:

$$(\tau(s) - \frac{1}{2s})^2 = \frac{1}{4s^2} - 1$$

$$\tau(s) = \frac{1}{2s} \pm \frac{1}{2s} \sqrt{1 - 4s^2}$$

$$\tau(s) = \frac{1}{2s} \pm \frac{1}{2s} \sum_{i=0}^{\infty} \binom{\frac{1}{2}}{i} (-1)^i (4s^2)^i .$$

If you choose the right sign for the square root, you get

$$\tau(s) = \frac{1}{2} \sum_{i=1}^{\infty} \binom{\frac{1}{2}}{i} (-1)^{i+1} \times 4^i s^{2i-1}$$

now

$$\binom{\frac{1}{2}}{i} = \frac{1}{2i} \binom{-\frac{1}{2}}{i-1} \quad \text{and} \quad \binom{-\frac{1}{2}}{j} = \frac{\frac{1}{2^j} (-1)^j (2j-1)!}{j! \times 2^{j-1}(j-1)!} .$$

Thus

$$\tau_{2i-1} = \frac{1}{2} (-1)^{i+1} 4^i \frac{1}{2^i} \frac{\frac{1}{2^{i-1}} (-1)^{i-1} (2i-3)!}{(i-1)!\, 2^{i-2} (i-2)!}$$

$$\tau_{2i-1} = 2 \frac{(2i-3)!}{i!\,(i-2)!} = 2\binom{2i-2}{i-2} \times \frac{1}{2i-2} = \frac{1}{i-1} \binom{2i-2}{i-2} = \frac{1}{i} \binom{2i-2}{i-1} .$$

The proof of proposition 4 is immediate with the help of the lemma and of proposition 3. The inverse of π' can be given explicitly, namely :

$$\tau \begin{pmatrix} a & b \\ c & d \end{pmatrix} = \tau\left(\frac{1}{a+d}\right) = \tau \ .$$

$$\frac{1}{x-y} \begin{pmatrix} a & b \\ c & d \end{pmatrix} = \frac{c}{\tau^{-1} - \tau}$$

$$\frac{xy}{x-y} \begin{pmatrix} a & b \\ c & d \end{pmatrix} = \frac{b}{\tau^{-1} - \tau}$$

$$\frac{x}{x-y} \begin{pmatrix} a & b \\ c & d \end{pmatrix} = \frac{a-\tau}{\tau^{-1} - \tau} \ .$$

(2.4). Let $PSL_2(K) = \{\pm \begin{pmatrix} a & b \\ c & d \end{pmatrix} ; \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in SL_2(K)\}$ be the projective special linear group and

$$PSL_2^{hb}(K) = \{\pm \begin{pmatrix} a & b \\ c & d \end{pmatrix} ; \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in SL_2^{hb}(K)\} \ .$$

Now

$$\tau\begin{pmatrix} -a & -b \\ -c & -d \end{pmatrix} = \tau\left(-\frac{1}{a+d}\right) = -\tau \begin{pmatrix} a & b \\ c & d \end{pmatrix}$$

and

$$\pi(-\tau , x , y) = -\pi(\tau , x , y) \ .$$

COROLLARY. - The mapping

$$\pm \begin{pmatrix} a & b \\ c & d \end{pmatrix} \longrightarrow \left(\tau^2\left(\frac{1}{a+d}\right) , \frac{a-\tau}{c} , \frac{b}{a-\tau}\right)$$

gives a bianalytic mapping

$$PSL_2^{hb}(K) \longrightarrow Hb(K) \ .$$

3. Teichmüller space.

(3.1) The set $\mathbb{S}_n$ of Schottky homomorphisms $\zeta : E_n \longrightarrow PSL_2(K)$ will be identified with a subset of $Hb^n(K) = \{w = (w_1 , \dots , w_n) ; w_i \in Hb(K)\}$. We identify $Hb(K)$ through the inverse of mapping $\pm\pi$ with $PSL_2^{hb}(K)$. As $\zeta(e_i)$ is hyperbolic, we get $(\zeta(e_1) , \dots , \zeta(e_n)) \in Hb^n(K)$.

We study the actions of $\mathrm{Aut}\, E_n$ and of $\mathrm{Aut}^i\, PSL_2(K)$ on $\mathbb{S}_n$. Let

$$\bar{\mathbb{S}}_n = \mathrm{Aut}E_n[\mathbb{S}_n)$$

$$\mathfrak{T}_n = (\mathbb{S}_n]PSL_2(K)$$

$$\mathfrak{M}_n = \mathrm{Aut}E_n[\mathbb{S}_n]PSL_2(K) \ .$$

Then we have a commutative diagram

$$\begin{array}{ccc} & \mathbb{S}_n & \\ \swarrow & & \searrow \\ \bar{\mathbb{S}}_n & & \mathcal{T}_n \\ \searrow & & \swarrow \\ & \mathfrak{M}_n & \end{array}$$

and group actions of $PSL_2(K)$ on $\bar{\mathbb{S}}_n$ and of Aut E_n on $\mathcal{T}_n$.

While $\bar{\mathbb{S}}_n$ corresponds biuniquely with the set of Schottky subgroups of $PSL_2(K)$ of rank n (see (1.3)), the set $\mathcal{T}_n$ consists of normed Schottky homomorphisms.

PROPOSITION 5. – $\mathcal{T}_n$ <u>can be identified with</u>

$\{w = (w_1 , \ldots , w_n) \in Hb^n(K) \ ; \ w \in \mathbb{S}_n \ ;$

$$w_i = (t_i , x_i , y_i) \in Hb(K) \ ; \ x_1 = 0 \ ; \ y_1 = \infty \ ; \ y_2 = 1\}.$$

<u>Proof</u>. – Let $\sigma(z) = (y_2 - y_1)/(y_2 - x_1) \times (z - x_1)/(z - y_1)$ be the fractional-linear transformation which maps x_1 to 0 , y_1 to ∞ and y_2 to 1 .

Now

$$\sigma\pi(t_1 , x_1 , y_1)\ \sigma^{-1} = \pi(t_1 , 0 , \infty)$$

$$\sigma\pi(t_2 , x_2 , y_2)\ \sigma^{-1} = \pi(t_2 , \sigma(x_2) , 1)$$

(see properties of π in (2.2)).

If $w \in \mathbb{S}_n$ with $x_1 = 0$, $y_1 = \infty$, $y_2 = 1$ and $\sigma \in PSL_2(K)$ such that

$$\sigma \circ w \circ \sigma^{-1} = (w'_1 , \ldots , w'_n) \ , \ w'_i = (t'_i , x'_i , y'_i) \ , \ x'_1 = 0 \ , \ y'_1 = \infty \ , \ y'_2 = 1 \ ,$$

then $\sigma(0) = 0$, $\sigma(\infty) = \infty$, $\sigma(1) = 1$ for which one concludes $\sigma = id$.

We consider $\mathcal{T}_n$ now as a subset of K^{3n-3} : a point $w \in \mathcal{T}_n$ is given by the coordinates $(t_1 , \ldots , t_n , x_2 , x_3 , y_3 , \ldots , x_n , y_n) \in K^{3n-3}$. The kernel of ineffectivity of the action of Aut E_n on $\mathcal{T}_n$ contains the inner automorphisms.

Let $\Psi_n :=$ Aut $E_n/\text{Aut}^i\, E_n$ be the group of outer automorphisms.

Then the action of Aut E_n induces an action of Ψ_n on $\mathcal{T}_n$.

(3.2). Let $w = (w_1 , \ldots , w_n)$, $w_i = (t_i , x_i , y_i)$, be a variable point of $Hb^n(K)$. In order to get shorter formulas we also write x_{-i} for y_i . Let

$$u_{ijk} = \frac{\left(\dfrac{x_j - x_i}{x_j - y_i}\right)}{\left(\dfrac{x_k - x_i}{x_k - y_i}\right)} = \frac{(x_j - x_i)(x_k - y_i)}{(x_j - y_i)(x_k - x_i)}$$

for $i \in \{1 , \ldots , n\}$, $j , k \in \{\pm 1 , \ldots , \pm n\}$ and $\pm j \neq i$, $\pm k \neq i$.

We can consider u_{ijk} to be a meromorphic function on $Hb^n(K)$. It is an analytic function without zeroes on the subdomain $Hb^N_0(K) := \{w \in Hb^n(K)$; $x_i \neq x_j$ for all $i \neq j$; $i , j \in \{\pm 1 , \dots , \pm n\}\}$ as

$$\frac{x_j}{x_j - x_k} , \frac{y_j}{x_j - x_k} , \frac{1}{x_i - x_k}$$

are analytic on $Hb^n_0(K)$. This can be seen as in the proof of proposition 2.

Now

$$u_{ijk} = \frac{x_j\, x_k}{(x_j - y_i)(x_k - x_i)} + \frac{x_i\, y_i}{(x_j - y_i)(x_k - x_i)} - \frac{x_j\, y_i}{(x_j - y_i)(x_k - x_i)} - \frac{x_i\, x_k}{(x_j - y_i)(x_k - x_i)}$$

and each term is clearly analytic on $Hb^n_0(K)$. As $\frac{1}{u_{ijk}} = u_{ijk}$ it has no zeroes on $Hb^n_0(K)$.

Let $\mathcal{B}_n := \{w \in Hb^n_0(K)$; $|t_i| < |u_{ijk}(w)| < |t_i|^{-1}$ for all i ; $k \in \{\pm 1, \dots, \pm n\}$; $i \in \{1 , \dots , n\}$; $i \neq \pm j$; $i \neq \pm k\}$.

PROPOSITION 6. – $\mathcal{B}_n \subseteq \mathcal{S}_n$.

<u>Proof.</u> – Let $\gamma_i = \pm \pi(\sqrt{t_i} , x_i , y_i)$ and $\nu_i(z) = (z - x_i)/(z - y_i)$. Then $\nu_i(\gamma_i\, z) = t_i\, \nu_i(z)$. If now $\rho_i = \sup_{j\neq i}|\nu_i(x_j)|$ and $\rho'_i = \inf_{j\neq i}|\nu_i(x_j)|$, then $|t_i| < \rho'_i/\rho_i \leqslant 1$.

Let $\rho''_i > \rho_i$ such that $|t_i|\, \rho''_i < \rho'_i$. Fix x_j with $\rho_i = |\nu_i(x_j)|$, and let

$$F_i = \{z \in \underset{\sim}{P} ;\ \rho''_i|t_i| \leqslant |\nu_i(z)| \leqslant \rho''_i\}$$

and

$$F = \cap_{i=1}^{n} F_i .$$

It is easy to see now that $\gamma_1 , \dots , \gamma_n$ generates a Schottky group of rank n , and that F is a fundamental domain for this group (see [1], chapter I, (4.1.3)).

PROPOSITION 7. – <u>The action of</u> Aut E_n <u>on</u> $\mathcal{B}_n$ <u>satisfies</u> :

(i) $\mathcal{B}_n \circ \alpha = \mathcal{B}_n$ <u>if</u> α <u>is an inner automorphism of</u> E_n .

(ii) <u>There is only a finite number of classes</u> $\in$ Aut E_n/Aut^i E_n <u>of automorphisms</u> $\alpha \in$ Aut E_n <u>such that</u>

$$(\mathcal{B}_n \circ \alpha) \cap \mathcal{B}_n \neq \emptyset .$$

(iii) $\bigcup_{\alpha \in \mathrm{Aut} E_n} \mathcal{B}_n \circ \alpha = \mathcal{S}_n$.

<u>Proof.</u> – The proof of (i) relies on the fact that the cross ratios u_{ijk} are invariant with respect to fractional linear transformations. The proof of (iii) is a corollary to [1] (chapter I, (4.3)).

In order to prove (ii) one has to introduce the canonical tree T for a Schottky group Γ. One has to use the fact that the geometric base systems and the fundamental domains $\subset T$ (see [2], p. 263, bottom), for this action correspond to the systems in $\mathfrak{B}_n$.

If F is a fundamental domain (= maximal subtree) $\subseteq T$ for the action of T, there are only a finite number of other fundamental domains F' such that $F \cap F' \neq \emptyset$. From this one can conclude (ii).

(3.3). Let now $\overline{\mathfrak{B}}_n = \mathfrak{B}_n \cap \mathfrak{T}_n$. Because $\overline{\mathfrak{B}}_n$ is an analytic polyhedron $\subseteq K^{3n-3}$, it has a canonical analytic structure as subdomain of K^{3n-3}. For any $\psi \in \Psi_n$, also $\psi(\overline{\mathfrak{B}}_n)$ is an analytic polyhedron $\subseteq K^{3n-3}$.

We consider the covering $\{\psi(\overline{\mathfrak{B}}_n) \ ; \ \psi \in \Psi_n\}$ and put on $\mathfrak{T}_n$ the analytic structure which is isomorphic on $\psi(\overline{\mathfrak{B}}_n)$ to the canonical one given there.

We call $\mathfrak{T}_n$ Teichmüller space and Ψ_n Teichmüller modular group.

THEOREM 1. – Ψ_n <u>acts discontinuously on</u> $\mathfrak{T}_n$.

One has to prove that the covering $\{\psi(\overline{\mathfrak{B}}_n) \ ; \ \psi \in \Psi\}$ is admissible (see [4], p. 194, botton), which means the following holds : if $\Phi \ ; \ X \longrightarrow K^{3n-3}$ is an analytic mapping of an affinoid space X into K^{3n-3} is given with $\Phi(X) \subseteq \mathfrak{T}_n$, then there is a finite set $\{\psi_1, \dots, \psi_r\}$ of elements of Ψ_n such that $\Phi(X) \subset \bigcup_{i=1}^{r} \psi(\overline{\mathfrak{B}}_n)$. It follows from the method given in [2], [3] and in the proof of the proposition in [1] (chapter I, (4.1.3)).

That the action of Ψ_n is discontinuous follows from proposition 2, (ii).

I will not work out the details as it seems to make more sense to prove the stronger statement that $\mathfrak{T}_n$ is a Stein manifold.

<u>Remark</u>. – One should construct analytic structures on $\overline{\mathfrak{S}}_n$ and on $\mathfrak{M}_n$ such that the mappings of the diagram

$$\begin{array}{ccccc} & & \mathfrak{S}_n & & \\ & \swarrow & & \searrow & \\ \overline{\mathfrak{S}}_n & & & & \mathfrak{T}_n \\ & \searrow & & \swarrow & \\ & & \mathfrak{M}_n & & \end{array}$$

are analytic quotient maps. It seems likely that the spaces $\mathfrak{S}_n$, $\mathfrak{T}_n$, $\overline{\mathfrak{S}}_n$ may be even $\mathfrak{M}_n$ are Stein spaces.

4. Siegel halfspaces

(4.1). Let $\mathcal{H}_n$ be the set of all symmetric $n \times n$ matrices $x = (x_{ij})$ with $x_{ij} = x_{ji} \in K_* = K - \{0\}$ for which the real matrix $(-\log |x_{ij}|)$ is positiv definite. $\mathcal{H}_n$ is a subset of the space $S_n(K_*)$ of all symmetric $n \times n$ matrices

$x = (x_{ij})$ with entries $x_{ij} \in K_*$. We identify $S_n(K_*)$ with the algebraic torus $K_*^{n(n+1)/2}$ by identifying the matrix $x = (x_{ij})$ with the $(n(n+1)/2)$-tupel $(x_{11}, x_{12}, \ldots, x_{21}, x_{22}, \ldots, x_{nn})$.

Let $a = (a_{ij})$ be a $n \times r$ matrix with entries $a_{ij} \in \mathbb{Z}$. For $x \in S_n(K_*)$, we define $x^a = (y_{ij})$, $y_{ij} := \prod_{k=1}^n x_{ik}^{a_{kj}}$.

Then x^a is $n \times r$ matrix with entries in K_*. Similarly, one defines ${}^a x = (z_{ij})$ if a is a $r \times n$ matrix with entries $\in \mathbb{Z}$ by $z_{ij} := \prod_{k=1}^n x_{kj}^{a_{ik}}$.

This matrix operations satisfy the usual rules of matrix calculations.

If a is a $n \times n$ matrix and if a^t denotes the transpose of a, then ${}^{a^t}x^a$ is a symmetrix $n \times n$ matrix $\in S_n(K_*)$ whenever $x \in S_n(K_*)$.

Moreover if $x \in \mathcal{H}_n$, then ${}^{a^t}x^a \in \mathcal{H}_n$ if $\det a \neq 0$. The mapping Φ_a which sends

$$x \longrightarrow {}^{a^t}x^a \quad \text{of} \quad S_n(K_*) \longrightarrow S_n(K_*)$$

is a morphism of algebraic spaces as the entries of ${}^{a^t}x^a$ are monomials in the variables x_{ij}. Because of $\Phi_a \circ \Phi_b = \Phi_{ba}$ one gets that $\Gamma_n := \{\Phi_a \,;\, a \in GL_n(\mathbb{Z})\}$ is a group of automorphisms of the K-algebraic space $S_n(K_*)$. It is easy to see that $\Gamma_n \cong PGL_n(\mathbb{Z})$.

(4.2). If $k = \begin{pmatrix} k_1 \\ \vdots \\ k_n \end{pmatrix}$ is a column vector with $k_i \in \mathbb{Z}$ and $x \in S_n(K_*)$, then ${}^{k^t}x^k$ is an element of K^*. It is the value of the multiplicative quadratic form associated to x at the point k. We write $x[k] = {}^{k^t}x^k$. Denote by M_n the set of all matrices $x \in S_n(K_*)$ which satisfy the following conditions :

For each i and all $k = \begin{pmatrix} k_1 \\ \vdots \\ k_n \end{pmatrix} \in \mathbb{Z}^n$ for which the greatest common divisor of the numbers $k_i, k_{i+1}, \ldots, k_n$ is 1, we have

$$1 > |x_{ii}| \geqslant |x[k]| .$$

We call M_n Minkowski domain. It consists of those matrice x for which the associated real matrices $(-\log |x_{ij}|)$ are half-reduced in the sense of Minkowski.

For any $x \in M_n$, we have $|x[k]| \leqslant |x_{11}| < 1$. This allows to conclude that $x \in \mathcal{H}_n$. Thus $M_n \subseteq \mathcal{H}_n$. It is a simple consequence of the definition that $\bigcup_{\Phi \in \Gamma_n} \Phi(M_n) = \mathcal{H}_n$ (see for example [6], chapter II, § 3).

An important theorem of classical reduction theory says, that M_n is actually defined by a finite number of inequalities (see [6], chapter II, § 5, theorem 10). This means, there are finite sets $F_1, \ldots, F_n \subset \mathbb{Z}^n$ such that

$$M_n = \{x \in S_n(K_*) \;;\; 1 > |x_{11}| \;;\; |x_{ii}| \geqslant |x[k]| \text{ for all } k \in F_i \text{, all } i\} .$$

<u>Example.</u> :- $M_2 = \{x \in S_2(K_*) \;;\; 1 > |x_{11}| \geqslant |x_{22}| \;;\; |x_{22}| \leqslant |x_{12}|^2 \leqslant |x_{22}|^{-1}\}$.

(4.3). The Minkowski domains are analytic polyhedra in $S_n(K_*)$.

They are therefore quasi-Stein subdomains of $K_*^{n(n+1)/2}$ in the sense of [5],, § 2. Thus there is a canonical analytic structure on M_n .

Each $\Phi \in \Gamma_n$ is an automorphism of the K-algebraic space $S_n(K_*)$ and thus also an analytic automorphism of $S_n(K_*)$. Thus $\Phi(M_n)$ is also a quasi-Stein subdomain of $S_n(K_*)$ and we have a canonical analytic structure on $\Phi(M_n)$. Thus we have defined an analytic atlas $\{\Phi(M_n) ; \Phi \in \Gamma_n\}$ on $\mathcal{H}_n$. We put on $\mathcal{H}_n$ the analytic structure given by this atlas. We call $\mathcal{H}_n$ together with this analytic structure the Siegel halfspace and Γ_n the Siegel modular group.

THEOREM 2. - $\mathcal{H}_n$ <u>is an analytic manifold on which</u> Γ_n <u>acts discontinuously</u>.

The proof of the fact that Γ_n acts discontinuously is left to the reader. It can be deduced from results in [6] (chapter II, § 5, especially statement 4 on page 67).

It means that for any affinoid polyhedron P of $S_n(K_*)$ which lies in $\mathcal{H}_n$ the set $\{\Phi \in \Gamma_n ; \Phi(P) \cap P \neq \emptyset\}$ is finite.

<u>Remark</u>. - It is very likely that the set $\mathcal{H}_n/\Gamma_n$ of Γ_n-orbits in $\mathcal{H}_n$ can be given a canonical analytic structure such that the quotient mapping is locally bianalytic outside the ramification set. One can prove that $\mathcal{H}_n$ is a Stein manifold. It seems possible that even $\mathcal{H}_n/\Gamma_n$ is a Stein space.

(4.4) One of the more interesting points in the study of these topics is the period mapping q which is an analytic mapping $\mathcal{T}_n \longrightarrow \mathcal{H}_n$ compatible with the actions of the Teichmüller and of the Siegel modular group (see [3], 8). Thus q induces a mapping $\bar{q} : \mathcal{T}_n/\psi_n \longrightarrow \mathcal{H}_n/\Gamma_n$. Local properties of $\bar{q}$ have been studied in [3] (see for example Satz 7).

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