Chapter 5. Elliptic modular forms and their L-functions

A modular form of weight k with respect to $SL_2(\mathbf{Z})$ is a holomorphic function on the upper half complex plane

$$\mathcal{H} = \{ z \in \mathbf{C} \mid \mathrm{Im}(z) > 0 \}$$

satisfying the functional equation

$$f\left(\frac{az+b}{cz+d}\right) = f(z)(cz+d)^k \quad \text{for all} \quad \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in SL_2(\mathbf{Z}).$$

Thus it is invariant under the translation $z \mapsto z+1$ and has Fourier expansion:

$$f(z) = \sum_{n=-\infty}^{\infty} a_n e(nz) \quad \text{for} \quad e(z) = \exp(2\pi\sqrt{-1}z).$$

We always assume that $a_n = 0$ if $n < 0$. A typical example of such a modular form is given by absolutely convergent Eisenstein series

$$E'_k(z) = \sum_{(m,n)}{}' (mz+n)^{-k} \quad \text{for every even integer} \quad k > 2,$$

where $\sum'$ means that the summation is taken over all ordered pairs of integers (m,n) but $(0,0)$. The Fourier expansion of $E'_k(z)$ is well known (we will verify the expansion later):

$$E_k(z) = \left(\frac{2(2\pi\sqrt{-1})^k}{(k-1)!}\right)^{-1} E'_k(z) = 2^{-1}\zeta(1-k) + \sum_{n=1}^{\infty} \sigma_{k-1}(n)q^n.$$

where $\sigma_m(n) = \sum_{0<d\mid n} d^m$ is the sum of m-th powers of divisors of n. In this section, we study the complex analytic theory of modular forms. To each holomorphic modular form $f = \sum_{n=0}^{\infty} a_n q^n$, we associate a Dirichlet series

$$L(s,f) = \sum_{n=1}^{\infty} a_n n^{-s},$$

and with each pair of modular forms f and $g = \sum_{n=0}^{\infty} b_n q^n$, we also associate another Dirichlet series

$$D(s,f,g) = \sum_{n=1}^{\infty} \bar{a}_n b_n n^{-s}.$$

Then, we will study algebraicity properties of these modular L-functions later in this chapter and Chapters 6 and 10.

§5.1. Classical Eisenstein series of $GL(2)_{/\mathbf{Q}}$

A subgroup of $SL_2(\mathbf{Z})$ is called a congruence subgroup if it contains all matrices $\alpha = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$ mod $N M_2(\mathbf{Z})$ in $SL_2(\mathbf{Z})$ for an integer $N > 0$. We study here Eisenstein series for congruence subgroups of $SL_2(\mathbf{Z})$. In this book, we are mainly concerned with modular forms with respect to the following type of congruence subgroups: for each positive integer N

$$\Gamma_0(N) = \left\{ \begin{pmatrix} a & b \\ c & d \end{pmatrix} \in SL_2(\mathbf{Z}) \mid c \in N\mathbf{Z} \right\}.$$

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Rajat Tandon

Elementary Theory Of L Functions And Eisenstein Series:

Elementary Theory of L-functions and Eisenstein Series Haruzo Hida,1993-02-11 The theory of p adic and classic modular forms and the study of arithmetic and p adic L functions has proved to be a fruitful area of mathematics over the last decade Professor Hida has given courses on these topics in the USA Japan and in France and in this book provides the reader with an elementary but detailed insight into the theory of L functions The presentation is self contained and concise and the subject is approached using only basic tools from complex analysis and cohomology theory Graduate students wishing to know more about L functions will find that this book offers a unique introduction to this fascinating branch of mathematics *Iwasawa Theory 2012* Thanasis Bouganis,Otmar Venjakob,2014-12-08 This is the fifth conference in a bi annual series following conferences in Besancon Limoges Irsee and Toronto The meeting aims to bring together different strands of research in and closely related to the area of Iwasawa theory During the week before the conference in a kind of summer school a series of preparatory lectures for young mathematicians was provided as an introduction to Iwasawa theory Iwasawa theory is a modern and powerful branch of number theory and can be traced back to the Japanese mathematician Kenkichi Iwasawa who introduced the systematic study of Z_p extensions and p adic L functions concentrating on the case of ideal class groups Later this would be generalized to elliptic curves Over the last few decades considerable progress has been made in automorphic Iwasawa theory e g the proof of the Main Conjecture for GL 2 by Kato and Skinner Urban Techniques such as Hida s theory of p adic modular forms and big Galois representations play a crucial part Also a noncommutative Iwasawa theory of arbitrary p adic Lie extensions has been developed This volume aims to present a snapshot of the state of art of Iwasawa theory as of 2012 In particular it offers an introduction to Iwasawa theory based on a preparatory course by Chris Wuthrich and a survey of the proof of Skinner Urban based on a lecture course by Xin Wan <u>Number Theory</u> Wenpeng Zhang,Yoshio Tanigawa,2006-06-05 Number Theory Tradition and Modernization is a collection of survey and research papers on various topics in number theory Though the topics and descriptive details appear varied they are unified by two underlying principles first making everything readable as a book and second making a smooth transition from traditional approaches to modern ones by providing a rich array of examples The chapters are presented in quite different in depth and cover a variety of descriptive details but the underlying editorial principle enables the reader to have a unified glimpse of the developments of number theory Thus on the one hand the traditional approach is presented in great detail and on the other the modernization of the methods in number theory is elaborated The book emphasizes a few common features such as functional equations for various zeta functions modular forms congruence conditions exponential sums and algorithmic aspects **Fourier Analysis on Number Fields** Dinakar Ramakrishnan,Robert J. Valenza,2013-04-17 This book grew out of notes from several courses that the first author has taught over the past nine years at the California Institute of Technology and earlier at the Johns Hopkins University Cornell University the University of Chicago and the University of

Crete Our general aim is to provide a modern approach to number theory through a blending of complementary algebraic and analytic perspectives emphasizing harmonic analysis on topological groups Our more particular goal is to cover Jolm Tate s visionary thesis giving virtually all of the necessary analytic details and topological preliminaries technical prereq uisites that are often foreign to the typical more algebraically inclined number theorist Most of the existing treatments of Tate s thesis including Tate s own range from terse to cryptic our intent is to be more leisurely more comprehen sive and more comprehensible To this end we have assembled material that has admittedly been treated elsewhere but not in a single volume with so much detail and not with our particular focus We address our text to students who have taken a year of graduate level courses in algebra analysis and topology While our choice of objects and methods is naturally guided by the specific mathematical goals of the text our approach is by no means narrow In fact the subject matter at hand is germane not only to budding number theorists but also to students of harmonic analysis or the representation theory of Lie groups

Advanced Analytic Number Theory: L-Functions Carlos J. Moreno,2005 Since the pioneering work of Euler Dirichlet and Riemann the analytic properties of L functions have been used to study the distribution of prime numbers With the advent of the Langlands Program L functions have assumed a greater role in the study of the interplay between Diophantine questions about primes and representation theoretic properties of Galois representations This book provides a complete introduction to the most significant class of L functions the Artin Hecke L functions associated to finite dimensional representations of Weil groups and to automorphic L functions of principal type on the general linear group In addition to establishing functional equations growth estimates and non vanishing theorems a thorough presentation of the explicit formulas of Riemann type in the context of Artin Hecke and automorphic L functions is also given The survey is aimed at mathematicians and graduate students who want to learn about the modern analytic theory of L functions and their applications in number theory and in the theory of automorphic representations The requirements for a profitable study of this monograph are a knowledge of basic number theory and the rudiments of abstract harmonic analysis on locally compact abelian groups *Elliptic Integrals, Elliptic Functions and Modular Forms in Quantum Field Theory* Johannes Blümlein,Carsten Schneider,Peter Paule,2019-01-30 This book includes review articles in the field of elliptic integrals elliptic functions and modular forms intending to foster the discussion between theoretical physicists working on higher loop calculations and mathematicians working in the field of modular forms and functions and analytic solutions of higher order differential and difference equations Modular Forms and Galois Cohomology Haruzo Hida,2000-06-29 Comprehensive account of recent developments in arithmetic theory of modular forms for graduates and researchers *Number Theory* Sinnou David,1995 This is the fourteenth annual volume arising from the Seminaire de Theorie de Nombres de Paris covering the whole spectrum of number theory Elliptic Curves and Arithmetic Invariants Haruzo Hida,2013-06-13 This book contains a detailed account of the result of the author s recent Annals paper and JAMS paper on arithmetic invariant including invariant

L invariant and similar topics This book can be regarded as an introductory text to the author s previous book p Adic Automorphic Forms on Shimura Varieties Written as a down to earth introduction to Shimura varieties this text includes many examples and applications of the theory that provide motivation for the reader Since it is limited to modular curves and the corresponding Shimura varieties this book is not only a great resource for experts in the field but it is also accessible to advanced graduate students studying number theory Key topics include non triviality of arithmetic invariants and special values of L functions elliptic curves over complex and p adic fields Hecke algebras scheme theory elliptic and modular curves over rings and Shimura curves   Algorithmic Number Theory Wieb Bosma,2000 This book constitutes the refereed proceedings of the 4th International Algorithmic Number Theory Symposium ANTS IV held in Leiden The Netherlands in July 2000 The book presents 36 contributed papers which have gone through a thorough round of reviewing selection and revision Also included are 4 invited survey papers Among the topics addressed are gcd algorithms primality factoring sieve methods cryptography linear algebra lattices algebraic number fields class groups and fields elliptic curves polynomials function fields and power sums   Mathematics: Frontiers and Perspectives Vladimir Igorevich Arnol'd,2000 A celebration of the state of mathematics at the end of the millennium Produced under the auspices of the International Mathematical Union IMU the book was born as part of the activities of World Mathematical Year 2000 It consists of 28 articles written by influential mathematicians   Automorphic Forms and Related Geometry: Assessing the Legacy of I.I. Piatetski-Shapiro James W. Cogdell,Freydoon Shahidi,David Soudry,2014-04-01 This volume contains the proceedings of the conference Automorphic Forms and Related Geometry Assessing the Legacy of I I Piatetski Shapiro held from April 23 27 2012 at Yale University New Haven CT Ilya I Piatetski Shapiro who passed away on 21 February 2009 was a leading figure in the theory of automorphic forms The conference attempted both to summarize and consolidate the progress that was made during Piatetski Shapiro s lifetime by him and a substantial group of his co workers and to promote future work by identifying fruitful directions of further investigation It was organized around several themes that reflected Piatetski Shapiro s main foci of work and that have promise for future development functoriality and converse theorems local and global functions and their periods adic functions and arithmetic geometry complex geometry and analytic number theory In each area there were talks to review the current state of affairs with special attention to Piatetski Shapiro s contributions and other talks to report on current work and to outline promising avenues for continued progress The contents of this volume reflect most of the talks that were presented at the conference as well as a few additional contributions They all represent various aspects of the legacy of Piatetski Shapiro   **Algebraic Geometry and Number Theory** Hussein Mourtada,Celal Cem Sarıoğlu,Christophe Soulé,Ayberk Zeytin,2017-05-07 This lecture notes volume presents significant contributions from the Algebraic Geometry and Number Theory Summer School held at Galatasaray University Istanbul June 2 13 2014 It addresses subjects ranging from Arakelov geometry and Iwasawa theory to classical projective geometry birational geometry and

equivariant cohomology Its main aim is to introduce these contemporary research topics to graduate students who plan to specialize in the area of algebraic geometry and or number theory All contributions combine main concepts and techniques with motivating examples and illustrative problems for the covered subjects Naturally the book will also be of interest to researchers working in algebraic geometry number theory and related fields **Hilbert Modular Forms and Iwasawa Theory** Haruzo Hida,2006-06-15 Describing the applications found for the Wiles and Taylor technique this book generalizes the deformation theoretic techniques of Wiles Taylor to Hilbert modular forms following Fujiwara s treatment and also discusses applications found by the author *Research Directions in Number Theory* Alina Bucur,Wei Ho,Renate Scheidler,2024-06-26 This is the fifth proceedings volume published under the Women in Numbers umbrella The WIN workshops and their proceedings volumes are part of the WIN network aimed at highlighting the research of women and gender minorities in number theory as well as increasing their participation and boosting their potential collaborations in number theory and related fields The volume contains research articles in the mathematical area of number theory written by teams of scholars at all levels in the field More information about the network its goals and purpose past and future conferences and past proceedings volumes can be found on the WIN website This volume contains research outcomes and results produced by the collaborative research groups created under the Women in Numbers V workshop the 5th in its series The actual workshop was to take place in 2020 at the Banff International Research Station in Banff Canada but could not take place onsite due to COVID The associated research groups each consisting of 1 2 leaders and 2 4 junior researchers were formed nevertheless and their collaborations went ahead in purely virtual form as well as other papers by author teams for which at least 50% of the authors identify as women or gender minorities These contributions include original research and survey articles in a wide variety of subareas within number theory The former present new cutting edge research that will be of interest to experts in the field to the benefit of their own research The survey articles serve as an accessible introduction for graduate students and other readers to areas of number theory that may be outside their area of expertise

P-adic Aspects Of Modular Forms Baskar Balasubramanyam,A Raghuram,Jacques Tilouine,Haruzo Hida,2016-06-14 The aim of this book is to give a systematic exposition of results in some important cases where p adic families and p adic L functions are studied We first look at p adic families in the following cases general linear groups symplectic groups and definite unitary groups We also look at applications of this theory to modularity lifting problems We finally consider p adic L functions for GL 2 the p adic adjoint L functions and some cases of higher GL n *Algebra and Number Theory* Rajat Tandon,2005-05-01 Contributed articles presented at the Conference *Analysis, Geometry, Number Theory: The Mathematics of Leon Ehrenpreis* Eric Grinberg,2000 This book presents the proceedings from the conference honoring the work of Leon Ehrenpreis Professor Ehrenpreis worked in many different areas of mathematics and found connections among all of them For example one can find his analytic ideas in the context of number theory geometric thinking within analysis

transcendental number theory applied to partial differential equations and more The conference brought together the communities of mathematicians working in the areas of interest to Professor Ehrenpreis and allowed them to share the research inspired by his work The collection of articles here presents current research on PDEs several complex variables analytic number theory integral geometry and tomography The work of Professor Ehrenpreis has contributed to basic definitions in these areas and has motivated a wealth of research results This volume offers a survey of the fundamental principles that unified the conference and influenced the mathematics of Leon Ehrenpreis **Geometric Modular Forms and Elliptic Curves** Haruzo Hida,2012 This book provides a comprehensive account of the theory of moduli spaces of elliptic curves over integer rings and its application to modular forms The construction of Galois representations which play a fundamental role in Wiles proof of the Shimura Taniyama conjecture is given In addition the book presents an outline of the proof of diverse modularity results of two dimensional Galois representations including that of Wiles as well as some of the author s new results in that direction In this new second edition a detailed description of Barsotti Tate groups including formal Lie groups is added to Chapter 1 As an application a down to earth description of formal deformation theory of elliptic curves is incorporated at the end of Chapter 2 in order to make the proof of regularity of the moduli of elliptic curve more conceptual and in Chapter 4 though limited to ordinary cases newly incorporated are Ribet s theorem of full image of modular p adic Galois representation and its generalization to big adic Galois representations under mild assumptions a new result of the author Though some of the striking developments described above is out of the scope of this introductory book the author gives a taste of present day research in the area of Number Theory at the very end of the book giving a good account of modularity theory of abelian varieties and curves Computations with Modular Forms Gebhard Böckle,Gabor Wiese,2014-01-23 This volume contains original research articles survey articles and lecture notes related to the Computations with Modular Forms 2011 Summer School and Conference held at the University of Heidelberg A key theme of the Conference and Summer School was the interplay between theory algorithms and experiment The 14 papers offer readers both instructional courses on the latest algorithms for computing modular and automorphic forms as well as original research articles reporting on the latest developments in the field The three Summer School lectures provide an introduction to modern algorithms together with some theoretical background for computations of and with modular forms including computing cohomology of arithmetic groups algebraic automorphic forms and overconvergent modular symbols The 11 Conference papers cover a wide range of themes related to computations with modular forms including lattice methods for algebraic modular forms on classical groups a generalization of the Maeda conjecture an efficient algorithm for special values of p adic Rankin triple product L functions arithmetic aspects and experimental data of Bianchi groups a theoretical study of the real Jacobian of modular curves results on computing weight one modular forms and more

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