ALGEBRAIC NUMBER THEORY

LECTURE 12 NOTES

1. SECTION 5.5

Note that $\tau(1)^2 = \left(\frac{-1}{p}\right)$ holds in characteristic 0 as well as characteristic q (set $w = e^{2\pi i/p}$), since it doesn't use any property of finite fields. It allows us to see what the unique quadratic subfield of $\mathbb{Q}(\zeta_p)$ is: start with a generator $\zeta_p = w$ of $\mathbb{Q}(\zeta_p)$ and symmetrize with respect to the unique subgroup of index 2 of the Galois group (which is isomorphic to $(\mathbb{Z}/p\mathbb{Z})^*$ under $a \in (\mathbb{Z}/p\mathbb{Z})^* \longmapsto (\zeta_p \mapsto \zeta_p^a)$). The subgroup consists of the squares in $(\mathbb{Z}/p\mathbb{Z})^*$, so the quadratic extension is generated by $\sum_{a \in (\mathbb{F}_p^*)^2} \zeta_p^{a^2}$ if the sum is nonzero. This sum equals

$$\sum_{a \in \mathbb{F}_p^*} \frac{1}{2}\left(1 + \left(\frac{a}{p}\right)\right)\zeta_p^a = -\frac{1}{2} + \frac{1}{2}\sum_{a \in \mathbb{F}_p^*}\left(\frac{a}{p}\right)\zeta_p^a = \frac{\tau(1) - 1}{2}.$$

This sum is nonzero since $|\tau(1)| = \sqrt{p}$. So the quadratic subfield in question is indeed $\mathbb{Q}(\sqrt{\left(\frac{-1}{p}\right)p})$ which is $\mathbb{Q}(\sqrt{p})$ if $p \equiv 1 \bmod 4$ and $\mathbb{Q}(\sqrt{-p})$ if $p \equiv 3 \bmod 4$.

We know the Gauss sum up to sign since we know its square. For the computation of the sign see for example Flath's book on number theory, which has a nice proof using the finite Fourier transform. For a good introduction to Gauss and Jacobi sums see Ireland and Rosen's book.

2. SECTION 5.6

To see that if n is a sum of two squares then every prime which is 3 mod 4 divides n to an even power we argue by contradiction. Let n be a smallest counterexample and let $p \equiv 3 \bmod 4$ divide n to an odd power. Write $n = a^2 + b^2$ and notice that p cannot divide a or b since then it would have to divide both (sum of their squares is divisible by p), and then $n/p^2 = (a/p)^2 + (b/p)^2$ would furnish a smaller counterexample. So $p \nmid b$ in particular, and so $(ab^{-1})^2 \equiv -1 \bmod p$, which contradicts $p \equiv 3 \bmod 4$.

3. SECTION 5.7

Proof of four squares theorem. By multiplicativity of quaternion norms, it's enough to see that every prime is a sum of four squares. Since this is trivial for 2, assume

1

Algebraic Number Theory And Algebraic Geometry

Ke-qin Feng,Ke-zheng Li

Algebraic Number Theory And Algebraic Geometry:

    Algebraic Number Theory and Algebraic Geometry S. V. Vostokov,Yuri Zarhin,2002 A N Parshin is a world renowned mathematician who has made significant contributions to number theory through the use of algebraic geometry Articles in this volume present new research and the latest developments in algebraic number theory and algebraic geometry and are dedicated to Parshin s sixtieth birthday Well known mathematicians contributed to this volume including among others F Bogomolov C Deninger and G Faltings The book is intended for graduate students andresearch mathematicians interested in number theory algebra and algebraic geometry Algebraic Number Theory Jürgen Neukirch,2013-03-14 From the review The present book has as its aim to resolve a discrepancy in the textbook literature and to provide a comprehensive introduction to algebraic number theory which is largely based on the modern unifying conception of one dimensional arithmetic algebraic geometry Despite this exacting program the book remains an introduction to algebraic number theory for the beginner The author discusses the classical concepts from the viewpoint of Arakelov theory The treatment of class field theory is particularly rich in illustrating complements hints for further study and concrete examples The concluding chapter VII on zeta functions and L series is another outstanding advantage of the present textbook The book is without any doubt the most up to date systematic and theoretically comprehensive textbook on algebraic number field theory available W Kleinert in Zentralblatt f r Mathematik 1992 **Algebraic Number Theory** H. Koch,Helmut Koch,1997-09-12 From the reviews of the first printing published as Volume 62 of the Encyclopaedia of Mathematical Sciences The author succeeded in an excellent way to describe the various points of view under which Class Field Theory can be seen In any case the author succeeded to write a very readable book on these difficult themes Monatshefte fuer Mathematik 1994 Koch s book is written mostly for non specialists It is an up to date account of the subject dealing with mostly general questions Special results appear only as illustrating examples for the general features of the theory It is supposed that the reader has good general background in the fields of modern abstract algebra and elementary number theory We recommend this volume mainly to graduate studens and research mathematicians Acta Scientiarum Mathematicarum 1993 *Algebraic Groups and Number Theory* Vladimir Platonov,Andrei Rapinchuk,Rachel Rowen,1993-12-07 This milestone work on the arithmetic theory of linear algebraic groups is now available in English for the first time Algebraic Groups and Number Theory provides the first systematic exposition in mathematical literature of the junction of group theory algebraic geometry and number theory The exposition of the topic is built on a synthesis of methods from algebraic geometry number theory analysis and topology and the result is a systematic overview ofalmost all of the major results of the arithmetic theory of algebraic groups obtained to date *Algebraic Number Theory* Aneta Hajek,2015-08 Algebraic number theory is the branch of number theory that deals with algebraic numbers Historically algebraic number theory developed as a set of tools for solving problems in elementary number theory namely Diophantine equations i e equations whose solutions are integers or rational numbers More recently

algebraic number theory has developed into the abstract study of algebraic numbers and number fields themselves as well as their properties Algebraic number theory is a major branch of number theory that studies algebraic structures related to algebraic integers This is generally accomplished by considering a ring of algebraic integers O in an algebraic number field K Q and studying their algebraic properties such as factorization the behaviour of ideals and field extensions In this setting the familiar features of the integerssuch as unique factorizationneed not hold The virtue of the primary machinery employedGalois theory group cohomology group representations and L functionsis that it allows one to deal with new phenomena and yet partially recover the behaviour of the usual integers The higher reaches of algebraic number theory are now one of the crown jewels of mathematics But algebraic number theory is not merely interesting in itself It has become an important tool over a wide range of pure mathematics and many of ideas involved generalize for example to algebraic geometry This book is intended both for number theorist and more generally for working algebraists *Algebraic Numbers and Algebraic Functions* P.M. Cohn,2018-01-18 This book is an introduction to the theory of algebraic numbers and algebraic functions of one variable The basic development is the same for both using E Artin s legant approach via valuations Number Theory is pursued as far as the unit theorem and the finiteness of the class number In function theory the aim is the Abel Jacobi theorem describing the devisor class group with occasional geometrical asides to help understanding Assuming only an undergraduate course in algebra plus a little acquaintance with topology and complex function theory the book serves as an introduction to more technical works in algebraic number theory function theory or algebraic geometry by an exposition of the central themes in the subject *Basic Number Theory* Andre Weil,2012-12-06 tPI jlOV e oxov 10CPUljlr1 CWV Aiux llpop dsup The first part of this volume is based on a course taught at Princeton University in 1961 62 at that time an excellent set of notes was prepared by David Cantor and it was originally my intention to make these notes available to the mathematical public with only quite minor changes Then among some old papers of mine I accidentally came across a long forgotten manuscript by Chevalley of pre war vintage forgotten that is to say both by me and by its author which to my taste at least seemed to have aged very well It contained a brief but essentially com plete account of the main features of classfield theory both local and global and it soon became obvious that the usefulness of the intended volume would be greatly enhanced if I included such a treatment of this topic It had to be expanded in accordance with my own plans but its outline could be preserved without much change In fact I have adhered to it rather closely at some critical points **Algebraic Geometry And Algebraic Number Theory -Procs Of The Spcial Prg At The Nankai Institute Of Maths** Ke-qin Feng,Ke-zheng Li,1992-12-11 This manual of geology discusses the major aspects of descriptive geology notably rock types and structural studies The basic techniques of rock descriptions are also dealt with at length <u>Distribution Theory of Algebraic Numbers</u> Pei-Chu Hu,Chung-Chun Yang,2008-12-10 The book timely surveys new research results and related developments in Diophantine approximation a division of number theory which deals with the approximation of real numbers

by rational numbers The book is appended with a list of challenging open problems and a comprehensive list of references From the contents Field extensions Algebraic numbers Algebraic geometry Height functions The abc conjecture Roth s theorem Subspace theorems Vojta s conjectures L functions   Hilbert's Tenth Problem: Relations with Arithmetic and Algebraic Geometry Jan Denef,2000 This book is the result of a meeting that took place at the University of Ghent Belgium on the relations between Hilbert s tenth problem arithmetic and algebraic geometry Included are written articles detailing the lectures that were given as well as contributed papers on current topics of interest The following areas are addressed an historical overview of Hilbert s tenth problem Hilbert s tenth problem for various rings and fields model theory and local global principles including relations between model theory and algebraic groups and analytic geometry conjectures in arithmetic geometry and the structure of diophantine sets for example with Mazur s conjecture Lang s conjecture and B cchi s problem and results on the complexity of diophantine geometry highlighting the relation to the theory of computation The volume allows the reader to learn and compare different approaches arithmetical geometrical topological model theoretical and computational to the general structural analysis of the set of solutions of polynomial equations It would make a nice contribution to graduate and advanced graduate courses on logic algebraic geometry and number theory   **Algorithmic Algebra and Number Theory** B.Heinrich Matzat,Gert-Martin Greuel,Gerhard Hiss,2012-12-06 This book contains 22 lectures presented at the final conference of the Ger man research program Schwerpunktprogramm Algorithmic Number The ory and Algebra 1991 1997 sponsored by the Deutsche Forschungsgemein schaft The purpose of this research program and of the meeting was to bring together developers of computer algebra software and researchers using com putational methods to gain insight into experimental problems and theoret ical questions in algebra and number theory The book gives an overview on algorithmic methods and on results ob tained during this period This includes survey articles on the main research projects within the program algorithmic number theory emphasizing class field theory constructive Galois theory computational aspects of modular forms and of Drinfeld modules computational algebraic geometry including real quantifier elimination and real algebraic geometry and invariant theory of finite groups computational aspects of presentations and representations of groups especially finite groups of Lie type and their Heeke algebras and of the isomorphism problem in group theory Some of the articles illustrate the current state of computer algebra sys tems and program packages developed with support by the research pro gram such as KANT and LiDIA for algebraic number theory SINGULAR RED LOG and INVAR for commutative algebra and invariant theory respec tively and GAP SYSYPHOS and CHEVIE for group theory and representation theory   Effective Methods in Algebraic Geometry Teo Mora,1991 The symposium MEGA 90 Effective Methods in Algebraic Geome try was held in Castiglioncello Livorno Italy in April 17 211990 The themes we quote from the Call for papers were the fol lowing Effective methods and complexity issues in commutative algebra pro jective geometry real geometry algebraic number theory Algebraic geometric methods in algebraic computing Contributions in related fields

computational aspects of group theory differential algebra and geometry algebraic and differential topology etc were also welcome The origin and the motivation of such a meeting that is supposed to be the first of a series deserves to be explained The subject the theory and the practice of computation in alge braic geometry and related domains from the mathematical viewpoin has been one of the themes of the symposia organized by SIGSAM the Special Interest Group for Symbolic and Algebraic Manipulation of the Association for Computing Machinery SAME Symbolic and Algebraic Manipulation in Europe and AAECC the semantics of the name is vary ing an average meaning is Applied Algebra and Error Correcting Codes

Number Theory and Algebraic Geometry Miles Reid,Alexei Skorobogatov,2003 Sir Peter Swinnerton Dyer s mathematical career encompasses more than 60 years work of amazing creativity This volume provides contemporary insight into several subjects in which Sir Peter s influence has been notable and is dedicated to his 75th birthday The opening section reviews some of his many remarkable contributions to mathematics and other fields The remaining contributions come from leading researchers in analytic and arithmetic number theory and algebraic geometry The topics treated include rational points on algebraic varieties the Hasse principle Shafarevich Tate groups of elliptic curves and motives Zagier s conjectures descent and zero cycles Diophantine approximation and Abelian and Fano varieties *Algebraic Number Theory* Serge Lang,2013-06-29 The present book gives an exposition of the classical basic algebraic and analytic number theory and supersedes my Algebraic Numbers including much more material e g the class field theory on which 1 make further comments at the appropriate place later For different points of view the reader is encouraged to read the collec tion of papers from the Brighton Symposium edited by Cassels Frohlich the Artin Tate notes on class field theory Weil s book on Basic Number Theory Borevich Shafarevich s Number Theory and also older books like those of W eber Hasse Hecke and Hilbert s Zahlbericht It seems that over the years everything that has been done has proved useful theo retically or as examples for the further development of the theory Old and seemingly isolated special cases have continuously acquired renewed significance often after half a century or more The point of view taken here is principally global and we deal with local fields only incidentally For a more complete treatment of these cf Serre s book Corps Locaux There is much to be said for a direct global approach to number fields Stylistically 1 have intermingled the ideal and idelic approaches without prejudice for either 1 also include two proofs of the functional equation for the zeta function to acquaint the reader with different techniques in some sense equivalent but in another sense suggestive of very different moods Arithmetic Geometry And Number Theory Lin Weng,Iku Nakamura,2006-06-02 Mathematics is very much a part of our culture and this invaluable collection serves the purpose of developing the branches involved popularizing the existing theories and guiding our future explorations More precisely the goal is to bring the reader to the frontier of current developments in arithmetic geometry and number theory through the works of Deninger Werner in vector bundles on curves over p adic fields of Jiang on local gamma factors in automorphic representations of Weng on Deligne pairings and Takhtajan Zograf metrics of Yoshida

on CM periods of Yu on transcendence of special values of zetas over finite fields In addition the lecture notes presented by Weng at the University of Toronto from October to November 2005 explain basic ideas and the reasons not just the language and conclusions behind Langlands fundamental yet notably difficult works on the Eisenstein series and spectral decompositions And finally a brand new concept by Weng called the Geometric Arithmetic program that uses algebraic and or analytic methods based on geometric considerations to develop the promising and yet to be cultivated land of global arithmetic that includes non abelian Class Field Theory Riemann Hypothesis and non abelian Zeta and L Functions etc

Algebraic Geometry and Algebraic Number Theory Ke-Qin Feng,Ke-Zheng Li,1992-01-01   *An Invitation to Arithmetic Geometry* Dino Lorenzini,2021-12-23 Extremely carefully written masterfully thought out and skillfully arranged introduction to the arithmetic of algebraic curves on the one hand and to the algebro geometric aspects of number theory on the other hand an excellent guide for beginners in arithmetic geometry just as an interesting reference and methodical inspiration for teachers of the subject a highly welcome addition to the existing literature Zentralblatt MATH The interaction between number theory and algebraic geometry has been especially fruitful In this volume the author gives a unified presentation of some of the basic tools and concepts in number theory commutative algebra and algebraic geometry and for the first time in a book at this level brings out the deep analogies between them The geometric viewpoint is stressed throughout the book Extensive examples are given to illustrate each new concept and many interesting exercises are given at the end of each chapter Most of the important results in the one dimensional case are proved including Bombieri s proof of the Riemann Hypothesis for curves over a finite field While the book is not intended to be an introduction to schemes the author indicates how many of the geometric notions introduced in the book relate to schemes which will aid the reader who goes to the next level of this rich subject   Number Theory Helmut Koch,2000 Algebraic number theory is one of the most refined creations in mathematics It has been developed by some of the leading mathematicians of this and previous centuries The primary goal of this book is to present the essential elements of algebraic number theory including the theory of normal extensions up through a glimpse of class field theory Following the example set for us by Kronecker Weber Hilbert and Artin algebraic functions are handled here on an equal footing with algebraic numbers This is done on the one hand to demonstrate the analogy between number fields and function fields which is especially clear in the case where the ground field is a finite field On the other hand in this way one obtains an introduction to the theory of higher congruences as an important element of arithmetic geometry Early chapters discuss topics in elementary number theory such as Minkowski s geometry of numbers public key cryptography and a short proof of the Prime Number Theorem following Newman and Zagier Next some of the tools of algebraic number theory are introduced such as ideals discriminants and valuations These results are then applied to obtain results about function fields including a proof of the Riemann Roch Theorem and as an application of cyclotomic fields a proof of the first case of Fermat s Last Theorem There are a detailed exposition of the theory of Hecke L series following

Tate and explicit applications to number theory such as the Generalized Riemann Hypothesis Chapter 9 brings together the earlier material through the study of quadratic number fields Finally Chapter 10 gives an introduction to class field theory The book attempts as much as possible to give simple proofs It can be used by a beginner in algebraic number theory who wishes to see some of the true power and depth of the subject The book is suitable for two one semester courses with the first four chapters serving to develop the basic material Chapters 6 through 9 could be used on their own as a second semester course **Noncommutative Geometry and Number Theory** Caterina Consani,Matilde Marcolli,2007-12-18 In recent years number theory and arithmetic geometry have been enriched by new techniques from noncommutative geometry operator algebras dynamical systems and K Theory This volume collects and presents up to date research topics in arithmetic and noncommutative geometry and ideas from physics that point to possible new connections between the fields of number theory algebraic geometry and noncommutative geometry The articles collected in this volume present new noncommutative geometry perspectives on classical topics of number theory and arithmetic such as modular forms class field theory the theory of reductive p adic groups Shimura varieties the local L factors of arithmetic varieties They also show how arithmetic appears naturally in noncommutative geometry and in physics in the residues of Feynman graphs in the properties of noncommutative tori and in the quantum Hall effect *Algebraic Number Theory and Diophantine Analysis* F. Halter-Koch,Robert F. Tichy,2011-06-24 The series is aimed specifically at publishing peer reviewed reviews and contributions presented at workshops and conferences Each volume is associated with a particular conference symposium or workshop These events cover various topics within pure and applied mathematics and provide up to date coverage of new developments methods and applications

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