EXPLICIT VERSIONS OF THE PRIME IDEAL THEOREM FOR
DEDEKIND ZETA FUNCTIONS UNDER GRH, II

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Abstract. We have recently proved several explicit versions of the prime ideal theorem under GRH. Here we further explore the method, in order to deduce its strongest consequence for the case where $x$ diverges.

1. Introduction

For a number field $K$ we denote by

- $n_K$ its dimension,
- $\Delta_K$ the absolute value of its discriminant,
- $\delta_K := (\Delta_K)^{(1/n_K)}$ its root discriminant,
- $r_1$ the number of its real places,
- $r_2$ the number of its imaginary places,
- $d_K := r_1 + r_2 - 1$.

In [2] we use a two step process to prove explicit versions of the prime ideal theorem under GRH: first we prove a bound for $|\psi_K(x) - x|$ depending on a parameter $T$ to be fixed later ([2, Theorem 1.1]), then we prove several formulas based on some choices for $T$ ([2, Corollaries 1.2 and 1.3]). A scheme to produce explicit versions of the prime ideal theorem for number fields has been proved by Lagarias and Odlyzko in [3] and recently Winckler computed the effective constants in [7]. In this paper, we reuse Theorem 1.1 of [2] with an additional parameter called $\kappa$ producing the general result in Theorem 2.4. We then choose $\kappa$ and $T$ in such a way as to obtain the best possible asymptotic expansion for $x \to +\infty$. By doing so we obtain a formula that is not too far from the best possible bound for $|\psi_K(x) - x|$ which can be proved by using this method.

We recall that the Lambert-$W$ function is the function such that $\forall x \geq 0, W(x)e^{W(x)} = x$.

Theorem 1.1. Assume GRH. Let $x \geq 3$,

$$w := W\left(\frac{e^{\sqrt{5}}}{2\pi} \delta_K \left[\frac{(\sqrt{5} - 1)\pi \sqrt{x}}{2n_K} + 21.3270 + \frac{33.3542}{n_K}\right]\right),$$

$$T := 8.2822 + \frac{1}{w} \left[\frac{(\sqrt{5} - 1)\pi \sqrt{x}}{2n_K} + 21.3270 + \frac{33.3542}{n_K}\right],$$

$$\epsilon_K(x, T) := \max \left(0, d_K \log x - 3.6133n_K \frac{\sqrt{x}}{T}\right).$$

Then

$$|\psi_K(x) - x| \leq$$

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\[
\frac{\sqrt{x}}{\pi} \left[ \left( \frac{1}{2} \log^2 (e^{w+1} + 33.5251 \delta_K) - \frac{1}{2} \log^2 \delta_K + 3.9792 \log \delta_K - 3.4969 \right) n_K + 25.5362 \right] \\
+ 1.0155 \log \Delta_K - 2.1042 n_K + 8.8590 + \epsilon_K (x, T).
\]

Moreover we also have

(1.2) \[ |\psi_K(x) - x| \leq (2.2543 \sqrt{x} + 1.0155) \log \Delta_K + (0.9722 \sqrt{x} - 2.1042) n_K \\
+ \frac{x}{10} + 9.0458 \sqrt{x} + 7.0320 + \epsilon_K (x, 10). \]

The choice of \( T \) we have made to deduce Theorem 1.1 from Theorem 2.5 gives the best coefficients for all terms in the asymptotic expansion, down to the term of order \( \sqrt{x} \). This choice is not too far from the best our method can achieve, even for finite \( x \); in other words, the \( T \) we choose in Theorem 1.1 is not too far from the optimal \( T \) for Theorem 2.5. Note that the values of the other parameters we fix in the proofs of Theorem 1.1 and Theorem 2.5 affect the term of order \( \sqrt{x} \) of the asymptotic expansion.

Inequality (1.2) is a kind of Chebyshev bound, which has the interesting property that the linear term has a coefficient independent of the field. It is better than (1.1) when \( x \) is very small with respect to \( \delta_K \).

**Asymptotic expansions.** We discuss the asymptotic expansions of (1.1) when \( x \) diverges and \( K \) is fixed. We have, as \( t \to +\infty \)

\[
W(t) = \log t - \log \log t + \frac{\log \log t}{\log t} + O \left( \left( \frac{\log \log t}{\log t} \right)^2 \right)
\]

and, even though we will not use it,

\[
\forall t \geq e, \quad W(t) \leq \log t - \log \log t + 1.024 \frac{\log \log t}{\log t}
\]

so that the asymptotic expansion we are computing is not too far from an upper bound. From the first expansion, we deduce

\[
\frac{1}{2} W(t)^2 + W(t) = \frac{1}{2} \log^2 t - \log t \log \log t + \log t + \frac{1}{2} (\log \log t)^2 + o(1).
\]

We have \( w \sim \frac{1}{2} \log x \) when \( x \) diverges, thus

\[
\log^2 (e^{w+1} + 33.5251 \delta_K) = \left( w + 1 + \frac{33.5251 \delta_K}{e^{w+1}} + O \left( \frac{1}{e^{2w}} \right) \right)^2 = w^2 + 2w + 1 + O \left( \frac{\log x}{\sqrt{x}} \right).
\]

We thus have, taking \( \nu := \frac{\sqrt{5} - 1}{2} e^\frac{5}{2} \)

\[
\frac{1}{2} \log^2 (e^{w+1} + 33.5251 \delta_K) - \frac{1}{2} \log^2 \delta_K \\
= \frac{1}{2} w^2 + w + 1 \frac{1}{2} \log^2 \delta_K + o(1) \\
= \left[ \log \delta_K + \frac{1}{2} \log x + \log \left( \frac{\nu}{2 n_K} \right) \right]^2 \\
- \left[ \log \delta_K + \frac{1}{2} \log x + \log \left( \frac{\nu}{2 n_K} \right) \right] \left[ \log \log x - \log 2 + \frac{2 \log \delta_K}{\log x} + \frac{2}{\log x} \log \left( \frac{\nu}{2 n_K} \right) \right] \\
+ \log \delta_K + \frac{1}{2} \log x + \log \left( \frac{\nu}{2 n_K} \right) + \frac{1}{2} \left[ \log \log x - \log 2 \right]^2 + \frac{1}{2} - \frac{1}{2} \log^2 \delta_K + o(1)
\]
\[
\begin{align*}
&= \frac{1}{8} \log^2 x - \frac{1}{2} \log x \log \log x + \frac{1}{2} \left[ \log \delta_K + \log \left( \frac{e^\nu}{n_K} \right) \right] \log x + \frac{1}{2} (\log \log x)^2 \\
&\quad - \left[ \log \delta_K + \log \left( \frac{\nu}{n_K} \right) \right] \log \log x + \frac{1}{2} \log^2 \left( \frac{\nu}{n_K} \right) + \log \left( \frac{\nu}{n_K} \right) \log \delta_K + \frac{1}{2} + o(1).
\end{align*}
\]
Thus the right hand side of (1.1) is
\[
n_K \sqrt{\frac{x}{n_K}} \left[ \frac{1}{4} \log^2 x - \log x \log \log x + \left[ \log \delta_K + \log \left( \frac{e^\nu}{n_K} \right) \right] \log x + (\log \log x)^2 \\
- 2 \left[ \log \delta_K + \log \left( \frac{\nu}{n_K} \right) \right] \log \log x + (2 \log \left( \frac{\nu}{n_K} \right) + 7.9584) \log \delta_K + \log^2 \left( \frac{\nu}{n_K} \right) - 5.9938 \\
+ 25.5362 \sqrt{x} + o(\sqrt{x}).
\]
Since \( \nu \approx 15.7187 \ldots \) the coefficient of \( n_K \sqrt{\frac{x}{n_K}} \log x \) is lower than \( \log \delta_K \) if \( n_K \geq 16 \).
We have verified that the first five terms in the asymptotic expansion cannot be improved by any choice of the parameters. On the other hand, the sixth term contains the constants 7.9584, -5.9938 and 25.5362 which can be changed acting on the parameters.
The constants hidden in the \( o(.) \) terms are unfortunately not uniform in \( K \) and are not even controlled by a linear bound in \( n_K \) and \( \log \Delta_K \): for instance, the rather innocent looking \( \frac{n_K \sqrt{x}}{2\pi} \) is asymptotic to \( \frac{2}{(\sqrt{3}-1)^n} n_K^2 \log x \).
To facilitate the comparison with earlier results, we reorganize this asymptotic expansion in a form similar to Lagarias and Odlyzko’s or Oesterlé’s results. In this form, the right hand side of (1.1) is
\[
\begin{align*}
&= \frac{\sqrt{x}}{2\pi} \left[ \log x - 2 \log \log x + 2 \log \left( \frac{\nu}{n_K} \right) + 7.9584 \right] \log \Delta_K \\
&\quad + \frac{\sqrt{x}}{8\pi} \left[ \log^2 x - 4 \log x \log \log x + 4 \log \left( \frac{e^\nu}{n_K} \right) \log x + 4(\log \log x)^2 - 8 \log \left( \frac{\nu}{n_K} \right) \log \log x \\
&\quad \quad + 4 \log^2 \left( \frac{\nu}{n_K} \right) + 4 - 23.9752 \right] n_K + 25.5362 \frac{\sqrt{x}}{\pi} + o(\sqrt{x}) \\
&\quad + 5.9938 \right] n_K + 25.5362 \frac{\sqrt{x}}{\pi} + o(\sqrt{x}) \\
&= \frac{\sqrt{x}}{2\pi} \left[ \log \left( \frac{e^\nu}{n_K^2} \frac{x}{\log^2 x} \right) + 5.9584 \right] \log \Delta_K \\
&\quad + \frac{\sqrt{x}}{8\pi} \left[ \log^2 \left( \frac{x}{\log^2 x} \right) + 4 \log \left( \frac{e^\nu}{n_K} \right) \log \left( \frac{x}{\log^2 x} \right) + 4 \log^2 \left( \frac{e^\nu}{n_K} \right) - 8 \log \left( \frac{\nu}{n_K \log x} \right) - 27.9752 \right] n_K \\
&\quad + 25.5362 \frac{\sqrt{x}}{\pi} + o(\sqrt{x}) \\
&= \frac{\sqrt{x}}{2\pi} \left[ \log \left( \frac{e^\nu}{n_K^2} \frac{x}{\log^2 x} \right) + 5.9584 \right] \log \Delta_K \\
&\quad + \frac{\sqrt{x}}{8\pi} \left[ \log^2 \left( \frac{e^\nu}{n_K^2} \frac{x}{\log^2 x} \right) - 4 \log \left( \frac{e^\nu}{n_K^2} \frac{1}{\log^2 x} \right) - 19.9752 \right] n_K + 25.5362 \frac{\sqrt{x}}{\pi} + o(\sqrt{x}).
\end{align*}
\]
As \( \delta_K \) diverges (1.1) is not very efficient, but still gives something similar to (1.2).

**Numerical experiments.** In [2] we prove the following results. First in Corollary 1.2:

\[
(1.3) \quad \forall x \geq 100, \quad |\psi_K(x) - x| \leq \sqrt{x} \left[ \left( \frac{\log x}{2\pi} + 2 \right) \log \Delta_K + \left( \frac{\log^2 x}{8\pi} + 2 \right) n_K \right].
\]
Then in Corollary 1.3:

\[(1.4) \quad \forall x \geq 3, \quad |\psi_K(x) - x| \leq \sqrt{x} \left[ \left( \frac{1}{2\pi} \log \left( \frac{18.8 x}{\log^2 x} \right) + 2.3 \right) \log \Delta_K + \left( \frac{1}{8\pi} \log^2 \left( \frac{18.8 x}{\log^2 x} \right) + 1.3 \right) n_K + 0.3 \log x + 14.6 \right] \]

and

\[(1.5) \quad \forall x \geq 2000, \quad |\psi_K(x) - x| \leq \sqrt{x} \left[ \left( \frac{1}{2\pi} \log \left( \frac{x}{\log^2 x} \right) + 1.8 \right) \log \Delta_K + \left( \frac{1}{8\pi} \log^2 \left( \frac{x}{\log^2 x} \right) + 1.1 \right) n_K + 1.2 \log x + 10.2 \right]. \]

We compare the upper bound (1.1) to these three formulas for several values of $n_K$ and four discriminants for each $n_K$. We test totally real and totally imaginary fields for the minimal discriminants allowed by Odlyzko’s Table 3 in [4] and for their squares. In each table we indicate the minimal $x$ after which Formula (1.1) is better than the corresponding formula.

One observes that (1.1) is always better than (1.4), nearly always better than (1.3) (except for quadratic fields) and most of the times better than (1.5). The best between (1.1) and (1.2) is always better than (1.3–1.5) except for the case of quadratic fields in Formula (1.3).

| $n_K$ | $\Delta_K$ | (1.3) | (1.4) | (1.5) | $\Delta_K$ | (1.3) | (1.4) | (1.5) |
|-------|-------------|-------|-------|-------|-------------|-------|-------|-------|
| minimal
| 2     | 4.9535     | 187929| 3     | 2000      | 2.9633     | 445897| 3     | 2000      |
|       | 6     | 2.9169 x 10^5| 107   | 3     | 2000      | 9.3896 x 10^3| 106   | 3     | 2000      |
|       | 10    | 2.3927 x 10^11| 100   | 3     | 2000      | 1.8967 x 10^8| 100   | 3     | 2000      |
|       | 20    | 6.5601 x 10^27| 100   | 3     | 2000      | 1.7076 x 10^20| 100   | 3     | 2000      |
|       | 50    | 7.1245 x 10^81| 100   | 3     | 2425      | 2.8528 x 10^39| 100   | 3     | 2306      |
|       | 100   | 1.5472 x 10^177| 100   | 3     | 2713      | 3.0629 x 10^128| 100   | 3     | 2663      |
|       | 200   | 8.0911 x 10^734| 100   | 3     | 2851      | 2.1888 x 10^271| 100   | 3     | 2843      |

| square
| 2     | 2.4538 x 10^14| 250000| 3     | 2000      | 8.7813     | 81922 | 3     | 2000      |
|       | 6     | 8.5086 x 10^10| 100   | 3     | 2000      | 8.8164 x 10^7| 100   | 3     | 2000      |
|       | 10    | 5.7250 x 10^22| 100   | 3     | 2000      | 3.5975 x 10^16| 100   | 3     | 2000      |
|       | 20    | 4.3035 x 10^35| 100   | 3     | 2074      | 2.9158 x 10^40| 100   | 3     | 2000      |
|       | 50    | 5.0759 x 10^163| 100   | 3     | 2597      | 8.1386 x 10^118| 100   | 3     | 2532      |
|       | 100   | 2.3937 x 10^354| 100   | 3     | 2757      | 9.3814 x 10^256| 100   | 3     | 2745      |
|       | 200   | 6.5467 x 10^749| 100   | 3     | 2830      | 4.7910 x 10^542| 100   | 3     | 2844      |
From when does the best of (1.1) and (1.2) get better than (1.3 – 1.5)

| $n_K$ | $\Delta_K$ | $\Delta_K$ |
|-------|-------------|-------------|
|       | real        | imaginary   |
| 2     | 4.9535      | 187929      | 2.9633      | 445897      |
| 6     | 2.9169$\times10^{5}$ | 100 | 3 | 2000 | 9.3896$\times10^{3}$ | 100 | 3 | 2000 |
| 10    | 2.3927$\times10^{11}$ | 100 | 3 | 2000 | 1.8967$\times10^{8}$ | 100 | 3 | 2000 |
| 20    | 6.5601$\times10^{27}$ | 100 | 3 | 2000 | 1.7076$\times10^{20}$ | 100 | 3 | 2000 |
| 50    | 7.1245$\times10^{81}$ | 100 | 3 | 2000 | 2.8528$\times10^{59}$ | 100 | 3 | 2000 |
| 100   | 1.5472$\times10^{177}$ | 100 | 3 | 2000 | 3.0629$\times10^{128}$ | 100 | 3 | 2000 |
| 200   | 8.0911$\times10^{374}$ | 100 | 3 | 2000 | 2.1888$\times10^{271}$ | 100 | 3 | 2000 |

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2. Reproofs

We reprove the results of [1] and [2] adding an additional parameter to the main result of [2] and with a couple more digits. The methods of proof are the same and will thus not be repeated.

We recall that $r_K$ is defined as the constant such that

$$\frac{\zeta_K'}{\zeta_K}(s) = \frac{r_1+r_2-1}{s}+r_K+O(s) \quad \text{as } s \to 0.$$ 

Lemma 2.1. Assume GRH. One has

$$|r_K| \leq 1.0155 \log \Delta_K - 2.1042 n_K + 8.3423 - e_K$$

where

$$e_K := \begin{cases} 
4.4002 & \text{if } (r_1, r_2) = (1, 0) \\
0.6931 & \text{if } (r_1, r_2) = (0, 1) \\
0 & \text{otherwise}.
\end{cases}$$

Proof. The proof of Lemma 3.1 in [1] gives the general case. Moreover, for $\mathbb{Q}$ we know that $r_0 = \log 2\pi$. For imaginary quadratic fields, an $r_2 \log 2$ term can be restored in the proof of the aforementioned lemma.

Lemma 2.2. Assume GRH. One has

$$\sum_{|\gamma| \leq 5} \frac{1}{|\rho|} \leq 1.0111 \log \Delta_K - 1.6550 n_K + 7.0320.$$ 

Proof. see Lemma 3.1 in [2].
As in [2] we will denote \( W_\kappa(T) := \log \Delta_\kappa + n_\kappa \log \left( \frac{T}{\pi} \right) \); this is obviously not the Lambert \( W \) function, and we believe that there is no risk of confusion.

**Lemma 2.3.** We have, for all \( T \geq 5 \),

\[
\begin{align*}
(2.1a) & \quad \sum_{|\gamma| \leq T} \frac{1}{|\gamma|^2} \leq \frac{1}{\pi} \left( 1 + \frac{1.4427}{T} \right) W_\kappa(T) - \frac{T}{\pi} \left( 1 - \frac{8.9250}{T} \right) n_\kappa + \frac{8.6542}{\pi}, \\
(2.1b) & \quad \sum_{|\gamma| \geq T} \frac{1}{|\rho|^2} \leq \left( 1 + \frac{2.8854}{T} \right) W_\kappa(T) + \left( 1 + \frac{18.6019}{T} \right) n_\kappa + \frac{17.3084}{\pi T^2}, \\
(2.1c) & \quad \sum_{|\rho| \leq T} \frac{\pi}{|\rho|^2} \leq \left( \log \left( \frac{T}{2\pi} \right) + 3.9792 \right) \log \Delta_\kappa + \left( \frac{1}{2} \log^2 \left( \frac{T}{2\pi} \right) - 1.4969 \right) n_\kappa + 25.5362.
\end{align*}
\]

**Proof.** These are just First sum, Second sum and Third sum, in [2] with more digits. To prove (2.1c), we use Lemma 2.2 instead of Lemma 3.1 of [2]. \( \square \)

**Lemma 2.4.** Let

\[
\begin{align*}
R_{r_1,r_2}(x) := -(r_1 + r_2 - 1)(x \log x - x) + r_2 \log x - (r_1 + r_2) f_1(x) - r_2 f_2(x).
\end{align*}
\]

Let \( x \geq 3 \), then

\[
-(r_1 + r_2 - 1) \log x \leq R'_{r_1,r_2}(x) \leq -\delta_{r_1,0} \log(1-x^{-2})-\delta_{r_2,0} \log(1-x^{-1})
\]

where \( \delta_{r_1,0} \) is 1 if and only if both indices are equal and 0 otherwise.

**Proof.** See Lemma 2.2 in [2]. \( \square \)

We now restate Theorem 1.1 of [2].

**Theorem 2.5.** For every \( x \geq 3 \), \( T \geq 5 \) and \( 0 < \kappa \leq 2 \) we have:

\[
\left| \psi_\kappa(x) - x + \sum_{|\gamma| < T} \frac{x^\rho}{\rho} \right| \leq \frac{\sqrt{x}}{\kappa} \left[ \frac{2}{\kappa} + \frac{\kappa}{2} \left( \frac{1.4427 \kappa^2 + 3 \kappa + 11.5416}{2 \kappa T} + \frac{0.5915 \kappa + 4.3282}{T} \right) \right] W_\kappa(T) + \frac{\sqrt{x}}{\kappa} \left[ \frac{2}{\kappa} + \frac{\kappa}{2} \left( \frac{8.9250 \kappa^2 + 3 \kappa + 74.4076}{2 \kappa T} + \frac{1.7702 \kappa + 27.9029}{T} \right) \right] n_\kappa + \frac{\kappa x}{2 T} \left[ \frac{1.3774 \kappa^2 + 11.0190}{\kappa T} + \frac{0.4133 \kappa + 8.2643}{T} \right] + |r_\kappa| + \tilde{c}_\kappa(x, T)
\]

where

\[
\tilde{c}_\kappa(x, T) := \begin{cases} - \log(1-x^{-2}) & \text{if } (r_1, r_2) = (1,0), \\ - \log(1-x^{-1}) & \text{if } (r_1, r_2) = (0,1), \\ \max(0, d_\kappa \log x - 3.6133 n_\kappa \sqrt{T}) & \text{otherwise}. \end{cases}
\]

**Proof.** The proof proceeds as for [2] Theorem 1.1], but now we choose \( h = \pm \frac{2\pi}{\kappa} \) with \( \kappa \in (0,2] \) instead of \( h = \pm \frac{2\pi}{\kappa} \). We start from [2] Inequality (4.2)] which, given the small modification of Lemma 2.4 above, now reads:

\[
-(r_1 + r_2 - 1) \log x
\]
\[
\begin{align*}
\frac{\psi^{(1)}(x+h) - \psi^{(1)}(x)}{h} & \leq (x + \frac{h}{2}) - \sum_{\rho} (x+h)^{\rho} - x^{\rho} + \frac{1}{h\rho(\rho+1)} - \frac{r_{\rho K}}{h}
\end{align*}
\]
\[
\leq -\delta_{(r,1)}(1.0) \log(1-x^{-2}) - \delta_{(r,2)}(0.1) \log(1-x^{-1}).
\]

As seen in [2, Section 4], under GRH we have
\[
\left| \sum_{|\gamma| \geq T} \frac{(x+h)^{\rho} - x^{\rho}}{h\rho(\rho+1)} \right| \leq \sum_{|\gamma| \geq T} x^{\frac{h}{2} \bar{\gamma} + \frac{1}{2}} \left( \frac{1+\frac{h}{2}}{h} \right)^{\frac{1}{2}} \leq A \frac{x^{\frac{h}{2}}}{h} \sum_{|\gamma| \geq T} \frac{1}{|\rho|^2},
\]
with \( A := 1 + \left(1 + \frac{h}{T}\right)^{\frac{3}{2}} \). For \( h > 0 \), we take \( h = \frac{\pi}{T} \) thus
\[
A = 1 + \left(1 + \frac{\kappa}{T}\right)^{\frac{3}{2}} \leq 2 + \frac{3\kappa}{2T} + \frac{3\kappa^2}{8T^2}.
\]

From Lemma 2.1 in [2] we know that \(|w_\rho| \leq \frac{1}{2}\) hence by (2.1b) and (2.1a)
\[
\frac{\pi}{\sqrt{T}} \sum_{\rho} \frac{(x+h)^{\rho} - x^{\rho}}{h\rho(\rho+1)} - \sum_{|\gamma| < T} \frac{x^{\rho}}{\rho} \leq \left[ \frac{2}{\kappa^2} \frac{3}{2T} \frac{3\kappa}{8T^2} \right] \left[ \left(1 + \frac{2.8854}{T}\right) \frac{W_K(T)}{\pi T} + \left(1 + \frac{18.6019}{T}\right) \frac{n_K}{\pi T} + \frac{17.3084}{T} \right] + \frac{\kappa}{2} \left[ \left(1 + \frac{1.4427}{T}\right) W_K(T) - \left(1 - \frac{8.9250}{T}\right) \frac{n_K}{T} + \frac{8.6542}{T} \right] = \left[ \left(1 + \frac{2}{\kappa^2} + \frac{3}{2T} + \frac{3\kappa}{8T^2}\right) \left(1 + \frac{2.8854}{T}\right) + \frac{\kappa}{2} \left(1 + \frac{1.4427}{T}\right) \right] W_K(T) + \left[ \left(1 + \frac{2}{\kappa^2} + \frac{3}{2T} + \frac{3\kappa}{8T^2}\right) \left(1 + \frac{18.6019}{T}\right) - \frac{\kappa}{2} \left(1 - \frac{8.9250}{T}\right) \right] n_K + \frac{17.3084}{T} + \frac{4.3271 \frac{\kappa}{T}}{2T^2}.
\]

After some simplifications it becomes, for \( T \geq 5 \),
\[
\frac{\pi}{\sqrt{T}} \sum_{\rho} \frac{(x+h)^{\rho} - x^{\rho}}{h\rho(\rho+1)} - \sum_{|\gamma| < T} \frac{x^{\rho}}{\rho} \leq \left[ \frac{2}{\kappa^2} + \frac{1.4427 \kappa^2 + 3\kappa + 11.5416}{2\kappa T} + \frac{0.5915 \kappa + 4.3281}{T^2} \right] W_K(T) + \left[ \frac{2}{\kappa^2} - \frac{8.9250 \kappa^2 + 3\kappa + 74.4076}{2\kappa T} + \frac{1.7702 \kappa + 27.9029}{T^2} \right] n_K + \frac{4.3271 \kappa^2 + 34.6168}{\kappa T} + \frac{1.2982 \kappa + 25.9626}{T^2}.
\]
which is an analogous of [2 Equation (4.3)].

For $h < 0$, we take $h = -\frac{\kappa}{T}$, then we have $x + h > 1$ if $\kappa \leq 3$, $x \geq 3$ and $T \geq 5$. We slightly modify the bound for $A$ in that case and take

$$A = 1 + \left(1 - \frac{\kappa}{T}\right)^{\frac{3}{2}} \leq 2 - \frac{3\kappa}{2T} + \frac{\kappa^2}{2T^2}.$$

We still have $|w_\rho| \leq \frac{1}{2} + \frac{\kappa}{6T}$ and Equation (4.4) of [2] becomes for $T \geq 5$

$$(2.3) \quad \frac{\pi}{\sqrt{x}} \left| \sum_{\rho} \frac{(x+h)^{\rho+1} - x^{\rho+1}}{h^\rho(\rho+1)} \sum_{|\gamma|<T} x^\rho \right| \leq \frac{\pi}{\sqrt{x}} \left[ \frac{2}{\kappa} + \frac{\kappa^3/3 + 1.4427\kappa^2 - 3\kappa + 11.5416}{2\kappa T} \right] W_\kappa(T) + \frac{\pi}{\sqrt{x}} \left[ \frac{2}{\kappa} + \frac{-\kappa^3/3 + 8.9250\kappa^2 - 3\kappa + 74.4076}{2\kappa T} \right] W_\kappa(T) + \frac{\pi}{\sqrt{x}} \left( \frac{4.3271\kappa^2 + 34.6168}{\kappa T} \right) \left( \frac{1.4424\kappa^2 + 1.7309\kappa - 25.9626}{T^2} \right) n_\kappa.

Let $M_{W,\pm}(T)$, $M_{n,\pm}(T)$ and $M_{c,\pm}(T)$ be the functions of $T$ such that the right hand side of (2.2) and (2.3) respectively are

$$M_{W,\pm}(T)W_\kappa(T) + M_{n,\pm}(T)n_\kappa + M_{c,\pm}(T),$$

and their differences let be denoted as

$$D_W(T) := M_{W,+}(T) - M_{W,-}(T) = \frac{18 - \kappa^2}{6T} + \frac{8.6562 - 0.1971\kappa - 0.2405\kappa^2}{T^2},$$

$$D_n(T) := M_{n,+}(T) - M_{n,-}(T) = \frac{18 + \kappa^2}{6T} + \frac{55.8057 - 0.5900\kappa - 1.4875\kappa^2}{T^2},$$

$$D_c(T) := M_{c,+}(T) - M_{c,-}(T) = \frac{51.9252 - 0.4327\kappa - 1.4424\kappa^2}{T^2}.$$

We then have

$$\left| \psi_\kappa(x) - x + \sum_{|\gamma|<T} x^\rho \right| \leq \frac{\sqrt{T}}{\pi} \left( M_{W,+}(T)W_\kappa(T) + M_{n,+}(T)n_\kappa + M_{c,+}(T) \right) + \frac{\kappa T}{2T} |r_\kappa| + \frac{\kappa T}{2T} |\delta_{(r_1, r_2)}(1.0)| \log(1-x^{-2}) + \frac{\kappa T}{2T} |\delta_{(r_1, r_2)}(0,1)| \log(1-x^{-2}) + \max \left( 0, (r_1 + r_2 - 1) \log x - \frac{\sqrt{T}}{\pi} \left( D_W(T)W_\kappa(T) + D_n(T)n_\kappa + D_c(T) \right) \right).$$

The claim follows if $d_\kappa = 0$ since $D_W(T)$, $D_n(T)$ and $D_c(T) \geq 0$ ($D_c$ and the coefficients of $1/T^2$ in $D_n$ and $D_W$ are positive $\forall \kappa \in [-6, 4]$). If $d_\kappa > 0$ we have $\frac{1}{n_\kappa} \log \Delta_\kappa \geq \frac{1}{2} \log 5$ thus

$$D_W(T) \frac{W_\kappa(T)}{n_\kappa} + D_n(T) \geq \left( \frac{18 - \kappa^2}{6T} + \frac{8.6562 - 0.1971\kappa - 0.2405\kappa^2}{T^2} \right) \log \left( \frac{\sqrt{T}}{2\pi} \right) + \frac{18 + \kappa^2}{6T} + \frac{55.8057 - 0.5900\kappa - 1.4874\kappa^2}{T^2} \geq \frac{3.6133\pi}{T}.$$
when $T \geq 5$ and $0 \leq \kappa \leq 2$. □

3. Proof of Theorem 1.1

By Equation (2.1c) we have for $T \geq 5$

$$
\sum_{|\gamma|<T} \frac{x^\beta}{\rho} \leq \frac{\sqrt{x}}{\pi} \left[ \left( \log \frac{T}{2\pi} + \alpha \right) \log \Delta_K + \left( \frac{1}{2} \log^2 \frac{T}{2\pi} + \beta \right) n_K + \gamma \right]
$$

with $\alpha = 3.9792$, $\beta = -1.4969$ and $\gamma = 25.5362$. Recalling the upper bound for $|\xi_K|$ in Lemma 2.1 from the result in Theorem 2.5 and (3.1) we deduce that for $x \geq 3$ and $T \geq 5$,

$$
|\psi_{\xi_K}(x) - x| \leq \left( \frac{\sqrt{x}}{\pi} F(T) + 1.0155 \right) \log \Delta_K + \left( \frac{\sqrt{x}}{\pi} G(T) - 2.1042 \right) n_K + H(x, T)
$$

with

$$
F(T) := \log \left( \frac{T}{2\pi} \right) + \frac{2}{\kappa} \frac{\kappa}{2} + \frac{1.4427\kappa^2 + 3\kappa + 11.5416}{2\kappa T} + \frac{0.5915\kappa + 4.3282}{T^2} + \alpha,
$$

$$
G(T) := \frac{1}{2} \log^2 \left( \frac{T}{2\pi} \right) + \frac{2}{\kappa} \frac{\kappa}{2} + \frac{1.4427\kappa^2 + 3\kappa + 11.5416}{2\kappa T} + \frac{0.5915\kappa + 4.3282}{T^2} \log \left( \frac{T}{2\pi} \right),
$$

$$
H(x, T) := \frac{\kappa x}{2T} + \frac{\sqrt{x}}{\pi} \left[ \frac{\kappa + 1.3774\kappa^2 + 11.0190}{\kappa T} + \frac{0.4133\kappa + 8.2643}{T^2} \right] + 8.3423 + \epsilon_{\xi_K}(x, T).
$$

We need to choose $T$ to get the lowest possible bound for $|\psi_{\xi_K}(x) - x|$, thus we choose the best $T$ by looking for an approximate zero of

$$
\frac{\partial}{\partial T} \left( \frac{\sqrt{x}}{\pi} F(T) \log \Delta_K + \frac{\sqrt{x}}{\pi} G(T) n_K + H(x, T) \right)
$$

above 5. Unfortunately we are not able to find $T$ as an explicit function of $x$.

Both $T \mapsto F(T)$ and $T \mapsto G(T)$ have a unique minimum while $T \mapsto H(x, T)$ is decreasing for any $x > 0$. The main increasing terms are $\frac{\sqrt{x}}{\pi} \left[ \log \left( \frac{T}{2\pi} \right) + \frac{\kappa + 1}{\kappa} \right] n_K$ from $F(T)$, and $\frac{\sqrt{x}}{\pi} \left[ \log \left( \frac{T}{2\pi} \right) + \frac{\kappa + 1}{\kappa} \right] \log \Delta_K$ from $F(T)$, while the main decreasing term is $\frac{\kappa x}{2T}$ from $H(x, T)$.

The derivative of the sum of these three terms is zero for $T \log \left( \frac{\kappa x + 2\kappa T}{2\pi} \right) = \frac{\kappa x}{2n_K}$, we should thus choose

$$
T = T_W := \frac{2\pi}{\delta_{\xi_K} e^{\frac{x}{\kappa} + \frac{\kappa}{2}}} W \left( \frac{\kappa x + 2\kappa \sqrt{x}}{4\kappa} \right) = \frac{\kappa \pi}{2n_K} W \left( \frac{\kappa x + 2\kappa \sqrt{x}}{4\kappa} \right).
$$

However, for $\delta_{\xi_K} \to \infty$ we have $T_W \to 0$. We thus slightly complicate the expression we are trying to minimize: this will have the effect to give a minimum that is both more precise and above 5. The expressions contain the parameter $\kappa$, which has to be fixed. To find a good value for $\kappa$, we computed the asymptotic expansion of the result with optimal $T$ and $\kappa$ unevaluated but independent of $x$. This is

$$
\frac{\sqrt{x}}{2\pi} \left( \log^2 \frac{x}{4} - \log x \log \log x + \left( \log \delta_{\xi_K} + \log \left( \frac{\kappa x + 2\kappa}{2\pi n_K} \right) + 1 \right) \log x + o(\log x) \right) n_K,
$$
so that the best value for $\kappa$ is the one minimizing $\kappa e^{\frac{\kappa}{2} + \frac{\kappa^2}{8}}$, i.e. $\sqrt{5} - 1$. Thus, to ease a little bit the computations, we set $\kappa = \sqrt{5} - 1$ right now, and we retain the symbol $\kappa$ only in those terms which will contribute to the main part of the result. Notice that $\frac{2}{\kappa} + \frac{\kappa}{2} = \sqrt{5}$ and $\frac{1}{\kappa} - \frac{\kappa}{2} = 1$ and that (3.2) and (3.3) give

$$F(T) \leq \log \left( \frac{T}{2\pi} \right) + \frac{2}{\kappa} \sigma + \frac{\kappa^2}{2} + \frac{7.0604}{T} + \frac{5.0593}{T^2} + 3.9792,$$

$$G(T) \leq \frac{1}{2} \left( \log \left( \frac{T}{2\pi} \right) \right) + \left( \frac{2}{\kappa} \sigma + \frac{\kappa^2}{2} + \frac{7.0604}{T} + \frac{5.0593}{T^2} \right) \log \left( \frac{T}{2\pi} \right)$$

$$-2.9969 + \frac{37.1145}{T} + \frac{30.0910}{T^2} + \frac{\kappa \pi \sqrt{T}}{2n_K T} + \frac{1}{n_K} \left( 25.5362 + \frac{33.3542}{T} + \frac{27.5673}{T^2} \right) + 8.3423 + e_K(x, T).$$

We have kept $\kappa$ in all terms which will contribute to the highest order terms of the asymptotic expansion in $x$, in order to make explicit the role of this parameter on the final quality of the result.

Since $e_K$ is small with respect to most other parameters and not differentiable, we remove it from the optimization process. Let then

$$E_0(x, T) := F(T) \log \delta_K + G(T) + \frac{\pi}{n_K \sqrt{x}} (H(x, T) - e_K(x, T))$$

$$\leq \left( \log \left( \frac{T}{2\pi} \right) \right) + \frac{2}{\kappa} \sigma + \frac{\kappa^2}{2} + \frac{7.0604}{T} + \frac{5.0593}{T^2} + 3.9792 \log \delta_K$$

$$+ \frac{1}{2} \left( \log \left( \frac{T}{2\pi} \right) \right) + \left( \frac{2}{\kappa} \sigma + \frac{\kappa^2}{2} + \frac{7.0604}{T} + \frac{5.0593}{T^2} \right) \log \left( \frac{T}{2\pi} \right)$$

$$-2.9969 + \frac{37.1145}{T} + \frac{30.0910}{T^2} + \frac{\kappa \pi \sqrt{T}}{2n_K T} + \frac{1}{n_K} \left( 25.5362 + \frac{33.3542}{T} + \frac{27.5673}{T^2} \right) + 8.3423 + \epsilon_K(x, T)$$

$$\leq \frac{1}{2} \left( \log \left( \frac{T}{2\pi} \right) \right) + \frac{\kappa^2}{2} + \frac{\kappa^2}{2} + \frac{2}{\kappa} \sigma \log \delta_K$$

$$+ \left( \frac{7.0604}{T} + \frac{5.0593}{T^2} \right) \left( \log \left( \frac{T}{2\pi} \right) \right) + \frac{\kappa \pi \sqrt{T}}{2n_K T} + \frac{21.3270}{T} + \frac{18.7781}{T^2} + \frac{1}{n_K} \left( 33.3542 + \frac{27.5673}{T^2} \right)$$

$$+ 3.9792 \log \delta_K - 2.9969 + \frac{25.5362}{n_K} + \frac{8.3423}{\pi} n_K \sqrt{x}$$

(3.4) $$=: E(x, T).$$

It is obvious that $\lim_{T \to \infty} E(x, T) = \infty$. We have

$$\frac{\partial E(x, T)}{\partial T} = \left( \frac{1}{T} - \frac{7.0604}{T^2} - \frac{10.1186}{T^3} \right) \left( \log \left( \frac{T}{2\pi} \right) + \frac{2}{\kappa} \sigma + \log \delta_K \right)$$

$$- \left[ \frac{14.2666}{T^2} + \frac{32.4969}{T^3} + \frac{1}{n_K} \left( 33.3542 + \frac{55.1346}{T^3} \right) + \frac{\kappa \pi \sqrt{x}}{2n_K T} \right].$$
Let \( T_F = 8.282137 \ldots \) be the positive root of \( T^2 - 7.0604T - 10.1186 \) (which is where the estimate of \( F \) reaches its minimum). We obviously have \( \frac{\partial E(x, T)}{\partial T} \big|_{T=T_F} < 0 \) and \( \frac{\partial E(x, T)}{\partial T} = 0 \) when

\[
(T - 7.0604 - \frac{10.1186}{T}) \left( \log \left( \frac{T}{2\pi} \right) + \frac{2}{\kappa} + \frac{\kappa}{2} \log \delta_K \right) = \frac{\kappa \pi \sqrt{x}}{2n_K} + 14.2666 + \frac{32.4969}{T} + \frac{1}{n_K} \left( 33.3542 + \frac{55.1346}{T} \right).
\]

The left hand side of this equation is increasing for \( T > T_F \) and maps \([T_F, +\infty)\) onto \([0, +\infty)\) while the right hand side is decreasing for \( T > 0 \) thus the equation has a single solution for \( T > T_F \). Thus for given \( K \) and \( x \), \( E(x, T) \) has a single local minimum for some \( T > T_F \) and this minimum is reached for the unique \( T > T_F \) satisfying (3.5). The solutions (in \( T \)) of (3.5) can unfortunately not be expressed with standard analytic functions. We thus slightly modify (3.5) to have a solution with a nice expression in terms of the Lambert-\( W \) function.

We will discuss in Remark 1 below the effect of the change we made to the equation.

Suppose we have found a \( T_0 \) satisfying

\[
(T_0 - 7.0604 - \frac{10.1186}{T_0}) \left( \log \left( \frac{T_0}{2\pi} \right) + \frac{2}{\kappa} + \frac{\kappa}{2} \log \delta_K \right) = \frac{\kappa \pi \sqrt{x}}{2n_K} + 21.3270 + \frac{33.5251}{n_K}.
\]

Denote

\[
w := \log \left( \frac{T_0}{2\pi} \right) + \frac{2}{\kappa} + \frac{\kappa}{2} \log \delta_K
\]

so that

\[
\frac{\kappa \pi \sqrt{x}}{2T_0 n_K} + \frac{21.3270}{T_0} + \frac{33.3542}{T_0 n_K} = \left( 1 - \frac{7.0604}{T_0} - \frac{10.1186}{T_0^2} \right) w.
\]

Then

\[
E(x, T_0) = \frac{1}{2} w^2 + w - \frac{1}{2} \log^2 \delta_K + \frac{18.7781 + \frac{27.5673}{n_K} - 5.0593 w}{T_0^2} + 3.9792 \log \delta_K - 2.9969 + \frac{25.5362}{n_K} + \frac{8.3423 \pi}{n_K \sqrt{x}}
\]

and so, according to Lemma 3.1, see below, it is

\[
\leq \frac{1}{2} (w+1)^2 - \frac{1}{2} \log^2 \delta_K + 3.9792 \log \delta_K - 3.4969 + \frac{25.5362}{n_K} + \frac{8.8590 \pi}{n_K \sqrt{x}}
\]

(3.8)

To have an upper-bound for \( E(x, T_0) \), we can substitute \( T_0 \) in (3.8) by anything greater than \( T_0 \). We define \( T_W \) and redefine \( w \) by

\[
a := \frac{\kappa \pi \sqrt{x}}{2n_K} + 21.3270 + \frac{33.3542}{n_K},
\]

\[
w := W \left( e^{\frac{2}{\kappa} + \frac{\kappa}{2}} \delta_K a \right),
\]
\[ T_W := \frac{2\pi e^w}{\delta_k e^{\frac{2}{\kappa} + \frac{\pi}{\delta_k}}} = \frac{a}{w}, \]

which means that \( T_W \) is the solution of the equation

\[ (3.9) \quad T \left( \log \left( \frac{T}{2\pi} \right) + \frac{2}{\kappa} + \frac{\kappa}{2} \log \delta_k \right) = \frac{\kappa\pi \sqrt{x}}{2n_k} + 21.3270 + \frac{33.3542}{n_k}. \]

Recalling the constant \( T_F \) defined above, \( T_F + T_W \) is larger than \( T_0 \). Indeed, if we replace \( T_0 \) by \( T_F + T_W \) in (3.6), the first factor is bigger than \( T_W \) while the second is bigger than the one in (3.9) so that the left hand side of (3.6) is bigger than its right hand side; since the left hand side is increasing this proves that \( T_F + T_W \geq T_0 \). We now replace \( T_0 \) by \( T_F + T_W \) in (3.8) obtaining

\[ E_0(x, T_0) \leq \frac{1}{2} \left( \log \left( \frac{\delta_k e^{\frac{2}{\kappa} + \frac{\pi}{\delta_k}} T_W + T_F}{2\pi} \right) + 1 \right)^2 + 3.9792 \log \delta_k - 3.4969 + \frac{25.5362}{n_k} + \frac{8.8590\pi}{n_k \sqrt{x}} \]

which is exactly the first claim in Theorem 1.1.

We now proceed for the second inequality (1.2). We fix a value for \( T \), postponing to Remark 2 the reason for this choice. The minimal value for \( F \) is reached when \( (\kappa, T) \simeq (2.141, 7.2773) \) and the actual value is \( \leq 2.2367\pi \). We make a slightly different choice, which is \( \kappa = 2 \) and \( T = 10 \), which increases slightly the coefficient of \( \sqrt{x} \log \Delta_k \) but decreases the coefficient of \( \sqrt{x} n_k \) and \( x \), and makes the formula slightly nicer. We then have

\[ F(T) \leq 2.2543 \pi \]

\[ G(T) \leq 0.9722 \pi \]

which gives

\[ |\psi_k(x) - x| \leq (2.2543 \sqrt{x} + 1.0155) \log \Delta_k + (0.9722 \sqrt{x} - 2.1042)n_k \]

\[ + \frac{x}{10} + 9.0458 \sqrt{x} + 7.0320 + \epsilon_k(x, 10) \]

proving the second claim in Theorem 1.1.

**Remark 1.** We discuss some choices we made for the first bound. Let us call \( T_{\text{min}} \) the zero of (3.5) above \( T_F \). When we define \( T_0 \) from (3.6) we obviously have \( T_0 \neq T_{\text{min}} \). However the difference between the functions appearing on the right hand side of (3.6) and (3.5) is

\[ 7.0604 - \frac{32.4969}{T} - \frac{55.1346}{n_k T}. \]

This means that, to obtain \( T_{\text{min}} \), we should remove from the right hand side of the equation defining \( T_0 \) a quantity that is asymptotic to 7.0604. Hence, to the first order for \( x \to +\infty \), \( T_0 - T_{\text{min}} \sim \frac{7.0604}{\log T_0} \). Thus \( \log T_0 - \log T_{\text{min}} \sim \frac{7.0604}{T_0 \log T_0} \), and \( \frac{1}{2} \log^2 T_0 - \frac{1}{2} \log^2 T_{\text{min}} \sim \frac{7.0604}{T_0} \). This difference produces a term of order \( \frac{n_k \sqrt{x}}{T_0} \simeq n_k \log x \) which is already much smaller than the main terms of the upper bound. On the other hand, when we substitute

\[ \frac{\kappa \pi \sqrt{x}}{2n_k T_{\text{min}}} + 21.3270 + \frac{33.3542}{n_k} \]
The situation where \( \delta \), which differs from \((1.2)\) by \(-\delta\) optimizing a smaller than \(n\) proves it, we chose \(\frac{T_0}{\sqrt{\log n}}\), which now do not tend to 0. However \((1.1)\) is not very good anyway because in several steps we dropped terms in \(-\frac{\delta}{T}\), including a term in \(-\frac{w}{\sqrt{x}}\), which we made affect the coefficient of \(\sqrt{x}\log \delta\) in \((1.2)\), thus to improve the bound it is more efficient, for instance, to increase the minimal value above which Theorem 2.5 is valid or to refine the bounds in Lemma 2.3.

**Remark 2.** One should keep in mind that \((1.2)\) is thought for fixed \(x\) and diverging \(\delta\). To prove it, we chose \(T = 10\). We could have used a technique similar to the one we used for \((1.1)\) optimizing \(T\) in terms of \(\delta\). However this is not worth it, because we would obtain a bound which differs from \((1.2)\) by \((-c_1+o(1))\frac{\sqrt{x}}{\log \delta}\). Meanwhile, all the approximations and choices we made affect the coefficient of \(\sqrt{x}\log \delta\) in \((1.2)\), thus to improve the bound it is more efficient, for instance, to increase the minimal value above which Theorem 2.5 is valid or to refine the bounds in Lemma 2.3.

**Lemma 3.1.** In the settings of the proof of Theorem 1.1,

\[
R := \frac{18.7781 + \frac{27.5673}{n_K} - 5.0593w}{T_0^2} \leq \frac{0.5167\pi}{n_K\sqrt{x}}.
\]

**Proof.** Letting \(L := \frac{2}{n} + \frac{\pi}{2} + \log \delta\) and \(S := \frac{e\sqrt{x}}{2n} + 21.3270 + \frac{33.3542}{n_K}\), we rewrite \((3.6)\) as

\[
f(T_0, L) = S.
\]

Using the implicit function theorem, it is then easy to see that

\[
\frac{\partial w}{\partial L} = \frac{\left(\frac{T_0 + 10.1186}{T_0}\left(\log \left(\frac{T_0}{2\pi}\right) + L\right)\right)}{\left(\frac{T_0 + 10.1186}{T_0}\left(\log \left(\frac{T_0}{2\pi}\right) + L\right)\right)} \geq 0
\]

and that \(\frac{\partial T_0}{\partial w} \geq 0\) and thus \(w\) is increasing with both \(L\) and \(x\). It is thus obvious that \(R\) is decreasing with \(x\). We now prove that, if \(n_K \geq 2\) and \(x\) is fixed, the maximum value of \(R\) is obtained for the minimal discriminant. Indeed we observe that

\[
\frac{\partial R}{\partial L} = \frac{2(\frac{T_0 - 7.0604 - 10.1186}{T_0})(18.7781 + \frac{27.5673}{n_K} - 5.0593w(3T_0 - 2.7.0604 - 10.1186))}{T_0^2((\frac{T_0 + 10.1186}{T_0})(\log \left(\frac{T_0}{2\pi}\right) + L) + (T_0 - 7.0604 - 10.1186))}
\]

which is negative if

\[
\log \delta \geq \frac{2(\frac{T_0 - 7.0604 - 10.1186}{T_0})(18.7781 + \frac{27.5673}{n_K}) - 5.0593w(3T_0 - 2.7.0604 - 10.1186)}{5.0593(3T_0 - 2.7.0604 - 10.1186)} - \log \left(\frac{T_0}{2\pi}\right) - \sqrt{5}.
\]

This is true because as a function of \(T_0\) the right hand side has a maximum value equal to 0.1366 \ldots (attained for \(n_K = 2\) and \(T_0 \approx 21.2153\)) while \(\log \delta \geq \frac{1}{x}\log 3\).

For each degree, we thus just need to bound \(R\) for the field with minimal absolute discriminant. For the first few \(n_K\) we determine the lowest possible value for \(\Delta_K\) using the “megrez” number field tables \([5]\) and for \(n_K \geq 8\) we use Odlyzko’s Table 3 in \([4]\).

For any increasing sequence \((x_n)\) let \(c_n := \frac{n_K\sqrt{x_n + 1}}{n}R(x_n)\). Since \(R\) is decreasing in \(x\) and \((x_n)\) is increasing, if \(c_{\text{max}} := \max c_n\), we have

\[
\forall x, \quad R(x) \leq \frac{c_{\text{max}}\pi}{n_K\sqrt{x}}
\]
We use the sequence \((x_n)\) defined as follows:

\[
x_1 := 3, \quad x_{n+1} := \begin{cases} 
1 & \text{if } x_n \in [3,5000) \\
10 & \text{if } x_n \in [5000, 10^4) \\
100 & \text{if } x_n \in [10^4, 10^5) \\
x_n & \text{otherwise.}
\end{cases}
\]

The table below shows the values of \(c_{\text{max}}\) for each degree, the point \(x_{n_{\text{max}}}\) where it is reached and the total number of points we compute (we stop as soon as \(R(x_n) < 0\)). For \(n_K \geq 9\), we used the general formula for \(n_K = 9\) with \(S = 21.3270\) and \(T_0 = T_F\), which ensures that the result is valid for all \(n_K \geq 9\).

| \(n_K\) | \(c_{\text{max}}\) | \(x_{n_{\text{max}}}\) | \(n_{\text{points}}\) |
|---|---|---|---|
| 1 | 0.2110 | 2810 | 6411 |
| 2 | 0.4644 | 4350 | 6402 |
| 3 | 0.5167 | 3986 | 6398 |
| 4 | 0.4443 | 2927 | 5809 |
| 5 | 0.1325 | 694 | 4177 |
| 6 | 0.0144 | 63 | 280 |
| 7 | < 0 | 3 | 1 |
| 8 | < 0 | 3 | 1 |
| \(\geq 9\) | < 0 | 3 | 1 |

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