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WACŁAW SIERPIŃSKI

ELEMENTARY THEORY OF NUMBERS

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"The elementary theory of numbers should be one of the very best subjects for early mathematical instruction. It demands very little previous knowledge, its subject matter is tangible and familiar; the processes of reasoning which it employs are simple, general and few; and it is unique among the mathematical sciences in its appeal to natural human curiosity."

*G. H. Hardy**

PREFACE

Contemporary mathematics comprises a number of branches whose traditional brief names, established for centuries, give no hint as to their actual scope and subject. This applies also to the Theory of Numbers, which, by the way, owing to its subject and methods, as well as its relation to other sciences, takes a special place among the various branches of mathematics.

The name of the Theory of Numbers might suggest that it is a kind of general theory concerning the notion of number and its generalisations which, starting from integers, introduces successively rational, real and complex numbers, and also some other kinds of numbers, and builds up a theory of operations on these numbers. This, however, is the subject of Higher Arithmetic. The subject of the Theory of Numbers is more special. It is concerned with the properties of integers, while the concept of integers and the theory of operations on them are taken ready-made from Higher Arithmetic and Algebra. However, the Theory of Numbers does not deal exclusively with integers. Many properties of integers have been discovered with the aid of irrational or complex numbers and many theorems about integers can be proved in a much simpler way if one makes use not only of irrational or complex numbers but also of the whole apparatus of the Calculus and the Theory of Functions. The part of the Theory of Numbers which makes extensive use of various parts of Analysis is called the Analytic Theory of Numbers, to be distinguished from the Elementary Theory of Numbers, which does not use the notion of limit.

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* Bull. Amer. Math. Soc. 35 (1929), p. 818.

The subject of this book is the Elementary Theory of Numbers, though a number of simple applications of the Analytic Theory of Numbers are also included. The book is prepared on the basis of two of my books issued between the years 1914 and 1959. These are

Teoria Liczb (Theory of Numbers), first edition, Warszawa 1914; second edition, Warszawa 1925; enlarged third edition, Warszawa-Wrocław 1950 (544 pages),

Teoria Liczb, Part II, Warszawa 1959 (487 pages).

To illustrate the progress which the Theory of Numbers has made in the last decade, it is sufficient to recall that the greatest prime number that was known in the year 1950 was $2^{127}-1$ of 39 digits and compare it with the number $2^{9691}-1$ of 2917 digits—the greatest prime number known to-day. In 1950 only 12 perfect numbers were known; to-day we know 21 of them.

In this book I have included various particular results of the Elementary Theory of Numbers that have been found in recent years in many countries.

I would like to express my thanks to Dr A. Hulanicki, who translated the manuscript of the book into English, to Doc. Dr A. Schinzel, who prepared the bibliography and added many valuable suggestions and footnotes concerning the results obtained recently, and to Dr A. Mąkowski, who helped me in reading the proofs. It is a pleasure to offer my thanks to Mrs. L. Izertowa, the editor of the book on behalf of PWN, who contributed so much to the preparation of the book so that it can be issued in the present form.

Wacław Sierpiński

Warsaw, May 1963

CHAPTER I

DIVISIBILITY AND INDETERMINATE EQUATIONS OF FIRST DEGREE

§ 1. Divisibility. By *natural numbers* we mean the numbers $1, 2, \ldots$, by *integers* we mean the natural numbers, the number zero and the negative numbers $-1, -2, -3, \ldots$

We say that an integer a is *divisible* by an integer b if there is an integer c such that $a = bc$. We then write

$$b \mid a.$$

We call b a *divisor* of a and a a *multiple* of b.

We write $b \nmid a$ if b does not divide a.

Since for each integer b we have $0 = 0\cdot b$, every integer is a divisor of zero. Since for each integer a we have $a = a\cdot 1$, we see that 1 is a divisor of every integer.

Suppose now that x, y, z are integers such that

$$(1) \qquad x \mid y \quad \text{and} \quad y \mid z.$$

Then there exist integers t and u such that $y = xt$ and $z = yu$. The number $v = tu$ is an integer (as the product of two integers). Thus, since $z = xv$, we obtain $x \mid z$. This proves that relations (1) imply the relation $x \mid z$ which means that a divisor of a divisor of an integer is a divisor of that integer. We express this by saying that the relation of divisibility of integers is *transitive*. It follows that if $x \mid y$, then $x \mid ky$ for every integer k.

It is easy to prove that a divisor of each of two given integers is a divisor of their sum and their difference. Moreover, if $d \mid a$ and $d \mid b$, then, for arbitrary integers x and y, $d \mid ax+by$.

In fact, the relations $d \mid a$ and $d \mid b$ imply that there exist integers k and l such that $a = kd$, $b = ld$, whence $ax+by = (kx+ly)d$ and consequently, since $kx+ly$ is an integer, $d \mid ax+by$.

Any two of the formulae $a = bc$, $-a = b(-c)$, $a = (-b)(-c)$, $-a = (-b)c$ are equivalent. Hence also any two of the formulae

$$b \mid a, \quad b \mid -a, \quad -b \mid a, \quad -b \mid -a$$

are equivalent. Consequently while examining divisibility of integers we can restrict ourselves to the investigation of divisibility of natural numbers.

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COMPLEX INTEGERS

W. Sierpiński

Elementary theory of numbers

CORRIGENDUM

Page, line	Instead of	should be
6^{12}	$2^{9891}-1$ of 2917 digits	$2^{11213}-1$ of 8376 digits
6^{14}	21	23
112_6	$F_{19}=2^{2^{19}}+1$	$F_{17}=2^{2^{17}}+1$
$112_{9\text{-}7}$	Recently the number $2^{101}-1$ was completely factorized into a product of two primes. One of its prime factors has 13 digits, the other has 18 digits.	
156^7	$1, 2, \ldots, n$	$1, 2, \ldots, a$
157^9	m	n
194_8	a_2x+b_2	a_2y+b_2
205 formula (26)	$p[|$	$p\,|\,[$