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# JOVAN KARAMATA AND HIS DIGITIZED WORKS

**Abstract**. It is generally considered that Jovan Karamata is one of the greatest and the most influential Serbian mathematicians in the XX century. His mathematical contributions belong mainly to mathematical analysis, particularly to the Tauberian theory. Probably his most known and most important work is his invention of slowly varying functions. Today, this theory has many applications, particularly in probability theory, but in ordinary differential equations, complex analysis, number theory and even in cosmology as well. In this paper we present a digital collection ofhis books deposited in the Virtual Library of the Faculty of mathematics in Belgrade.

**Keywords:** Jovan Karamata, digitized works, mathematics,XX century.

## Introduction

In this paper we present digitized works of Jovan Karamata (1902–1967), professor at Belgrade University and one of the most outstanding Serbian mathematicians. Digital copies of his works and books are available at the Virtual Library of the Faculty of Mathematics in Belgrade, http://elibrary.matf.bg.ac.rs. They are a part of a large collection of retrodigitized books, manuscripts and other documents in the mathematical sciences of Serbian scholars from the eighteenth century till the first half of the twentieth century.

We also give special consideration to his somewhat forgotten university textbooks *Complex Number* and *Theory and Application of Stieltjes Integral*. These books were printed after World War II and were official university textbooks at the Belgrade University. Although Karamata wrote several textbooks, some alone, others as a coauthor, on this occasion we decided to present these books, since a reader can see all the features of his work in mathematics, from originality to the fields of his interest.

## Short biography of Jovan Karamata

Jovan Karamata was born in Zagreb on February 1, 1902, in a prosperous Greek –Aromanian merchant family. He was a member of the eighth generation of this family, whose ancestors immigrated to Zemun in the mid - 18th century. Jovan spent his childhood in Zemun, which was then a border town in the Austro-Hungarian Empire. He completed most of his elementary education there, and with the start of World War I his parents took him to Lausanne, Switzerland, where he graduated from the high school with orientation to mathematics and natural sciences.

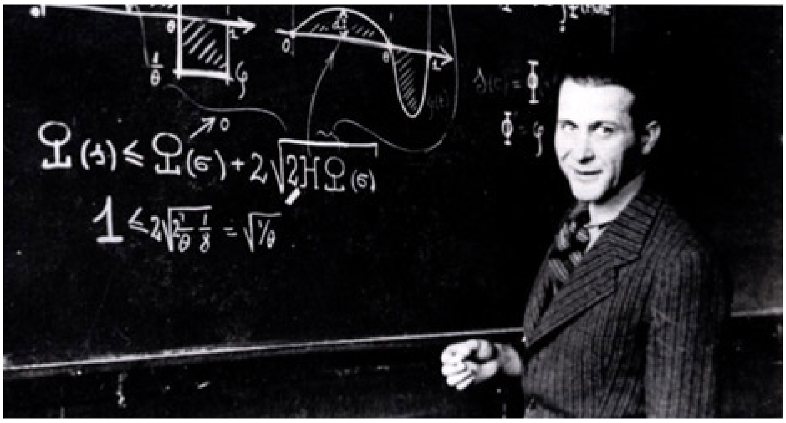


Figure 1. Jovan Karamata lecturing.

After the end of the Great War, he enrolled in studies at the Faculty of Engineering at the University of Belgrade. But very soon, in 1922, he went on to study mathematics at the Faculty of Philosophy. He finished these studies in 1925 and was immediately appointed to the position of assistant of mathematics at the same college. At the same time, he had the first presentation of his results at the Academy mathematical seminar. Later, these results are included in his doctoral dissertation *O jednoj vrsti granica sličnih određenim integralima* (A type of limits similar to certain definite integrals), which he defended in 1926. He was the fifth doctoral student of MihaloPetrović Alas, the founder of the Belgrade School of Mathematics.

Although Karamata wrote several papers that were based on Petrović's works, he still had his own way in mathematics. In fact, the greatest influence on him had English mathematicians Godfrey Harold Hardy and John Edensor Littlewood, as well as German mathematician Emil Landau. He went to Paris in 1927, where he spent one year studying and simultaneously preparing his first scientific papers.Two works from this period have a particular place and importance and have made Karamata a mathematician of world reputation.Both papers were published in 1930, the first one in the renowned German journal “Mathematische Zeitschrift”, the paper *Über die Hardy-Littlewoodsche Umkehrungen des Abelschen Stätigkeitssatzes*, while the second one in the little-known Romanian journal “Mathematica” (Cluj), *Sur une mode de croissancerégulière des fonctions*.

The first paper, which consisted only of two pages, provides a new, concise and elegant proof of theLittlewood's theorem in the theory of summability of infinity series. The second paper established the foundations for the theory of regularly varying functions, which will later find numerous applications in probability theory, number theory, differential equations, complex analysis, and even mathematical analysis of cosmological parameters.

Most of Karamata's mathematical opuslay in Tauberian function theory and slowly varying functions theory. He formed a world-renowned Serbian school of analysis, and his students and doctoral students were: Vojislav Avakumović, MiodragTomić, Slobodan Aljančić, VladetaVučković, RankoBojanić, BogoljubStanković, Šefkija Raljević, Bogdan Bajšanski and Ronald Cofman. Several thematic books have been published - monographs (Seneta, Bigham-Goldie-Teugels, Marić, Rechak) with world-recognized publishers, which present and further develop Karamata's theory of slowly varying functions.

In the 1930s he was elected for a member of several academies, in 1933 of Croatian Academy of science JAZU (Jugoslavenskaakademijaznanostiiumetnosti), of Czech Academy of Sciences (1936) and in 1946 of SANU (Serbian Academy of Science and Arts). It is interesting that he got full professor position at Belgrade University after these elections, only in 1950. Since that year he has mostly lived and worked in Switzerland, but regularly visited

Belgrade and took a part in the mathematical life there through seminars and conductions of doctoral dissertations. He is also one of the founders of the Mathematical Institute of SANU (1946).He was elected for a full professor at the University of Geneva in 1951. In the 1960s, he spent some time at the Mathematics Center in Madison, Wisconsin (USA).Professor JovanKaramata died in Geneva on August 14, 1967.


Several his mathematical successors and other mathematicians as well wrote about his life and works. His student, academician MiodragTomić wrote an enlightening article about Karamata's mathematical achievements. A well-known Serbian historian of mathematics and professor at the University, Dragan (Miodrag) Trifunović, wrote several detailed biographical papers on Karamata. Milan Božić, professor at Belgrade University, also wrote about Karamata's life. Professor at the University of Novi Sad, Aleksandar Nikolić, wrote particularly extensively about Jovan Karamata. Serbian publishing house "Zavod za udžbenike I nastavna sredstva" in cooperation with SANU published in the period 2005 – 2007 collected works of Jovan Karamata in four volumes. The Yugoslav Post in his honor issued a postage stamp with his image.

**Mathematicians Club**

For better understanding of Karamata's work at Belgrade University it is important to know the academic circumstances that were ruling among Belgrade's mathematicians at that time. Mathematicians of older generation, Mihailo Petrović Alas,Bogdan Gavrilović and Milutin Milanković, each in his own way, contributed to the development of mathematics in Serbia and the creation of a special atmosphere, owing to which Belgrade was transformed from a provincial town intoa scientific centre. The conditions they created at Belgrade University is best described by words of Radivoj Kašanin, Petrović's doctoral student and Gavrilović's assistant and successor at the Mathematics Department of the Faculty of Technical Sciences: "In addition to their exceptional educational background and original scientific works, all three of them featured something that I value the most and consider the highest human value – love towards young generations, understanding of young people, unselfishness and sincere help to young, talented people in their advancement. They knew how to rejoice and enjoy when young people advanced. *I was lucky to develop myself and work next to them – those great authorities of science and morality. To take pride in their friendship. I do not believe there was anywhere such an environment as was created by Gavrilović, Petrović and Milanković*".

Due to this state of affair, in the 1920s, a new generation of mathematicians appeared: Tadija Pejović, Radivoj Kašanin, Jovan Karamata and Miloš Radojčić. They were all Mihailo Petrović's graduate and doctoral students. In the 1930s, Dragoslav Mitrinović, Danilo Mihnjević, Konstantin Orlov, Petar Muzen and Dragoljub Marković also defended their doctoral theses under the tutorship of professor Petrović. Here are the names of all mathematicians at Belgrade University in 1926. The Department of Theoretical Mathematics of the Faculty of Philosophy consisted of: full professors Mihailo Petrović and Nikola Saltikov, lecturer Tadija Pejović and administrative assistants Jovan Karamata and Miloš Radojčić. The Department of Applied Mathematics consisted of: full professors Milutin Milanković and Anton Bilimović, associate professor Vojislav Mišković and lecturer Vjačeslav Žardecki. The Mathematics Department of the Faculty of Technical Sciences consisted of: full professors Bogdan Gavrilović and Petar Zajončkovski, lecturer Radivoj

Kašanin; and the Department of Applied Mathematics consisted of: Ivan Arnovljević and Jakov Hlitčijev. All professors and assistants of theoretical and applied mathematics from the University made up the Club of Mathematicians of Belgrade University. This seminar was in fact the Mathematics School of Belgrade University and the main point of gathering of Belgrade mathematicians. We can freely say that this time was the golden age of Serbian mathematics. The Club did not have anyspecial rules, except for monthly meetings, when works of Club members were presented andacademic discussions held. We see that Jovan Karamata was a member of that club. Later, Karamata will become the leader of the Club, a mathematician who will lay the foundations of Serbian school of mathematical analysis.

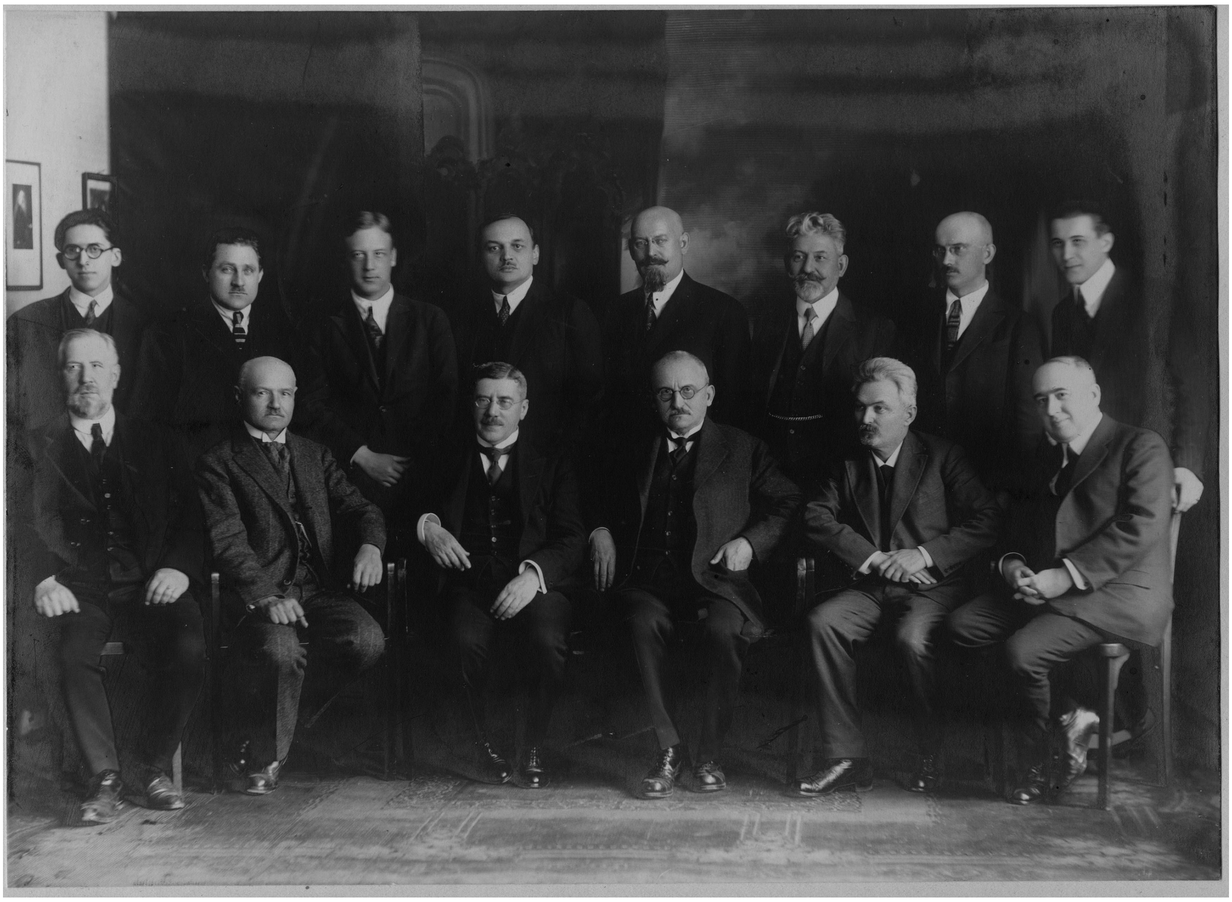


Figure 2. Historical recording: Club of Mathematicians - Belgrade Mathematical School 1926.
Milos Radojčić,TadijaPejović,Vyacheslav Zardecki, Anton Bilimović, PetarZajankovski, JelenkoMihailović (seismologist),RadivojKašanin, Jovan Karamata (standing). Nikola Saltikov, MihailoPetrović, PavlePopović (Rector),
Bogdan Gavrilović, K. Petković (Dean of the Faculty of Philosophy) and Milutin Milanković (sitting).

From the members of the Club, such as Milanković, Bilimović, Mišković, Hlitčijev, and the fields they were working in, we see that applied mathematics was represented, or better to say, included in the work of the Club. Applied mathematics at that time meant theoretical mechanics, astronomy and other sciences bordering on mathematics.

To give the complete image of Belgrade mathematics between two World wars, we have to mention that in Belgrade there were few other mathematicians who did not cooperate with the Club. Dimitrije Danić (1862-1932) was first Serbian doctor of mathematics[1] and the professor of the Military Academy in Belgrade. He wrote several very good text-books in

[1] He got defended his doctoral dissertaton in 1885, at the University of Jena, Germany.

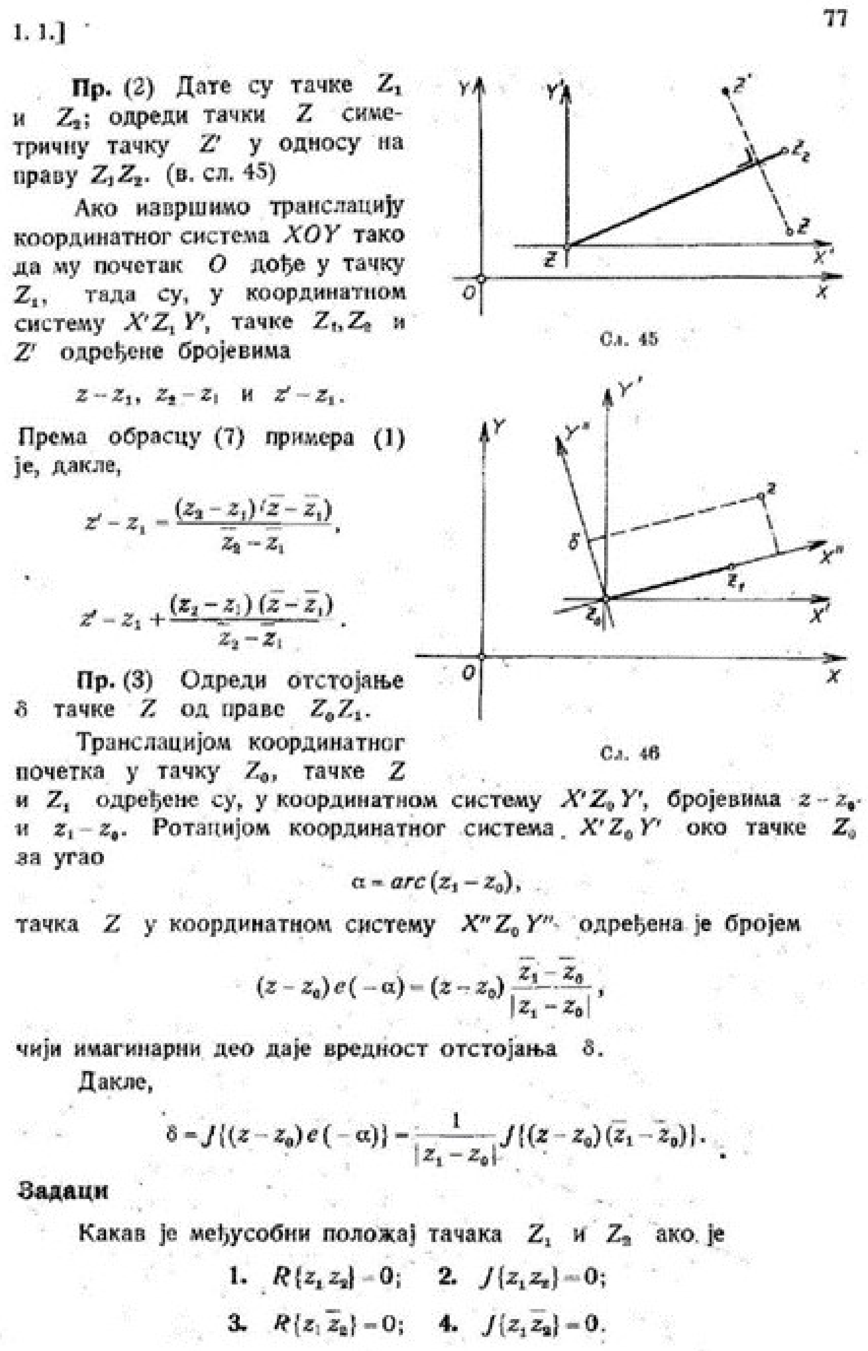
mathematics and applications that were not used only at the Academy, but at the Belgrade University as well. Danić did not attend Club meetings. The reason were probably the circumstances during his early attempts to get a professorship at the High School, the predecessor of the Belgrade University,competing with Bogdan Gavrilović for this position. The other two mathematicians are Mladen Berić(1885-1935) and Sima Marković (1888-1939), the first Petrović's doctoral students. Even if they were working at the University for some time, they left the University shortly after the renewal of its work after the end of World War I. Berić left it for personal and somewhat tragic reasons and stopped doing science, while Marković was deeply involved in politics. It should be mentioned that Marković was very gifted mathematician, but probably the most tragic figure of the Serbian scientific scene. Not only his professorship at the Univerity in 1919 was not approved by King Alexander, but he was jailed for several years as a co-president of Yugoslav communist party. There he wrote a rather fine book on the theory of relativity (special and general), showing his broadness in science. In the late 1920s he went to Russia working in the Historical Institute in Moscow. There he was also a member of Politburo. In 1937, he was convicted as an opponent and shot dead the same day outside the hotel where he was living. Ironically, he was against forcible, or revolutionary methods in politics. He believed that the system could be changed in a democratic way, in elections. It is not known that the members of the Club ever mentioned these three mathematicians in a negative context. It is known that Petrović in fact favored his doctoral students, Berić and Marković.

## Karamatas's Textbooks

Jovan Karamata has published 120 scientific papers, 15 monographs and textbooks, as well as 7 professional-pedagogical works. Digital copies of 29 of these works and books are in the Virtual Library of the Faculty of Mathematics in Belgrade, http://elibrary.matf.bg.ac.rs.
Here we give an overview of the university textbooks *Complex Number* and *Theory and Applications of Stieltjes Integral.*


Figure 3.The cover page of the university textbook *Complex Number*.

The textbook *Complex Number* consists of two parts - Algebra of Complex Numbers and Applications in Geometry. In the first part, the notion of a complex number is informally introduced, in relation to solving algebraic equations. Afterwards, the structure of complex numbers is based on the axiomatic method. The concepts of general algebra are mentioned, such as algebraic structures of rings, fields and groups and algebraic laws - associative and commutative law, as well as the law of the neutral element and others. Using these identities, the other algebraic properties of the considered algebraic operations are formally derived. The field of complex numbers is defined as it is generally accepted today - complex numbers are ordered pairs(complexes) with common definitions of addition and multiplication operations.Trigonometric and Euler's formulasfor complex numbers are also introduced, as well as power and exponential functions for complex numbers.



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**Пр.** (2) Дате су тачке $Z_1$ и $Z_2$; одреди тачки $Z$ симетричну тачку $Z'$ у односу на праву $Z_1Z_2$. (в. сл. 45)

Ако извршимо транслацију координатног система $XOY$ тако да му почетак $O$ дође у тачку $Z_1$, тада су, у координатном систему $X'Z_1Y'$, тачке $Z_1, Z_2$ и $Z'$ одређене бројевима

$$z - z_1, \quad z_2 - z_1 \quad и \quad z' - z_1.$$

Према обрасцу (7) примера (1) је, дакле,

$$z' - z_1 = \frac{(z_2 - z_1)(\bar{z} - \bar{z}_1)}{\bar{z}_2 - \bar{z}_1},$$

$$z' - z_1 + \frac{(z_2 - z_1)(\bar{z} - \bar{z}_1)}{\bar{z}_2 - \bar{z}_1}.$$

Сл. 45

Сл. 46

**Пр.** (3) Одреди отстојање $\delta$ тачке $Z$ од праве $Z_0Z_1$.

Транслацијом координатног почетка у тачку $Z_0$, тачке $Z$ и $Z_1$ одређене су, у координатном систему $X'Z_0Y'$, бројевима $z - z_0$ и $z_1 - z_0$. Ротацијом координатног система $X'Z_0Y'$ око тачке $Z_0$ за угао

$$\alpha = arc\,(z_1 - z_0),$$

тачка $Z$ у координатном систему $X''Z_0Y''$ одређена је бројем

$$(z - z_0)\,e(-\alpha) = (z - z_0)\frac{\bar{z}_1 - \bar{z}_0}{|z_1 - z_0|},$$

чији имагинарни део даје вредност отстојања $\delta$.

Дакле,

$$\delta = J\{(z - z_0)\,e(-\alpha)\} = \frac{1}{|z_1 - z_0|} J\{(z - z_0)(\bar{z}_1 - \bar{z}_0)\}.$$

**Задаци**

Какав је међусобни положај тачака $Z_1$ и $Z_2$ ако је

1. $R\{z_1 z_2\} = 0$; 2. $J\{z_1 z_2\} = 0$;

3. $R\{z_1 \bar{z}_2\} = 0$; 4. $J\{z_1 \bar{z}_2\} = 0$.

Figure 4. Page from the textbook *Complex number*.

In the second part of the book, Karamata applied the theory of complex numbers in elementary geometry, showing that basic geometric constructions in a plane can be represented by algebraic operations with complex numbers, and vice versa. By introducing the orthogonal and parallel product of complex numbers, he solved problems from planar geometry and trigonometry by analytical method. He proved a number of famous theorems from elementary geometry such as Ptolemy's theorem, as well as Desargues's, Ceva's, Menelaus's and Pappus's theorems in the original way, applying the algebra of complex numbers.

The main Karamata'sgoal in the textbook *Theory and application of Stieltjes integral* was to show that Stieltjes integral is a concept which at the same time encompasses both the ordinary integral and the infinite series. Considering this, it allows to work similarly with the functions of a real argument and with the functions of a discrete argument.The first part of the book presents the features of the functions that are crucial for the development of the Stieltjes integral - functions of bounded variation and monotone functions, while the second part presents the theory of the Stieltjes integral itself.

ОДЕЉАК В.

## STIELTJES-ОВ ИНТЕГРАЛ



### I. Одређени Stieltjes-ов интеграл

I. 1. (1) Нека је функција $f(x)$ ограничена у размаку $(a, b)$ и нека је функција $\alpha(x)$ ограничене варијације у томе размаку. Stieltjes-ов интеграл функције $f(x)$, у односу на функцију $\alpha(x)$, дефинише се овако:

Дефиниција. Нека је

$\{x_\nu\}$: $$a = x_0 < x_1 < \dots < x_n = b$$

произвољна подела размака $(a, b)$ на $n$ делова и нека је $\xi_\nu$ произвољно изабрана тачка у размаку $(x_{\nu-1}, x_\nu)$, $\nu = 1, 2, \dots n$. Означимо са $S_n$ збир

$$S_n = \sum_{\nu=1}^{n} f(\xi_\nu)\{\alpha(x_\nu) - \alpha(x_{\nu-1})\}, \qquad (1)$$

а за $\delta_n$ дужину највећег од размака $(x_{\nu-1}, x_\nu)$, тј.

$$\delta_n = \operatorname{Max}_{1 \leq \nu \leq n} \{x_\nu - x_{\nu-1}\}.$$

Ако збир (1) конвергира одређеној граници $S$, кад

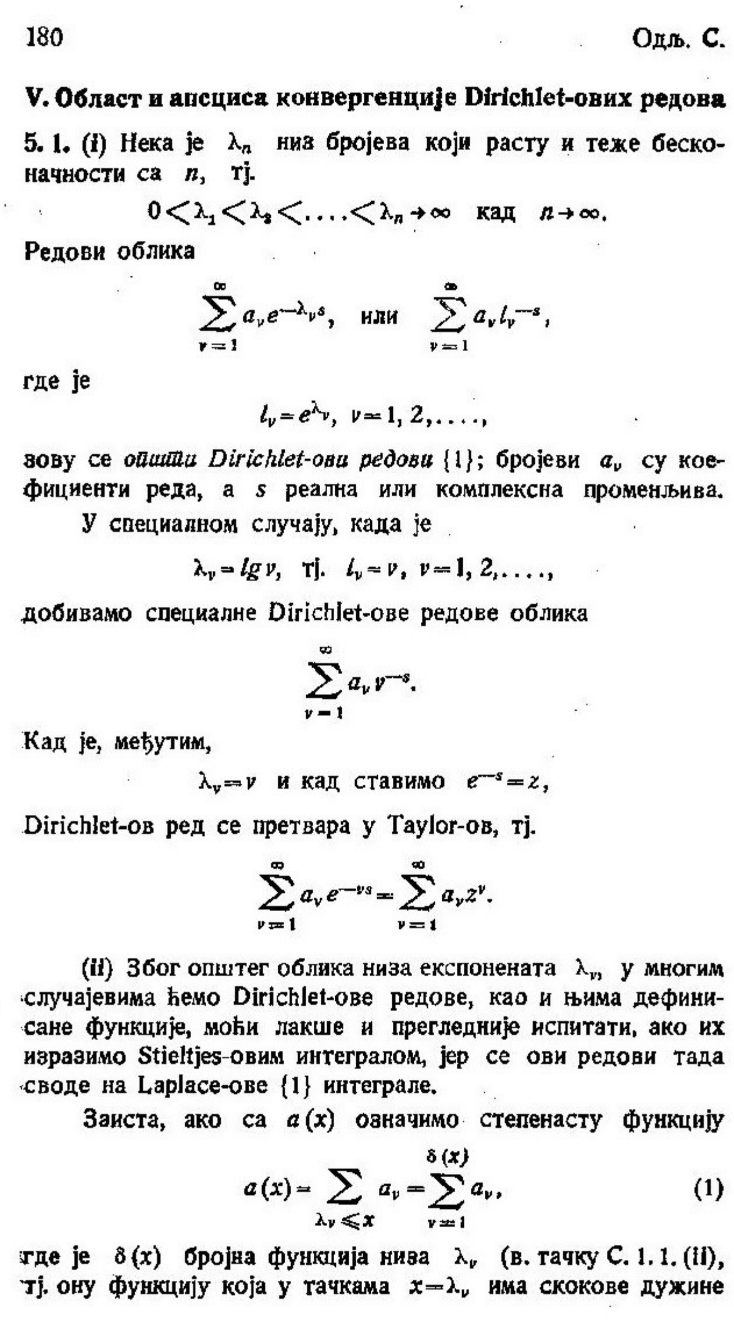
$$\delta_n \to 0,$$

и то независно од тачака поделе $\{x_\nu\}$ и избора тачака $\xi_\nu$, тада се та гранична вредност назива *Stieltjes-ов интеграл функције* $f(x)$ *у односу на функцију* $\alpha(x)$ и пише

$$S = \int_a^b f(x)\, d\{\alpha(x)\} = \int_a^b f(x)\, d\alpha(x).$$

Figure 5. Page from the textbook *Theory and Applications of Stieltjes Integral*.

The main theorems relate to the conditions under which the Stieltjes integral exists, as well as to the mean value theorem and various integral estimations and inequalities. In the third part, the reader is convinced that "*the Stieltjes integral is a very strong analytical apparatus…*"that serves to successfully solve various tasks frommathematical analysis. The first chapter of this section deals with the basic tasks of analytic number theory, while the remaining three provide applications to the theory of infinite series. Also, the theory of Dirichlet series, which can be represented by Stieltjes integral, is being developed in a complex domain. Let us mention that the theory of Dirichletseries is extremely important in analytic number theory.



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**V. Област и апсциса конвергенције Dirichlet-ових редова**

**5. 1. (*i*)** Нека је $\lambda_n$ низ бројева који расту и теже бесконачности са $n$, тј.

$$0<\lambda_1<\lambda_2<\ldots<\lambda_n\to\infty \quad \text{кад} \quad n\to\infty.$$

Редови облика

$$\sum_{\nu=1}^{\infty} a_\nu e^{-\lambda_\nu s}, \quad \text{или} \quad \sum_{\nu=1}^{\infty} a_\nu l_\nu^{-s},$$

где је

$$l_\nu = e^{\lambda_\nu}, \quad \nu=1, 2, \ldots,$$

зову се *општи Dirichlet-ови редови* {1}; бројеви $a_\nu$ су коефицијенти реда, а $s$ реална или комплексна променљива.

У специалном случају, када је

$$\lambda_\nu = lg\,\nu, \quad \text{тј.} \quad l_\nu=\nu, \quad \nu=1, 2, \ldots,$$

добивамо специалне Dirichlet-ове редове облика

$$\sum_{\nu=1}^{\infty} a_\nu \nu^{-s}.$$

Кад је, међутим,

$$\lambda_\nu=\nu \quad \text{и кад ставимо} \quad e^{-s}=z,$$

Dirichlet-ов ред се претвара у Taylor-ов, тј.

$$\sum_{\nu=1}^{\infty} a_\nu e^{-\nu s} = \sum_{\nu=1}^{\infty} a_\nu z^\nu.$$

(*ii*) Због општег облика низа експонената $\lambda_\nu$, у многим случајевима ћемо Dirichlet-ове редове, као и њима дефинисане функције, моћи лакше и прегледније испитати, ако их изразимо Stieltjes-овим интегралом, јер се ови редови тада своде на Laplace-ове {1} интеграле.

Заиста, ако са $a(x)$ означимо степенасту функцију

$$a(x) = \sum_{\lambda_\nu \leqslant x} a_\nu = \sum_{\nu=1}^{\delta(x)} a_\nu, \qquad (1)$$

где је $\delta(x)$ бројна функција низа $\lambda_\nu$ (в. тачку С. 1. 1. (*ii*), тј. ону функцију која у тачкама $x=\lambda_\nu$ има скокове дужине

Figure 6. Page from the textbook *Theory and Applications of Stieltjes Integral*.

The fourth (last) part of the book provides an overview of the basic concepts and theorems from the analysis, which are necessary for understanding the previous sections of the book.

Both books are valuable forstudents of mathematics of all ages, as well as for already formed mathematicians.Both can learn a lot from extremely skilled style and techniques in manipulating formulas and performing various analytical estimations and inequalities.

## Conclusion

Jovan Karamatawasa distinguished Serbianmathematician of World reputation due to his invention of slowly varying functions and work in Tauberian theory. In the paper we presented in short his life and work, but also the atmosphere at the Belgrade University during two world wars Karamata's scientific home. Also, the digital collection of his books deposited in the Virtual Library are presented, with a broader review of the books *Complex Number* and *Theory and Application of Stieltjes Integral*.

## Acknowledgment

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