



C. T. RAJAGOPAL, 1903-1978

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C. T. Rajagopal who died on 25th April 1978 was the eldest son of Cadambathur Tiruvenkatacharlu and Padmamma. He was born in 1903 and after schooling in the Hindu High School, Triplicane, Madras, he followed the Intermediate and B.A. (Honours) courses in the Madras Presidency College, obtaining the first rank in the Honours Examination in mathematics in 1925. The inspiration which Rajagopal drew from K. Ananda Rau, who taught him in the Honours course, left an indelible impression on him throughout his life. Rajagopal married Rukmini in 1925. After a short spell of clerical service followed by a teaching career in the Annamalai University, Rajagopal joined the Madras Christian College in 1931 to serve it for two decades. He settled down near the college in his "Anchorage" and became renowned not only for his lucid and often original exposition of classical mathematical analysis but for the tender care he bestowed on his students. In 1951, Rajagopal switched over to the Ramanujan Institute of Mathematics in deference to the wishes of his senior college-mate and great friend, T. Vijayaraghavan, who headed the Institute. On the demise of Vijayaraghavan in 1955 the headship devolved on Rajagopal. Rajagopal's contribution to the Institute in attaining its present size and importance as a national centre for research is immeasurable. He died of a massive heart attack and without pain nearly a decade after his retirement.

Rajagopal's numerous papers fall under three heads: (I) Sequences, series, summability; (II) Functions of a complex variable; (III) History of medieval Kerala mathematics. The account of his work which follows is just a "random sampling".

I

His initial work (see [1]–[11]) was on the unification of tests for convergence of series of positive terms. His mainstay was the theme of generalization and unification of Tauberian theorems, which began with [12]. To trace the history of the first result of Rajagopal's a little, let $\lambda = \{\lambda_n\}$ be a strictly increasing sequence of non-negative numbers diverging to ∞ . Write $s_n = a_0 + a_1 + \dots + a_n$. If

$$\frac{1}{\lambda_{n+1}} \sum_{v=0}^n (\lambda_{n+1} - \lambda_v) a_v = \frac{1}{\lambda_{n+1}} \sum_{v=0}^n (\lambda_{v+1} - \lambda_v) s_v \rightarrow s \quad (\text{a})$$

as $n \rightarrow \infty$, the series $\sum_{n=0}^{\infty} a_n$ (or the sequence $\{s_n\}$) is said to be summable $(R, \lambda, 1)$ to s . It had been conjectured that if (a) holds and if

$$a_n = O_L \left(\frac{\lambda_n - \lambda_{n-1}}{\lambda_n} \right), \quad (\text{b})$$

then $\{s_n\}$ converges to s ; this conjecture, however, was shown to be false by Ananda Rau. In [12], Rajagopal gave simple proofs of the following results (some of which were previously known). If (a) holds, then any one of the following assumptions is sufficient to ensure that $\{s_n\}$ converges to s :

- (i) $a_n = O\left(\frac{\lambda_n - \lambda_{n-1}}{\lambda_n}\right)$;
- (ii) $a_n = O_L\left(\frac{\lambda_n - \lambda_{n-1}}{\lambda_n}\right)$, $\frac{\lambda_{n+1}}{\lambda_n} \rightarrow 1$ as $n \rightarrow \infty$;
- (iii) $a_n = O_L\left(\frac{\lambda_n - \lambda_{n-1}}{\lambda_n}\right)$, $\underline{\lim} a_n \geq 0$;
- (iv) $a_n = O_L\left(\frac{\lambda_n - \lambda_{n-1}}{\lambda_n}\right)$, $a_{n-1} = O_L\left(\frac{\lambda_n - \lambda_{n-1}}{\lambda_n}\right)$.

Moreover, if we assume only (a) and (b), then, while we cannot assert the convergence of $\{s_n\}$ we can still deduce that

$$\overline{\lim}_{n \rightarrow \infty} s_n = s.$$

Later, in [25] he extended this last result by replacing (b) by

$$\lim_{n \rightarrow \infty} \min_{\lambda_n < \lambda_m < (1+\epsilon)\lambda_n} (a_{n+1} + \dots + a_m) = O_L(1) \text{ as } \epsilon \rightarrow 0.$$

In [56] he showed that under hypotheses (a) and (b) $\{s_n\}$ converges to s in “ λ -density”. He put these results in a more general perspective later (see [79]) in the context of the transform

$$\Phi_\lambda(t) = \sum_{n=1}^{\infty} a_n \phi(t\lambda_n), \quad t > 0, \tag{c}$$

when $t \rightarrow 0$. For the transform (c) with $\phi(u) = \int_u^\infty \psi(x)dx$ and $\psi(u)$ satisfying the conditions:

$$\psi(u) \geq 0 \ (u \geq 0), \quad \int_0^\infty \psi(u)du = 1, \quad \int_0^\infty \psi(u)|\log u|du < \infty,$$

$$\int_0^\infty u^{ix} \psi(u)du \neq 0 \quad (-\infty < x < \infty),$$

he established, generalizing an earlier result of M. C. Austin [*J. London Math. Soc.* 26 (1951), 304–307], the following: If $\Phi_\lambda(t)$ exists for $t > 0$ and converges to a finite limit

as $t \rightarrow +0$ only for series with bounded terms, then the high-indices condition $\overline{\lim} \frac{\lambda_{n+1}}{\lambda_n} > 1$ is fulfilled and such series converge. This result is a sort of converse for “high-indices” theorems.

H. Hadwiger [*Comment. Math. Helv.* 20 (1947), 319–322] and R. P. Agnew [*Duke Math. J.* 12 (1945), 27–36] showed that if the Abel transform $A(x) = \sum_{n=0}^{\infty} a_n x^n$ of the series $\sum_{n=0}^{\infty} a_n$ exists for $0 \leq x < 1$ and $s_n = a_0 + a_1 + \dots + a_n$, then

$$\overline{\lim}_{n \rightarrow \infty} |A(x) - s_n| \leq C \overline{\lim}_{n \rightarrow \infty} |na_n| \tag{d}$$

when $x = 1 - \frac{1}{n}$ where a best possible constant C independent of $\sum a_n$ exists.

Rajagopal, independently of Vijayaraghavan, showed (see [42, 45]) that

$$\overline{\lim}_{n \rightarrow \infty} |B(x) - s_n| \leq \left(\frac{2}{\pi}\right)^{\frac{1}{2}} \overline{\lim}_{n \rightarrow \infty} |n^{\frac{1}{2}} a_n| \tag{e}$$

when $B(x) = e^{-x} \sum_{k=0}^{\infty} \frac{s_k x^k}{k!}$ is the Borel transform which is assumed to exist and $n = [x]$ is the integral part of $x > 0$, the constant $(2/\pi)^{\frac{1}{2}}$ being best possible. The existence of such ‘Tauberian constants’ was further established by him (see [26, 28, 29, 39, 42, 45, 86]), more generally, for families of summability methods. The existence of such constants in the context of one-sided versions of Vijayaraghavan’s theorem (see G. H. Hardy, *Divergent series*, p. 308, Theorem 238) was established by him and Vijayaraghavan in [51, 54].

Another topic in which Rajagopal [49] treated families of summability methods rather than individual methods was that of “product theorems”.

The (A_{λ}) method of summability introduced by him (see [49]) independently of Jakimovski, was shown by him [82] and, later, by V. K. Krishnan [*Math. Proc. Cambridge Philos. Soc.* 78 (1975), 497–500] to be a weaker alternative for Abel summability in most of the Tauberian results for the latter.

Extension of certain results of Ananda Rau on Dirichlet series using a set of difference formulae, in collaboration with S. Minakshisundaram [15, 16, 17], and later, on his own (see [80]), and generalization [68, 70, 71, 72, 73, 75, 76] of tests for uniform and ordinary convergence of Fourier series, were two more interesting aspects of his work.

Gap Tauberian theorems and high-indices theorems received his attention [78, 83, 84] for two or three years before his death. The connexion [78] of the function Φ introduced by Hardy in the context of Vijayaraghavan’s theorem (*loc. cit.*), with gap Tauberian theorems, an analogue [84] of V. I. Mel’nik’s idea for λ -type methods and the establishment [83] of the condition

$$\lim_{\eta \rightarrow 0} \overline{\lim}_{n \rightarrow \infty} \max_{\lambda_n \leq \lambda_r \leq (1+\eta)\lambda_n} \sum (|a_r| - a_r) = 0$$

as a Tauberian condition for $(\mathfrak{R}, \lambda, 2)$ summability of $\sum_{n=0}^{\infty} a_n$ to imply convergence

are some of the highlights of his study of these two topics, mostly in collaboration with the writer.

II†

If $f(z)$ is a periodic integral function of order $\rho > 1$ and

$$f(z) = a_0 + \sum_{n=1}^{\infty} 2 \left\{ a_n \cos\left(\frac{2\pi n z}{\lambda}\right) \pm b_n \sin\left(\frac{2\pi n z}{\lambda}\right) \right\},$$

Rajagopal showed [94] that $a_n, b_n = O(\exp(-n^{\rho^* - \varepsilon}))$ for all positive ε where ρ^* is defined by $\frac{1}{\rho} + \frac{1}{\rho^*} = 1$. As an analogue of a theorem of Landau's on the partial

sums of Fourier series, he proved (see [95]): For $f(z) = \sum_{n=0}^{\infty} a_n z^n$ analytic in $|z| \leq R$

we have $|\operatorname{Re} s_n(z)| < C(\log n) A^*(r)$ where $s_n(z) = \sum_{k=0}^n a_k z^k$, $A^*(r) = \max_{|z|=r} |\operatorname{Re} f(z)|$ and

C is an absolute constant. Study of the relation of the growth of the maximum modulus or mean values of an entire function as such, or represented by an absolutely convergent Dirichlet series with the order, lower order, type etc., of the function, was the subject matter of [96, 97, 98, 102]. In [99] Rajagopal and A. R. Reddy showed that the functional equation

$$g(z + \omega) - \lambda g(z) = f(z)$$

where $f(z)$ is an entire function of order ρ ($0 < \rho < \infty$) and type σ ($0 \leq \sigma < \infty$), with ω, λ non-zero constants, has an entire solution $g(z)$ of order ρ and type λ . A self-contained treatment followed in [100].

III

Taking the cue from an article of C. M. Whish's [*Transactions of the Royal Asiatic Society of Great Britain and Ireland* 3 (1835), 509–523], Rajagopal, with the help of competent collaborators, presented in [103, 105] satisfactory modern forms of the proof of the series-expansions:

- (i) Gregory's power series for $\arctan x$ (1671 A.D.)
- (ii) Newton's power series for $\sin x, \cos x$ (1670 A.D.),

carefully moulding the proof upon their originals in Yuktibhāsa, a work in a Sanskritized form of Malayāḷam. On the basis of these papers and further elucidation in [104, 106, 107, 108], leading western historians of mathematics such as D. T. Whiteside, J. E. Hofmann and A. P. Juschkewitch, have accepted that the series were known to the Hindus at least a century-and-a-half before they were discovered in the West. Further evidence enabling the assigning of these series to Mādhava, a

† The review in this section is by Professor T. V. Lakshminarasimhan.

Kerala Brahmin, c.1350–1400 A.D., was recorded in [109]. A sequel to [109] confirming this finding is unpublished.

Rajagopal was a teacher *par excellence* and a reliable and inspiring research guide. No words can adequately describe his modesty. Rational thinking and interest in psychic studies were two attributes which he imbibed with pride from his teacher Ananda Rau. His lighter reading material was high class detective stories. No visitor to the Anchorage can forget the warmth of the reception and treatment by Rajagopal and his gracious wife Rukmini.

Publications

I. Sequences, series, summability

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II. Functions of a complex variable

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