Nikhil Rajan Sen – The Formative Years

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Abstract

Nikhilranjan Sen or Nikhil Ranjan Sen is considered as the founder of Calcutta School of Theory of Relativity and Applied Mathematics. He did his D.Sc. from Calcutta and Ph.D. from Berlin. Documents regarding these two degrees were obtained from archives. In the present communication a detailed review of his theses is given.

Key words: Max von Laue, N.-R. Sen, Theory of relativity, University of Calcutta.

1 Introduction

Nikhilranjan Sen or Nikhil Ranjan Sen (May 23, 1894–Jan 13, 1963) was one of the initiators of the Theory of Relativity in India (Figure 1). He is considered as the "Father of Applied Mathematics in India." Also, he is said to be the first Indian doctorate in the theory of relativity (Mitra 2009, pp. 417–440). He was associated with important institutions such as Indian National Science Academy, Indian Association for the Cultivation of Sciences and University of Calcutta (Table 1). There are a few short articles written on his life and science (Burman 1963, Bhattacharjee et al. 2013, Bose 1963, Duben & Parikh 2010, Dani 2012, INSA - Dec. 2, 2019). However, none of these deals either with his initial career as a scientist, or the contents of his D.Sc. (Kolkata) and Ph.D. (Berlin) theses. The present article intends to fill the gap.

Figure 1 N. R. Sen. Courtesy: INSA.

2 Beginning of Research Carrier

NRS joined the Department of Applied Mathematics as Lecturer, in the newly founded University College of Sciences, University of Calcutta in September 1917. NRS conducted tutorial on statistics (Report of syndicate 1917, pp. 2602–2604). In 1919–1920, Sen was one of the nine Post-Graduate teachers (Minutes 1920, p. 559).

Applied mathematics, statics, dynamics, hydromechanics, astronomy were taught to general students in 1916. Apart from them, special subjects were theory of elasticity, advanced hydrodynamics including theory of tides, advanced dynamics and advanced (spherical) astronomy (Banerjee et al., 1957, pp. 240–250). Not surprisingly, Sen's initial work was on hydrodynamics and elasticity.

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Table 1 N. R. Sen association with important institutions.

1913	B.Sc., Presidency College, Calcutta
1916	M.Sc., Presidency College, Calcutta
1917	Lecturer, Dept. Applied Mathematics, University College of Science.
1921	D.Sc., University of Calcutta.
Sept. 1922	Appointed as Ghosh Professor, Applied Mathematics.
1922–1924	University of München, and Humboldt-University Berlin
1923	Ph.D., Humboldt University
1924–1959	Ghosh Professor, Applied Mathematics, CU
1934	Member, Subcommittee Earthquake Research Commission, India (Anonymous 1935)
1935	Fellow of National Institute of Sciences of India (now INSA). First Treasure, Indian Science News Association, Kolkata
1936	President, Mathematics Section, Indian Science Congress Association (ISCA).
1935–1941	Member of INSA Council
1940–1941	Member, Sectional Committee, Math. & Statistics, ISCA
1949–1951	Member of Council
1951	Rippon Professor, IACS
1952–1953	Member of the Council, IACS
1959–1960	Vice-President, INSA
The above data is from the above referred articles.	

During his stay in Germany, his focus turned to the theory of relativity.

2.1 Research work for D.Sc. degree

As far as research is concerned, Sen's initial interest was in the fields of the theory of Newtonian potential, theory of elasticity, solid geometry and hydrodynamics (Minutes 1920, p. 540). N. R. Sen read his first article on February 10, 1918, before the Calcutta Mathematical Society, "On the potentials of uniform and heterogeneous elliptic cylinders at an external point", which was later published in the Bulletin of the Society (Sen 1918a). The second article published was "On the potentials of heterogeneous incomplete ellipsoids and elliptic discs" (Sen 1918b, 1920). The articles published in the British journal *Philosophical Magazine* were communicated by Devendra Nath Mallik of Presidency College, Calcutta. In the first article, NRS thanked Ganesh Prasad, Head of Mathematics Department, for help and encouragement, and his (Sen's) friend S. N. Bose for useful criticism and encouragement (Sen 1919, 1921). A summary of his publications is presented in next section.

Newtonian Potential

In the 19th century, gravity and electrostatic force were considered as two fundamental forces of nature. It was realized that they could be modelled with gravitational and electrostatic functions known as gravitational potential and electrostatic potential (Wiki, May 21, 2020). NRS in his article "On the potentials of uniform and heterogeneous elliptic cylinders at an external point" derived an integral method to express the potential of an infinite elliptic cylinder in trigonometrical series. He followed an integration method, which was applicable in certain cases of heterogeneity. He simplified the "problem by considering only the logarithmic potential of the elliptic section to which the (Newtonian) potential of the elliptic cylinder" was "equivalent but for an infinite constant and the constant multiplier 2" (Sen 1919). By using discontinuous integrals method, he solved the problem of the potentials, in the cases of heterogeneous incomplete ellipsoids and elliptic discs (Sen 1918b).

Propagation of waves in elastic media

Augustus Edward Hough Love, U. K., in "*A Treatise on the Mathematical Theory of Elasticity*", devoted a chapter to the history of the subject (elasticity) (Love 1892, pp. 1–34). He gave credit to Galileo Galilei, for considering the nature of the resistance of solids to applied force. In 1660, Robert Hooke proved that the stretching of a solid is proportional to the applied force. This later came to known as Hooke's law. In 1822, French Mathematician and Engineer Augustin Louis Cauchy generalized Hooke's law for three dimensional objects. He observed that in elastic bodies, the six components of stress are linearly related to the six components of strain. His countryman, Claude Louis Marie Henri Navier showed that:

> The behavior of deformable bodies is governed by 15 coupled partial differential equations, 3 equations of equilibrium, 6 strain displacement relations and 6 compatibility relations. With the help of these 15 partial differential equations, one can theoretically obtain the 15 unknowns, 3 displacements, 6 strains and 6 stresses that define the state of the deformable body (Rao 2011, pp. 45–47).

In 1905, A. E. H. Love pointed out the applications of Geodynamics in the fields of earth tides, gravitational instability and the vibrations of a compressible planet. "Some of these investigations are very complex, but have throughout the massive stateliness of the elasticity" (Love 1905, pp. 88–113), wrote the author. NRS investigated the case of an elastic shell, under equality of traction and pressure at the spherical surface. He found that the resulting motion consisted of two parts: (i) damped harmonic, and (ii) purely exponential. Further, he observed that the period of vibration depends on the ratio of the thickness of the shell to the radius. However, there were "two critical thicknesses within which the motion" was entirely aperiodic (Sen 1921).

Theory of Seiches

A seiche is defined as a temporary disturbance or oscillation in the water level of a lake or partially enclosed body of water, especially one caused by changes in atmospheric pressure. Disturbances in the surface-level of lakes are caused by the action of rain, wind, waves, motion of boats, earthquakes etc. In 1730, Fatio deDuillier, a Swiss engineer systematically studied such factors and found a rhythmic variation. He observed: "Owing to the peculiar configuration of the Geneva end of Lake Léman, these variations occasionally reach a magnitude of 5 or even 6 feet;..." (Chrystal 1906c). In 1906, G. Chrystal presented his results of investigations on the theory of seiches for a lake whose depth, cross section, and surface breadth did not vary rapidly from point to point (Chrystal 1906a). In the first decade of the 20th century, various aspects of the hydro dynamical theory of seiches were experimentally studied by some of the British scientists (Chrystal 1906b, White & Watson 1906).

Sen referred to the above stated literature. He studied propagation of long waves in canals of varying sections. He discussed some special solutions, which were analogous to the motion of progressive waves. He deduced the laws of variations of depth and breadth for which such types of motion could exist (Sen 1924b). He did not claim any novelty in his results, but obtained some simple formulae, which automatically adjusted the "two arbitrary functions in such a way as to lead directly to the solutions under consideration" (Sen 1924b). To sum up, while working on the propagation of waves in isotropic/non-isotropic media, he found:

> The energy which flows from the disturbed to the undisturbed part of the media in an infinitesimal interval of time one half is the kinetic energy of motion and the other half is the potential energy of deformation. This principle led to a simple deduction of the velocities of wave propagation in a non-isotropic medium (Burman 1963).

2.2 Submission and evaluation of D.Sc. thesis

NRS payed Rs. 100 as fee, and requested the University authorities to evaluate his research work for Doctor of Science degree. According to the requirement, two faculty members had to give testimonials in his support. The Board of Examinations requested G.T. Walker, D. N. Mallik and Asutosh Mukherjee for evaluating the thesis (Minutes 1921, Part II, p. 364). In a meeting on September 23, 1921 their evaluation report was read. Just in one sentence the examiners wrote that they had the honour to state that they examined thesis submitted by Nikhilranjan Sen M.Sc., and are of the opinion that he is worthy of being awarded the Doctorate (D.Sc.) degree (Minutes of Senate, provisional committee 1921, pp. 714–715). We have seen that his thesis was based on different published article. This seems to be the reason that the title of the thesis, according to the official record was "Potentials of Uniform etc" (Report of Syndicate 1921, p. 69).

On July 25, 1922, NRS was appointed as Ghosh Professor, and sanctioned an allowance of Rs. 500 per mensen with effect from Sept. 1, 1922, which enabled him to carry special research in Europe (Minutes 1924, pp. 343–344). He spent one year in Munich with Arnold Sommerfeld, and one year in Berlin with Max von Laue. He did his Ph.D. and wrote two articles under the guidance of von Laue.

3 Ph.D. work in Berlin

As N.R. Sen's Ph.D. thesis was on theory of relativity, thus, before proceeding further, it would be relevant to mention in brief about the general theory of relativity. In 1905, Einstein introduced the 'Special Theory of Relativity', to explain electrodynamic phenomenon. He hypothesized that light has constant velocity; and physical laws are invariant in stationary and moving systems. Space, time, and mass are not absolute. They vary depending on whether the observer is at rest or in motion (Einstein 1905a). Apart from that, he proved the equivalence of mass and energy, and change of mass with velocity (Einstein 1905b, 1907). Einstein's ingenuity lies in the fact that he combined the previous experimental and theoretical knowledge from various fields to give "the fundamentals of the general theory of relativity". In his theory Einstein generalized the special relativity and refined Newton's law of universal gravitation, and provided a unified description of gravity as a geometric property of space and time or four-dimensional space-time. He showed that the curvature of space-time was directly related to the energy and momentum of whatever matter and radiation were present. The relation was specified by field equations, that is a system of 10 coupled, non-linear partial differential equations (Einstein 1916).

3.1 N. Sen's Ph.D. Thesis

The title of NRS's Ph.D. thesis was "Über die Grenzbedingungen des Schwerefeldes an Unstetigkeitsflächen" (On the boundary conditions for the gravitational field equations on surfaces of discontinuity) (Sen 1924a).

NRS in the introduction of the thesis stated that according to Einstein, the gravitational field is defined with ten differential equations. Their solution, the ten components of mass-tensor's at a point of the four-dimensional (space-time) form the world. This idea relates the geometry with matter in the world, and its inner dynamic state. Einstein's recent work shows that if the world is considered as a closed and finite entity, the right solution to the equations needs only the linearity properties. In his thesis N.R. Sen wrote that based on the concept of a linear mass-tensor in gravitational fields, it would be interesting to study special properties of a surface, where there are certain nonlinearities. From physical point of view, we can think of a surface covered with matter. Now, the question is– which special properties of gravitational field are noticeable?

Sen further wrote that according to Einstein's theory of relativity, in all coordinating systems, the laws of nature are equivalent. With coordinate transformation, the non-linearity/ discontinuity can be removed from a surface. And in some cases, it is also possible to produce nonlinearity with coordinate transformation. The latter is a mathematical artifact and has no physical meaning. We can think of nonlinearities, which have physical meaning, e.g. a surface-density of matter and electricity. Such nonlinearities, according to their nature must remain unchanged in different coordinate systems. Now, the question is - which of these nonlinearities are only mathematical, and which have physical origin?

The objective of NRS's thesis was to answer the above question, which, in the past, was not dealt with, systematically. His thesis is divided into two parts: Part I having 7 and Part II having 5 chapters. According to the translated summary of "conclusions" (Sen 1924a):

> Chapters 1, 2 and 3 of part I focus on setting up the boundary conditions of the gravitational field on a surface where the mass-tensor is linear. Whether there is a surface density on such a surface is determined by equation (II) (Figure 3. These equations also provide the nec-

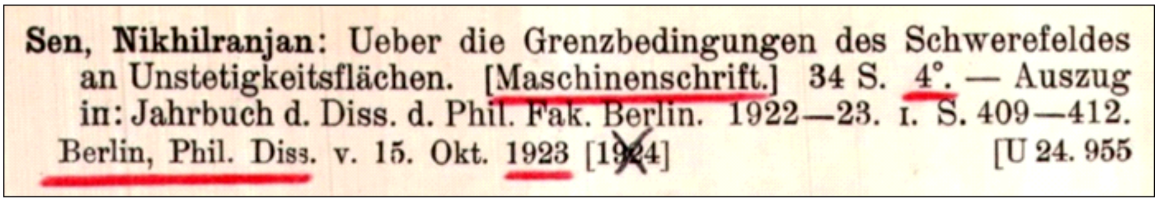

Sen, Nikhilranjan: Ueber die Grenzbedingungen des Schwerefeldes an Unstetigkeitsflächen. [Maschinenschrift.] 34 S. 4°. — Auszug in: Jahrbuch d. Diss. d. Phil. Fak. Berlin. 1922—23. I. S. 409—412. Berlin, Phil. Diss. v. 15. Okt. 1923 [1924] [U 24. 955

Figure 2 Record at the Library of the University of Berlin. Courtesy: Humboldt University of Berlin.

> essary and sufficient conditions. Chapter 4 deals with the consideration of the equations in a special coordinate system. Chapter 5 gives proof of the theorem that in the static field g_{44} is always linear (nonlinearity of any kind can be eliminated by coordinate transformation) and $\delta_{g_{44}}/\delta\nu$ suffers a jump on a material-covered surface. Chapter 6 considers the two tensors associated with the tensor in equation (II). In chapter 7 it is shown that adding the λ-term (cosmological constant) to the gravitational equations does not change equations (I) and (II) (Sen 1924a) (Figure 3).

Chapter 1 of Part II of the thesis is on 'the spherical-symmetric solution of the gravitational equations in the static field for any energy pulse tensor'. Chapter 2 deals with 'considering the solution in some special cases. Two examples are given, where, in the immediate vicinity of the infinitely large mass-density the speed of light (assuming, it remains finite) disappears', whereas Chapter 3 deals with 'boundary conditions on a spherical shell covered with material'. Chapter 4 is devoted to 'the gravitational field of a spherical shell calculating the surface-density and the tension-components from the boundary conditions (I) and (II) of the first part'. The last chapter, 5th discusses 'the equations with the λ-term' (Sen 1924a) as:

> In order to avoid the difficulties of the boundary conditions and the others problems that arise from astronomical considerations, Einstein supplemented λ-term (that is cosmological constant) in his gravitation-equations I & II. Boundary conditions are also valid for the Einstein cosmological gravitation-equations.

To sum up Sen's results–according to A. Einstein's field equations, gravitational forces hold together the parts of a particle. Considering these equations and recognising the electrical origin of matter, Sen calculated the problem of equilibrium of a charged particle with a definite spherical boundary (Burman 1963).

3.2 Submission of the thesis and the opinion of the examiners

Figure 4 shows Sen's certificate for the registration of Ph.D. examination. On June 20, 1923, NRS wrote a letter to the Faculty and asked for permission to submit his dissertation "*Über die Grenzbedingungen des Schwerefeldes an Unstetigkeitsflächen*" ("On the boundary conditions for the gravitational field equations on surfaces of discontinuity") and personal documents. Further, he wrote that he wanted to be examined in main subject – Theoretical Physics, and optional subjects – Experimental Physics, Mathematics and Philosophy. He also assured that not any part of the thesis was published. Other document, which reached the Philosophy Faculty on June 30, 1923, NRS wrote therein that he studied 10 semester at the University of Calcutta and four semesters in German Universities in Munich and Berlin.

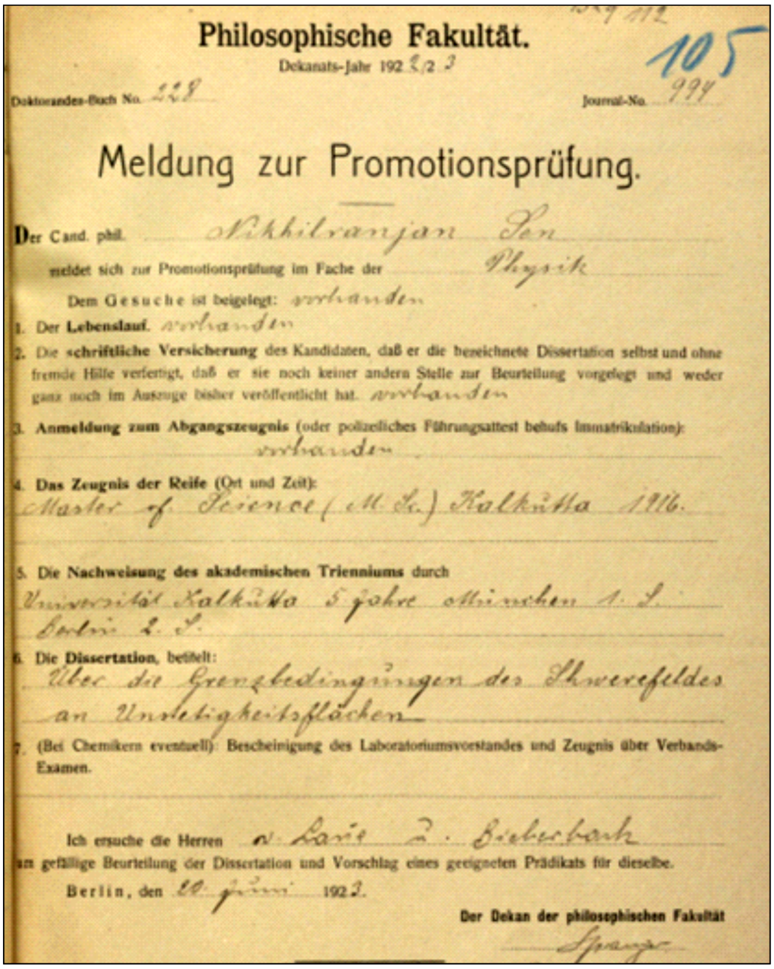
NRS submitted one and half pages long CV. After writing about his school education, he stated that he did his B.Sc. with English, Mathematics and Science (Natural Science) in 1913 from the Presidency College, Bengal. After finishing his M.Sc. in Mathematics in 1916, he worked as Research Scholar, and Lecturer in the Department of Applied Mathematics, Calcutta University for four years. During this time, he published research articles in the *Bulletin of Calcutta Mathematical Society*, and the British journal (*Philosophical Magazine* 1919, 1921). For one year (1921–1922), he worked with Professor Arnold Sommerfeld in Munich. The research work was published in the *Physikalische Zeitschrift* (20/21, 1922). Since, summer 1922, he was in Berlin and studied Physics, Mathematics and Philosophy under Max von Laue.

The University asked two experts to evaluate Sen's the-

$$\text{(I)} \qquad \left[g^{ks} \begin{Bmatrix} k\,m \\ m \end{Bmatrix} - g^{kl} \begin{Bmatrix} k\,l \\ s \end{Bmatrix} \right]_2^1 v_s = \varkappa\,\mathfrak{T},$$

$$\text{(II)} \qquad \begin{Bmatrix} \breve{k}\,m \\ m \end{Bmatrix}_2^1 v_l - \begin{Bmatrix} k\,l \\ s \end{Bmatrix} v_s = \varkappa\,\mathfrak{T}_{kl} \qquad (k, l = 1, 2, 3, 4),$$

Figure 3 The gravitational field of a spherical shell. Equations (I) and (II) are boundary conditions to calculate the surface density and the tension-component. Equation II shows that there is no need of coordinate transformation to determine the nature and physical origin of linearities. Courtesy: *Annalen der Physik*.



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Dekanats-Jahr 1922/23

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Meldung zur Promotionsprüfung.

Der Cand. phil. Nikhilranjan Sen

meldet sich zur Promotionsprüfung im Fache der Physik

Dem Gesuche ist beigelegt: vorhanden

1. Der **Lebenslauf**. vorhanden
2. Die **schriftliche Versicherung** des Kandidaten, daß er die bezeichnete Dissertation selbst und ohne fremde Hilfe verfertigt, daß er sie noch keiner andern Stelle zur Beurteilung vorgelegt und weder ganz noch im Auszuge bisher veröffentlicht hat. vorhanden
3. **Anmeldung zum Abgangszeugnis** (oder polizeiliches Führungsattest behufs Immatrikulation): vorhanden
4. **Das Zeugnis der Reife** (Ort und Zeit): Master of Science (M. Sc.) Kalkutta 1916.
5. Die **Nachweisung des akademischen Trienniums** durch Universität Kalkutta 5 Jahre München 1 S. Berlin 2 S.
6. Die **Dissertation**, betitelt: Über die Grenzbedingungen des Schwerefeldes an Unstetigkeitsflächen
7. (Bei Chemikern eventuell): Bescheinigung des Laboratoriumsvorstandes und Zeugnis über Verbands-Examen.

Ich ersuche die Herren v. Laue u. Bieberbach

um gefällige Beurteilung der Dissertation und Vorschlag eines geeigneten Prädikats für dieselbe.

Berlin, den 20. Juni 1923.

Der Dekan der philosophischen Fakultät

Spranger

Figure 4 Registration certificate for Ph.D. examination showing the details that N.R. Sen did M.Sc. in 1916; studied five years at the University of Calcutta; one year in Munich and one year in Berlin and his thesis on "*Über die Grenzbedingungen des Schwerefeldes an Unstetigkeitsflächen*". The proposed examiners are Max von Laue and Ludwig Bieberbach. Courtesy: Humboldt University of Berlin.

sis. In general, the first expert is always the person, who guided the research work. In N. R. Sen's case, Nobel Laureate Max von Laue was the first expert and second one was von Laue's colleague Ludwig Bieberbeck, a mathematician. What they wrote on Sen's work is described in the next section.

3.3 Report by Max von Laue and L. Bieberbach

According to the regulations, after the official record is examined, and found correct, the experts are asked to send evaluation report on the written thesis. Max von Laue wrote a long report, whereas L. Bieberbach in a short note stated that he agrees with von Laue's judgement, but he suggests to improve mathematical equations before the publication of the thesis.

According to the translated summary of Max von Laue report of July 5, 1923 –The first part of Sen's dissertation deals with the boundary conditions, which result from Einstein's field equations for the gravity for discontinuous areas in a similar way as the boundary conditions of electrodynamics for Maxwell equations. This very important task, which has never been solved properly, is solved in equation II for all coordinate systems in which the mass-tensor remains constant on the surface. The simple equation (I) also had a meaning. It answers the question in a given case in a short possible way, where you have to assume that the surface will be occupied by mass. This is certainly the case, if its left side does not disappear. If it is zero, the final decision can only be made using equation (II). The latter paragraphs of the first part deal with the special case of the static field and the boundary conditions that apply to it.

In Part II, the field of an infinite thin spherical shell is then derived from Einstein's equations, and the boundary conditions from Part I are tested on this solution. I suggest to accept the thesis as a dissertation and giving it a laudable grade.

After the report of experts reach the office. A date is fixed for defending thesis. The candidate has to give a short lecture to present his work followed by questions posed by the members of the examination committee.

3.4 Defending the dissertation

According to the available documents NRS defended his dissertation on July 26, 1923. He was examined by Max von Laue (theoretical physicist), Arthur Wehnelt (experimental physicist), Ludwig Bieberbach (mathematician) and Max Dessoir (Professor of Philosophy).

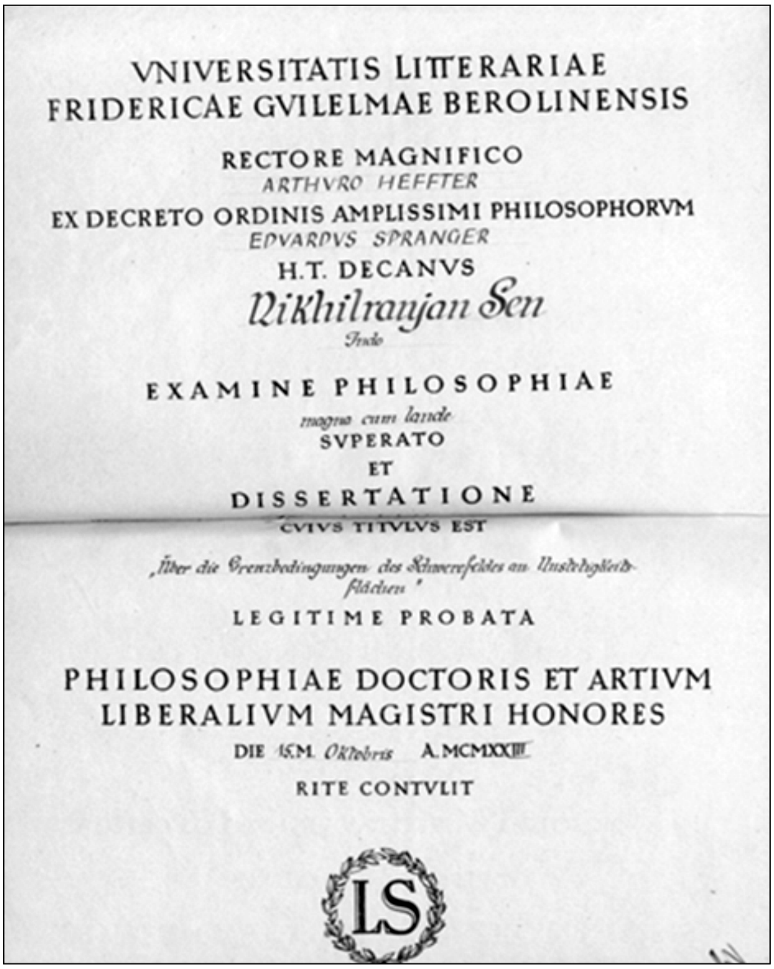
We learn from the keynotes in examination protocol that A. Wehnelt asked questions on the determination of electron's charge by Thomson, Wilson and Millikan methods. He also asked about Bohr atom theory and quantum theory and lastly questions on para-, dia- and ferromagnetism. He evaluated the candidate with grade '*gut*', which is equivalent to 2.

Max von Laue examined NRS in theoretical physics. He asked questions on Newton motion equations, potential energy, momentum, angular momentum, Hamilton tensor, wave equation and Zeeman Effect etc. Max von Laue gave grade '*sehr gut*', that is, 1.

Unfortunately, the handwriting of the mathematician L. Bieberbach is not readable. What we know for sure is that he asked questions on the potential of an inhomogeneous ellipsoid. He evaluated NRS with grade '*gut*', that is, 2.

The fourth examiner, the philosopher, asked questions on the natural science of Aristotle and modern natural philosophy. He noted that the examinee knew better on the Greek philosophy than the modern. He gave grade '*durchaus befriedegend*', that is, quite satisfactory, which is equivalent to grade 3. All in all, the total grade was 2, that is, '*magna cum laude*', the second best grade (Figure 5). According to rules and regulation of German universities, the Ph.D. thesis must be published. Sen published it in the form of an article in *Zeitschrift für Physik* as mentioned earlier. However on analysing the journal no reference to Sen's article was found. Also, the author did not find any article in *Nature* referring to Sen's thesis. It suggests that initially the paper did not make high impact. However, this statement needs to be interpreted very carefully, because results are based on the analysis of only two journals. During his stay in Germany Sen wrote two more articles with his guide von Laue dealing with de Sitter's world (von Laue & Sen 1924a), and change in potential of ions and emitted electrons of glowing metals (von Laue & Sen 1924b).

It will be of interest to check, whether NRS met or communicated with Albert Einstein? The answer seems to be positive. For instance, an Indian student A.M. Bose, who was in Belin in those days, requested Einstein for a recommendation letter for the Guruprasanna Scholarship of the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ARTHVRO HEFFTER
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EDVARDVS SPRANGER
H.T. DECANVS
Nikhilranjan Sen
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DISSERTATIONE
CVIVS TITVLVS EST
„Über die Grenzbedingungen des Schwerefeldes an Unstetigkeitsflächen"
LEGITIME PROBATA
PHILOSOPHIAE DOCTORIS ET ARTIVM
LIBERALIVM MAGISTRI HONORES
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Figure 5 N. R. Sen's Ph.D. Certificate. Courtesy: Humboldt University of Berlin.

University of Calcutta. In his letter of June 18, 1925, he informed Einstein that he (Bose) wrote to the authorities of the university about attending his (Einstein's) lectures on the theory of relativity, and also the weekly seminar held by Einstein and Professor Max von Laue together. Was there any correspondence between Einstein and Sen? I have written a book *Einstein Rediscovered: Interactions with Indian Academics* based on Einstein's letter to Indian scientists as well as Tagore and other less known persons. To the best of my knowledge, there was no correspondence between Einstein and Sen (Singh 2019). Thus, it cannot be said about Einstein's view about Sen's work?

After returning back to India, NRS extensively worked on the theory of relativity; and earned name as the founder of the 'Kolkata School of Theory of Relativity'. M. N. Saha and S. N. Bose, who had written the first book in India, on the theory of relativity (Saha & Bose 1920), did not play a big role on this subject in later years, as did N. R. Sen.

4 Conclusion

N. R. Sen's formative years are of great interest. Sen was a product of Presidency College Calcutta. He called it as the best College in Bengal which was not an exaggeration. Many famous Bengal based physicists and chemists came from this college suggesting that in those days, Presidency Colleges had very high standard, even better than Universities. Thus if a nation wants to have good quality scientists, it should raise the standard of colleges.

Sen's teachers, D. N. Mallik and J. C. Bose themselves were researchers whose teaching and research influenced the young scholars. Before publishing his results, Sen got the chance to present them in the meetings of the Calcutta Mathematical Society, mainly dominated by experienced researchers like Asutosh Mookerjee, C. V. Raman, G. Prasad, D. N. Mallik. They provided valuable feedback to young scholars like Sen. It can be seen that societies like the Mathematical Society of Calcutta played a big role in nurturing young researchers providing platform for close interaction between young and experienced scholars. It also shows the importance of high quality researchers at the initial stage, particularly at college level.

Sen's initial scientific work was closely related to the subjects he was teaching. It suggests that if a teacher is interested in research it can be found from textbooks. Sen, before leaving India, definitely knew about the theory of relativity. However, his interaction with Arnold Sommerfeld; and in particular Max von Laue made him one of the experts on the theory of relativity. Sen's story shows the importance of working under a renowned scientist.

Indian physicist, A. K. Raychaudhuri is known for an equation named after him in the theory of relativity who was Sen's contemporary. It would be of interest to find out, whether Sen influenced him. As I do not possess their biographies or correspondences between them nothing can be said definitely. Further research is needed on the lives and science of these two great men.

Acknowledgements

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