Arpan Dey

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SUMMARY

Arpan Dey is a Masters student at the University of Montpellier's IDIL (Inter-Disciplinary In-Lab) Graduate Program (*Modelling Biological and Environmental Systems – Fundamental Physics and Applications* track). He holds a Bachelor of Science degree in physics from St. Xavier's College, Kolkata. In physics, he is mainly interested in quantum mechanics, statistical mechanics, nonlinear dynamics, complex systems and the philosophy of physics. He has written and edited many science articles (research and review) for different journals and magazines. He has worked on several research projects and also presented his work at different institutions and conferences. He has published a popular science book on physics: *Our Physics So Far: A Journey through Spacetime, Consciousness and the Fundamental Nature of Reality*. He is also the founder of a physics blogging site, *The Journal of Young Physicists*, where students can submit their physics articles for review and publication.

EDUCATION

- **University of Montpellier, Montpellier, France**

IDIL Masters student, Fundamental Physics and Applications
2025 - Present
Modelling Biological and Environmental Systems (MoBiEn) – Physics track

- **St. Xavier's College (Autonomous), Kolkata, India**

Bachelor of Science B.Sc. (Honors) in Physics
General Elective Subjects: Mathematics, Computer Science
CGPA: 8.02/10 (First class)
2022 - 2025
Undergraduate dissertation project: Feynman's path integral formulation of quantum mechanics

- **Delhi Public School, Burdwan, India**

Senior secondary high-school graduate
2008 - 2022
Senior School Certificate Examination (CBSE) – 12th Standard (Science), Score: 94.33%
Secondary School Examination (CBSE) – 10th Standard, Score: 98.17%

EXPERIENCE AND EXTRACURRICULAR ACTIVITIES

- **Research Intern, Laboratoire Charles Coulomb**

September 2025 - Present

I am currently working on polymer physics and biophysical modelling of DNA-protein interactions under the supervision of Jean-Charles Walter at Laboratoire Charles Coulomb (L2C), a joint lab of CNRS and Montpellier University. I am exploring both the analytical and computational aspects of the problem, and in the process trying to develop a deeper understanding of statistical physics and biological systems.

- **Summer Research Intern, Institute of Mathematical Sciences**

Jun 2025 - Jun 2025
I was accepted into the Summer Research Program (under *Theoretical Physics* category) offered by the Institute of Mathematical Sciences (IMSc), Chennai. As part of my internship, I worked in the intersection of nonlinear dynamics

and computational biology under the guidance of Sitabhra Sinha, by studying synchronization in coupled Kuramoto-type oscillators with nonlinear feedback. I am interested in further studying the effect of different lattice geometries (square, hexagonal etc.) and the different types of networks (fully-connected, randomly-connected, directed, undirected etc.) on synchronization.

- **Summer Research Fellow, Physical Research Laboratory**

Jun 2024 - Jul 2024

I received the Summer Research Fellowship (2024) offered by the Indian Academy of Sciences. As part of the fellowship, I studied the modular group and modular symmetries. More specifically, I investigated the fundamental domain of the modular group, and possible applications of the same in the Standard Model and other areas of theoretical high energy physics. I worked under the supervision of Ketan Patel of the *Theoretical Physics* division at Physical Research Laboratory (PRL), Ahmedabad.

- **Executive Editor (Physical Sciences), Young Scientists Journal**

Jan 2026 - Present

I currently serve as the executive editor for physical sciences at the Young Scientists Journal (YSJ) – an international, peer-reviewed publication for young students. As executive editor, I coordinate all the editorial teams of all subjects that fall under the physical sciences. I have served as senior physics editor of the YSJ for over five years since 2020. As part of my role, I was in charge of reviewing and managing all physics articles (research and review) that are submitted to the journal, as well as coordinate the junior physics editors. Before my appointment as a senior physics editor, I worked as a junior editor of physics, mathematics and astrophysics for the YSJ. I also briefly served as a curriculum developer for YSJ's *reSTEM* project, which was an initiative to introduce high-school students to research.

- **Mentor (Physics), Young Scientists Journal**

Jan 2026 - Feb 2026

I served as a mentor for the Young Scientists Journal Research Program 2026. I mentored four high-school students, guiding them on forming research questions, literature review and exploring physics with an emphasis on thinking rather than output. With the four mentees, I explored topics ranging from holographic principle and the Ryu-Takayanagi conjecture to coupled oscillators and the Kuramoto model.

- **Virtual SOAR Scholar, Emory University Laney Graduate School**

Jun 2023 - Aug 2023

I was selected to Emory University's 2023 LGS-SOAR (Laney Graduate School – Summer Opportunity of Academic Research) program, and was recognized by the university upon successful completion of the program.

- **Associate Student Editor-in-chief - Pebbles 2025, St. Xavier's College Science Association**

Nov 2024 - March 2025

I have served as the associate editor-in-chief of *Pebbles 2025*, the annual magazine of the Science Association of our college. Prior to this, I was a member of the editorial board of *Pebbles 2024*. As part of my role, I reviewed articles and interviewed researchers from different scientific disciplines. I was also a part of the student committee of *Horizon 202*5 – the annual magazine of the Department of Physics of my college. I was involved in editorial, interviewing and advisory responsibilities, and also contributed an article to the magazine.

- **Founder and Contributor, The Journal of Young Physicists**

Jul 2020 - Present

The Journal of Young Physicists is a platform for young physics aspirants to get their physics articles reviewed and published for free. We are committed to popularizing physics and fostering the growth of young physicists.

- **Research Guide, Xaverian Astronomical Society**

Oct 2024 - April 2025

As a research guide of the Xaverian Astronomical Society (XAS) of my college, I have mentored a junior on a project exploring the interplay between entropy, information, quantum information and potential applications in understanding the black hole information paradox. The final result was a report titled "Preserving Information in the Void: A Quantum Computational Approach to Black Holes." During my time at XAS, I was also part of a student group that was learning Bayesian cosmology.

- **Young Member of The Junior Academy, The New York Academy of Sciences**

Sep 2020 - Jul 2022

The Junior Academy is a program for high-school students, where students from all over the world are put in small groups and given the opportunity to work on real-life, challenging STEM problems. I worked in an international team of five students on two challenges: first, designing a telemedicine app and second, studying COVID vaccination statistics in different countries and designing an effective vaccine distribution scheme.

- **Science communicator and content creator, YouTube**

Jun 2019 - Present

I create physics and science videos for my YouTube channel – *Arpan D*, as well as videos on philosophy, travel, life and other stuff I find interesting. My channel currently has over 3 lakh views and over 1000 subscribers. In my free time, I also write songs and produce music. I have collaborated with several vocalists worldwide and released eighteen original songs and two albums (*Unsettled Bliss* and *Anti-Simulation*). All of my songs can be found in my second YouTube channel – *Arpan Amplified*.

BOOKS

- **Our Physics So Far: A Journey through Spacetime, Consciousness and the Fundamental Nature of Reality (2022)**

ISBN: 978-1685090234, ASIN: B0BD8MC5NW

Our Physics So Far is a popular science book on physics which narrates the story of physics and science from Newton's days to the present. The book starts with a discussion on cosmology, then moves on to mathematics, classical physics, special and general relativity and quantum mechanics. The next part focuses on particle physics, information paradox and the hunt for a unified theory. Then the book turns to the physics of complexity and chaos theory, following which the question of the nature of consciousness is addressed, with some brief discussion of neuroscience and psychology. Finally, there is a discussion on metaphysics, paradoxes and the fundamental nature of reality. Adding to the book's appeal is an interview with renowned physicist Edward Witten. The book has mostly received positive feedback from readers worldwide.

- **The Adventure of the Injured Cabman (and a Short Story) (2022)**

ISBN: 979-8886671018, ASIN: B09XPTKVCS

The Adventure of the Injured Cabman is a Sherlock Holmes pastiche, an enthralling story that retains the original flavor of Conan Doyle's famous detective. The book also contains a short story: *The Last Lure*.

SELECTED SCIENTIFIC ARTICLES

- **Monte Carlo Simulations of Polymer Dynamics on a 2D Lattice: Rouse Constraints, Heterogeneous Update Rules and Emergent Global Behavior (2025)**

DOI: 10.5281/zenodo.19152875

In this report, we study polymer dynamics using a discrete, lattice-based analogue of the Rouse model, where monomers move subject to a nearest-neighbor distance constraint (we analyze the polymers both with and without self-avoidance). Through Monte Carlo simulations, we quantify chain evolution via the end-to-end distance, radius of gyration and mean-squared displacement, observing a subdiffusive-to-diffusive crossover consistent with Rouse scaling (when self-avoidance is neglected). Building on this, we construct several alternating-rule toy models (alternating copolymers) and a block-copolymer toy model that impose spatially heterogeneous geometric constraints. By changing only which moves different monomers may attempt - without adding forces, potentials or energetic biases - we make the polymers break detailed balance and generate a spectrum of nonequilibrium responses. Some remain close to Rouse-like behavior due to geometric suppression of rule heterogeneity, while others exhibit strong nonequilibrium expansion driven by bond-length fluctuations. We study the block-copolymer model in particular detail. In this model, two halves of the chain evolve under distinct dynamical rules with temporal heterogeneity in addition to geometric heterogeneity. We systematically analyze the diffusion of both halves separately, as well as the diffusion of the center of mass, for different degrees of heterogeneity in the biased update frequency and different chain lengths. In the appendices, we look at a minimal model of polymer collapse where only the end monomers experience an energetic attraction, and finally also reconstruct the mean-field phase diagram of the magnetic polymer model of Garel et al. (1999).

- **Statics and Dynamics of an Interacting Polymer: Application to the Bacterial DNA Segregation (2026)**

M1 personal project, IDIL Graduate Program, University of Montpellier

Supervision: Jean-Charles Walter, Andrea Parmeggiani and Linda Delimi, Laboratoire Charles Coulomb, Montpellier

This report explores how physical models can be used to describe the organization and dynamics of an interacting polymer in biological contexts. We first discuss the ParABS system for bacterial DNA segregation, and how cooperativity in biological systems can be studied using Ising-type models. Next, we introduce magnetic polymers, where magnetic Ising-like spins on the monomers coupled to polymer conformation give rise to transitions between swollen and collapsed phases. We extend our discussion to polymer dynamics through the Rouse model and explore it using lattice Monte Carlo simulations. We then discuss Walter et al.'s 2017 reaction-diffusion model that explains the segregation and equipositioning of ParBS complexes in bacterial DNA, actively driven by ParA gradients, and finally we discuss some relevant open questions and future directions.

- **Nonlinear Dynamics of Dyads with Self-Regulating Internal States and Nonreciprocal, Time-Decaying Interactions (2026)**

Preprint: 10.21203/rs.3.rs-9390873/v1

In this work, we introduce a minimal model for emotional and relational interactions between two individuals. The framework consists of four coupled nonlinear differential equations: two describing the time evolution of the individuals' emotional states and two describing the directed relational feelings between them. The model incorporates key mechanisms relevant to interpersonal dynamics, including internal emotional regulation, nonreciprocal influence, time-decaying interaction strength, coupling between (internal) emotional dynamics and (external) relational dynamics, and stochastic perturbations. To summarize the evolving dyadic state, we introduce a bounded scalar metric that quantifies overall emotional and relational alignment between the two individuals. We further analyze the qualitative behavior of the system using numerical simulations. The model is minimal and operates under explicit assumptions. Within these limits, however, it provides a compact mathematical framework for studying coupled emotional and relational dynamics at the level of a dyad, complementing mean-field approaches that focus on large populations.

- **Path Integral Formulation of Quantum Mechanics (2025)**

DOI: 10.5281/zenodo.15564781

Supervision: Tanaya Bhattacharyya, St Xavier's College, Kolkata

In this article, we present a rigorous introduction to Feynman's path integral formulation of quantum mechanics. We start by outlining the motivation behind the path integral formulation. Then we build the mathematics required for defining the sum-over-paths and derive the free particle propagator, as well as the propagator for a particle with a non-zero potential energy, with particular focus on linear and quadratic potential energies. We use these results to arrive at some standard results in quantum physics: namely Planck-Einstein equation, de-Broglie equation and Schrödinger equation. This helps us appreciate the equivalence between the path integral and the canonical formulation, as well as understand the difference in the approaches employed by the two formulations to arrive at the results. We also use Python to generate plots of the free particle wave function and propagator as functions of position and time, and explore the conceptual difference between the wave function in canonical quantum mechanics and the propagator used in the path integral formulation. We also introduce the basic idea behind perturbation theory, by using the free particle propagator to study a particle that moves between two potential-free points in spacetime, but via intermediate points with non-zero potentials, in one of the appendices. In the end, we discuss path integrals in a broad perspective, and make some general comments on the future of theoretical physics.

- **Magnetization in the 1D Ising Model and the Metropolis Algorithm: A Glimpse into Statistical Physics and Monte Carlo Simulations (2025)**

DOI: 10.5281/zenodo.17992558

In this report, we explore the one-dimensional Ising model using exact analytical methods and Monte Carlo simulations. Although it is the simplest nontrivial, exactly solvable lattice model, the 1D Ising system still captures cooperative low-temperature behavior, making it an ideal platform for understanding numerical sampling techniques. Analytically, the 1D model shows no true thermodynamic phase transition at finite temperature; finite-size effects lead to nonzero low-temperature magnetization. By comparing transfer-matrix results, mean-field approximations and Metropolis Monte Carlo data, we demonstrate how fluctuations and correlations - ignored in mean-field theory - remain crucial even in this minimal spin system. We also visualize space-time spin evolution

across temperatures, revealing the crossover from stable ordered domains to rapidly fluctuating disordered states as thermal agitation competes with coupling. Though brief and unoriginal in results, the report emphasizes a pedagogical viewpoint, using the 1D Ising model as a laboratory to understand ergodicity, equilibration and emergent order, while highlighting its role as a testing ground for numerical methods despite the absence of true phase transitions. We also briefly discuss the 2D Ising model in the end.

- **Investigations on the Fundamental Domain of the Modular Group (2024)**

DOI: 10.5281/zenodo.15737745

Supervision: Ketan Patel, Physical Research Laboratory, Ahmedabad

The aim of this study is to understand the fundamental domain of the modular group, and investigate the nature of transformations that map points outside the fundamental domain to points inside the fundamental domain of the modular group. This has also been verified computationally: the upper half complex plane has been divided into appropriate regions and a Python simulation has been run to verify the transformations that maps the points inside the fundamental domain for each region. This enriches our understanding of modular groups, which is crucial to understand modular forms, which have wide-ranging applications in the fields of mathematics, physics and even beyond. The sheer richness of the theory of modular forms provides powerful tools for understanding certain physical and mathematical phenomena where modular symmetry naturally arises, such as in string theory, number theory and cryptography.

SELECTED ESSAYS

- **Beyond Quantum Mechanics: Black Holes, Information, Unification, Extra Dimensions and the Future of Theoretical Physics (2025)**

DOI: 10.5281/zenodo.16793345

Commemorating the first hundred years of quantum mechanics, in this essay we discuss some foundational (and often misunderstood) ideas in quantum mechanics and some novel approaches toward a theory of quantum gravity.

- **Complexity: The Next Big Thing in Physics (2024)**

DOI: 10.5281/zenodo.13913639

This essay starts with a brief discussion on the various approaches to quantify complexity. Then assembly theory - a recent, novel and promising approach to study complex systems - is discussed in some detail. We also touch upon other new and relevant theories like constructor theory. Then some interesting properties of complex systems - like emergence, self-organization and unpredictability - are discussed. Then finally we demonstrate how ordered complexity can arise from randomness, and discuss consciousness from a complexity perspective.

- **On the Quantum Mechanical and Temporal Origins of Entropy: Exploring the Interplay between the Cosmological Arrow of Time, Thermodynamic Arrow of Time and Heisenberg's Uncertainty Principle (2025)**

DOI: 10.5281/zenodo.19153395

In this essay, we explore the possibility of understanding the increase in the entropy of our universe as a consequence of microscopic uncertainty, as dictated by the uncertainty principle in quantum mechanics. We also discuss whether the arrow of time is a result of the second law of thermodynamics or the other way round. The most widely accepted view is that entropy is responsible for the unidirectional nature of time. However, in this essay, we argue that the cosmological arrow of time - which is a result of the expansion of the universe - comes first, and the thermodynamic arrow of time and the second law of thermodynamics follow. And while quantum uncertainty might not be directly responsible for driving the increase in entropy, it provides the foundational framework that allows entropy to be defined and to evolve meaningfully in our universe.

- **Mathematics: The Future of Physics? (2025)**

Pebbles 2025 (Annual magazine, Science Association, St. Xavier's College, Kolkata)

In this speculative essay, I highlight that recent decades have seen fewer fundamentally new breakthroughs in physics, and argue that further progress may come from mathematics, which often reveals itself as the natural language of physical reality. I also explore the idea that mathematics may underlie the universe at a deeper level, potentially explaining the emergence of spacetime and resolving conceptual tensions between physical theories.

- **The Method in Nature's Madness: Synchronization, Collective Behavior and Phase Transitions (2026)**

Pebbles 2026 (Annual magazine, Science Association, St. Xavier's College, Kolkata)

In this essay, we explore how large-scale order can emerge from randomness through interactions, using the Kuramoto model of synchronization and the Ising model of phase transitions as complementary frameworks. We see how simple local rules, combined with noise, give rise to collective behavior in both temporal and spatial domains, illustrating that complexity in natural systems arises not despite randomness, but through it, offering a unified perspective on emergent phenomena across physical and biological contexts.

- **Boltzmann's Past Hypothesis: Why Yesterday was Special? (2025)**

The Journal of Young Physicists

In this essay, I explain the arrow of time problem and discuss Boltzmann's "past hypothesis," which proposes that the universe began in an extraordinarily low-entropy state to account for why yesterday was "special" and why time appears to flow forward. I also explore its consequences, puzzles like Boltzmann brains, and why this idea may ultimately be a postulate we simply have to accept or reinterpret through broader cosmological ideas.

- **Energy versus Entropy: The Battle for the Control Wheel (2025)**

Horizon 2025 (Annual magazine, Department of Physics, St. Xavier's College, Kolkata)

This short essay briefly explores how the universe is driven by two fundamental players - energy, which tends to spread and stabilize systems, and entropy, which measures disorder and inevitably increases with time.

- **Did Einstein believe in God? (2020)**

The Journal of Young Physicists

In this speculative piece, I explore the tension between science and religion, using Einstein's view of God to emphasize my point. I trace how Einstein's philosophical discomfort with quantum uncertainty and his deep faith in a precise, deterministic universe might have shaped his view of God. Ultimately, I argue that Einstein's "God" was probably more a poetic symbol for the beauty and inevitability of fundamental physical laws than a figure of religion.

- **A Discussion on the Theory of Everything (2022)**

Horizon 2022 (Annual magazine, Department of Physics, St. Xavier's College, Kolkata)

In this essay, I outline the quest for a "theory of everything," explaining why unifying all four fundamental forces requires reconciling general relativity with quantum mechanics. I walk through major attempts toward this goal - like string theory and loop quantum gravity - highlighting both their promise and limitations, and finally reflect on whether a truly complete final theory is possible at all.

SELECTED PRESENTATIONS AND INTERVIEWS

- **Phase Diagram of the Semiflexible Magnetic Polymer – Poster Presentation at the GDR ADN&G (Architecture and Dynamics of the Nucleus and Genomes), CNRS Research Network, 2026** *(First annual meeting of GDR ADN-Physics, ENS de Lyon)*

  Collaborators: Linda Delimi, Jean-Charles Walter (Laboratoire Charles Coulomb, CNRS and University of Montpellier)

  In this poster, we present some preliminary results from our investigation of the phase diagram of the semiflexible magnetic polymer, where bending rigidity introduces a new competing energy scale alongside magnetic interactions. Using Monte Carlo simulations and a mean-field framework, we identify three phases: coil, disordered globule and crystalline, and show that both transitions are first-order. We are currently further investigating different structural candidates for the ground state of the polymer, as well as what happens in presence of an external magnetic field.

- **Ground State Structural Selection in the Semiflexible Magnetic Polymer – Poster Presentation at the GDR ADN&G (Architecture and Dynamics of the Nucleus and Genomes), CNRS Research Network, 2026** *(First annual meeting of GDR ADN-Physics, ENS de Lyon)*

  Collaborators: Linda Delimi, Jean-Charles Walter (Laboratoire Charles Coulomb, CNRS and University of Montpellier)

  In this poster, we focus on the ground state of the semiflexible magnetic polymer, where bending rigidity competes with attractive interactions between non-bonded, neighboring monomers. Using minimal analytical ansätze, we identify a crossover from contact-rich helical states to low-curvature folded-sheet structures as stiffness increases, providing a microscopic basis for the emergence of the different structures observed within the crystalline phase of the finite-temperature phase diagram.

- **Exploring Synchronized Oscillations in Kuramoto-type Oscillators with Nonlinear Feedback – Summer Research Program, 2025** *(Institute of Mathematical Sciences, Chennai)*
  Slides: https://doi.org/10.5281/zenodo.19153368
  Supervision: Sitabhra Sinha, Institute of Mathematical Sciences, Chennai
  Synchronization is a hallmark of complex systems, emerging from the interplay of randomness, coupling and nonlinear dynamics. In this project, I explore synchronization in a system of coupled oscillators using the Kuramoto model, with an additional nonlinear feedback term. I examine how frequency distributions, coupling strength and network topology influence synchronization through the time series of the phases for fully-connected and loosely-connected networks, and also for different lattices (toroidal, square, hexagonal). I also investigate cluster synchronization arising from multimodal initial frequency distributions. Together, these results show how randomness, combined with coupling and nonlinear feedback, produces rich collective behavior.

- **Dyadic Emotional Modeling: A Nonlinear Dynamics Approach – International School on Urban Physics and Environmental Research, 2026** *(University of Montpellier, University of Stuttgart, Vienna University of Technology)*
  Poster: https://drive.google.com/file/d/1-Ov7O_B7zuFFaZUf3keV5Dy_S3ei5OZ2
  Slides: https://drive.google.com/file/d/1KfcAUjTSf0yDobd5-3ORBZXD433AQuSI
  In this presentation, I introduce a mathematical model for studying the emotional and relationship dynamics between two individuals. The framework is based on a system of four coupled nonlinear differential equations, two of which represent the time evolution of the emotional states of the two individuals, and the other two equations represent how their feelings for each other evolve over time. The differential equations were designed to reflect key features of emotional and relationship dynamics, drawing on insights from empirical psychological studies. The model incorporates features such as internal emotional regulation, asymmetrical relationship influence, reciprocity and noise (external and internal). To summarize the evolving dyadic state, I also introduce a bounded scalar metric that quantifies overall emotional and relational alignment between the two individuals. I further analyze the qualitative behavior of the system using numerical simulations. This minimal model is meant to provide a compact mathematical framework for exploring dyadic emotional and relationship dynamics, deliberately focusing on the simplest nontrivial social unit of two interacting individuals, in contrast to mean-field approaches that begin at the level of large populations.

- **How Stiffness and Interactions shape the Structure of Magnetic Polymers – Working meeting on Bacterial DNA Segregation (BaDS), 2026** *(Laboratoire Charles Coulomb, University of Montpellier)*
  Supervision: Jean-Charles Walter, Linda Delimi, Laboratoire Charles Coulomb, Montpellier
  I presented my mean-field model of semiflexible magnetic polymers on an FCC lattice. I derived approximate free-energy upper bounds for coil, disordered globule, and crystalline phases, showing how entropy, magnetic attraction, and bending rigidity generate a three-phase diagram. The model predicts stiffness-stabilized crystalline ordering and first-order transitions between the competing phases. I also discuss different candidates for the crystalline ground state.

- **Statics and Dynamics of an Interacting Polymer: Application to the Bacterial DNA Segregation – M1 Personal Project, 2026** *(Laboratoire Charles Coulomb, University of Montpellier)*
  Slides: https://drive.google.com/file/d/14YaRpCOEtUQFknn8O5P9PiOx7vcRpl35
  Supervision: Jean-Charles Walter, Andrea Parmeggiani and Linda Delimi, Laboratoire Charles Coulomb, Montpellier
  This project, carried out as part of my personal project in the first semester of my Masters, explores how physical models can be used to describe the organization and dynamics of an interacting polymer in biological contexts, with particular focus on the ParABS system.

- **Path Integrals, Uncertainty, Entropy and Information (100 Years of Quantum Mechanics) – Quantum Foundations Summer School, 2025** *(Bhaktivedanta Institute, Kolkata and Centre for Development of Advanced Computing, Patna)*
  Slides: https://drive.google.com/file/d/1IJvlNZBsgOt19teKILuP6axEDnqSNF8U
  In this presentation, I discuss key ideas beyond standard quantum mechanics, focusing on the path integral formulation, uncertainty, entropy and information. I cover how Feynman's path integrals provide a global picture of quantum evolution, contrast propagators with wave functions and clarify the physical meaning of uncertainty. I finally also attempt to draw out a potential connection between quantum uncertainty, entropy and the arrow of time.

- **Assessing Large Language Model reasoning on Ordinary Differential Equations – Non-Core Unit on AI, 2025** *(IDIL Graduate Program, University of Montpellier)*
  Supervision: Ovidiu Radulescu, Gabriele Orlando, University of Montpellier
  Slides: https://drive.google.com/file/d/1QN_ulaolB8b1rTjDcYyk-tBlGd92Gyv1
  This short-term project was carried out in the first semester of my Masters course as part of a non-core unit on the impact of Large Language Models across various disciplines. In the presentation, I systematically evaluate how a general-purpose Large Language Model (ChatGPT-5.1) reasons about Ordinary Differential Equations (ODEs). Through carefully controlled prompts, the same ODEs were presented as text as well as visual plots, in order to assess the model's mathematical reasoning, visual interpretation and consistency. The study demonstrates that while the model performs confidently on familiar and well-documented systems (such as harmonic oscillators), it struggles with backward inference from graphs, subtle distinctions (like additive phase difference versus multiplicative phase factors) and complex or less conventional ODE systems.

- **Assembly Theory and the Evolution of Complex Systems – Paper Presentation Competition, Spectrum 2024** *(Annual fest, Department of Physics, St Xavier's College, Kolkata)*
  Slides: https://docs.google.com/presentation/d/1HV3gbNrkBa6oBoFCPuGZAl7GXYsLAjK5Xs08PPmqyHk
  In this presentation, I introduce complexity science as a key emerging theme in modern physics, explaining why many natural systems cannot be understood by analyzing their parts alone. I discuss different measures of complexity, assembly theory and the crucial role of history, selection and copy number in shaping complex structures. The presentation also highlights emergence, downward causation, competing effects and why complexity thrives "at the edge of chaos." I conclude by discussing how ordered complexity can arise from randomness.

- **The Journey of a Young Physicist – by Mayank Dora, STEMz Perspectives, 2024** *(Young Scientists Journal science podcast)*
  URL: https://www.youngscientistsjournal.com/podcast/episode/1aaf8292/episode-15-the-journey-of-a-young-physicist-an-interview-with-arpan-dey
  I talk about my journey and science popularization with Mayank Dora in this episode of STEMz perspective, a science podcast by the Young Scientists Journal. I talk about how I got interested in physics, why I wrote *Our Physics So Far* and created *The Journal of Young Physicists* and how aspiring students should start their journey in STEM.

- **Interview with An Aspiring Physicist – by Aaradhana Umesh, 2023** *(Travelling through Pages, YouTube)*
  URL: https://youtu.be/x_Zvn9IVOS0
  In this interview with Aaradhana Umesh, I talk about my journey into physics, passion for science communication, my work with youth-focused journals and also about my music.

- **Young author Arpan Dey talks about his book *Our Physics So Far*, 2021** *(The Literature Times)*
  URL: https://www.theliteraturetimes.com/young-author-arpan-dey-talks-about-his-book-our-physics-so-far-a-journey-through-spacetime-consciousness-and-the-fundamental-nature-of-reality/
  In this feature, I was interviewed about my debut popular science book *Our Physics So Far*. I discussed the motivation behind writing the book as a teenager, my aim of making modern physics and fundamental questions accessible to young readers and how the project grew out of my early fascination with quantum mechanics and consciousness.

- **'Dey'light at the end of a quantum tunnel as teen physicist Arpan explores consciousness – by Darshana Ramdev, 2022** *(Global Indian)*
  URL: https://www.globalindian.com/youth/global-indian-exclusive/deylight-at-the-end-of-a-quantum-tunnel-as-teen-physicist-arpan-explores-consciousness/
  This feature highlights my early journey as a teenager. It also touches on how my reading, writing and research interests evolved into building communities and engaging with complex scientific ideas.

- **All that matters is physics – by Hasini Lakshminarayanan, 2022** *(The First Step)*
  URL: https://www.arpandey.net/exclusive-interview-the-first-step
  This exclusive interview explores my early scientific journey, motivations behind writing *Our Physics So Far* and the ideas that shaped my path in physics and writing. I discuss how curiosity about quantum mechanics, consciousness and other fundamental questions inspired my research and communication efforts. I also discuss my interests apart from physics.

- **Emergence and Consciousness – Summer Opportunity of Academic Research, 2023** *(Laney Graduate School, Emory University, Atlanta)*

  Slides: https://docs.google.com/presentation/d/1GneY_hqzPwnpEfJEwCC8-eIpIVCVpt8RnWXyITsI7n4

  In this presentation, I talk about the concept of emergence, explaining how complex properties arise from interactions among simpler components, with consciousness used as a possible example. I examine whether consciousness is best understood as an emergent property of matter or a fundamental feature of the universe, drawing on perspectives from physics and neuroscience. I also explore weak versus strong emergence, emphasizing open questions about whether existing physical laws are sufficient to explain consciousness or whether new principles are required.

SELECTED INTERVIEWS WITH LEADING PHYSICISTS AND AUTHORS

- **In Conversation with Edward Witten on Fundamental Physics (2020)**

Interviewed for my book Our Physics So Far

In this interview, I ask Edward Witten about fundamental questions in theoretical physics, including holography, quantum gravity, emergent spacetime and the limits of human understanding. The conversation provides insight into Witten's perspectives on fundamental physics and its future directions.

- **An Interview with John Horgan, Author of *The End of Science* (2023)**

The Journal of Young Physicists

In this interview, I speak with author John Horgan about his provocative view that the era of revolutionary scientific breakthroughs may be drawing to a close. We discuss consciousness, the limits of scientific explanation, the challenges facing fundamental research and what it means for the future of physics and human knowledge. The conversation blends critical insight with thoughtful reflection on the nature and trajectory of science itself.

- **An Interview with Leonard Mlodinow, Author of *The Grand Design* (with Stephen Hawking) (2023)**

The Journal of Young Physicists

In this interview, I ask physicist and author Leonard Mlodinow about a wide range of topics, from cosmology and unification to consciousness and free will. The conversation weaves together accessible insights with profound reflections on physics and the philosophy and future of science in general.

- **An Interview with Paul Halpern, Author of *Einstein's Dice and Schrödinger's Cat* (2023)**

The Journal of Young Physicists

In this interview, I talk with physicist and author Paul Halpern about his views on theoretical physics and the philosophical foundations of physics. Through unique and thoughtful questions and answers, the conversation blends scientific insight with philosophical depth, offering a reflective look at how physics shapes our understanding of reality.

- **An Interview on Quantum Foundations and Theoretical Physics with Tejinder Singh of TIFR (2025)**

The Journal of Young Physicists, YouTube

In this interview, I dive deep into quantum foundations, gravity and unification with Tejinder Singh of the Tata Institute of Fundamental Research (TIFR). We discuss his views on why addressing foundational problems in quantum theory is important, and we delve into his research on extra time dimensions, algebraic structures like quaternions and octonions and how these ideas might reshape our understanding of the universe.

- **A Discussion on the Physics of Life with Apratim Chatterji of IISER Pune (2025)**

Interviewed for my YouTube channel

In this interview, I speak with Apratim Chatterji of the Indian Institute of Science Education and Research (IISER), Pune to explore the physics of life. We discuss how the principles of statistical mechanics and soft matter physics are used to study the self-organization of non-living molecules into living cellular structures, with a particular focus on his research into chromosome organization and entropic forces. Our conversation also delves into the necessity of bridging theory with experimental validation and the importance of improving physics education and making it more relatable and accessible to young minds.

EXPLORATORY HIGH-SCHOOL WORKS

- **Investigations on Isotopic Elements in Terms of Quarks (2020)**

DOI: 10.5281/zenodo.18078451

This work explores isotopic elements from a quark-level perspective, expressing isotopes not in terms of protons and neutrons, but in terms of their constituent up and down quarks. By classifying isotopic elements into different categories and incorporating natural abundance percentages, quantitative relations are derived linking isotope mass differences with differences in quark content, and then verified through multiple examples across light, medium and heavy nuclei, demonstrating consistent patterns. Although primarily conceptual and with no direct practical applications, the study offers an interesting quark-based viewpoint on isotopes and their structural differences.

- **Can the de Broglie Relation be Modified for Accommodating Relativistic Modifications in the Schrödinger Equation? (2020)**

DOI: 10.5281/zenodo.18078465

In this article, we explore whether the de Broglie relation can be modified by incorporating relativistic expressions and the consequences of such a modification on Schrödinger's equation. Using the relativistic mass-energy-momentum relation, we derive an alternative wavelength expression and analyze how it alters the Hamiltonian in Schrödinger's equation. We then compare these results with the standard results and discuss their physical validity.

- **A Conceptual Design for Improving Aircraft Take-Off Efficiency (2020)**

DOI: 10.5281/zenodo.18078486

In this article, we propose a conceptual "VR-Flap" design – a downward-movable leading-edge control surface in the airplane wing positioned near the fuselage – to improve aircraft take-off efficiency and pitch performance. Using established principles, we argue that a carefully-engineered, brief deployment of this surface during VR could significantly increase lift and assist or supplement the action of the elevators. We qualitatively discuss its potential benefits in short-runway operations, emergency situations and maneuverability, while also addressing practical challenges such as drag, fuel storage, engine placement and ground clearance.

SELECTED CERTIFICATIONS

- **Summer Research Program – Institute of Mathematical Sciences (2025)**
  https://drive.google.com/file/d/1uxVqI8qrkpikHf0ZpqkyOmsh73GIqFV4

- **Summer Research Fellowship Program – The Three National Science Academies of India (2024)**
  https://drive.google.com/file/d/1WJL2zSACZ0DBcIqpy0Dv9VhA98y2MTq0

- **Summer Internship Program – Physical Research Laboratory (2024)**
  https://drive.google.com/file/d/1j75TsuS0wD4YXhuV93r1BGIdiSGJmaL9

- **Research Mentor, Xaverian Astronomical Society – St. Xavier's College, Kolkata (2025)**
  https://drive.google.com/file/d/1zhCcX1KrBz5ptWsXqTiMzw5uoo1g1aJY

- **Summer Opportunity for Academic Research – Laney Graduate School, Emory University (2023)**
  https://drive.google.com/file/d/1FjobvYBJ-EL0oBn30OXWu36sWd6byznP

- **Top 100 Innovators – Student Innovation Challenge, Smartcircuits Innovation Pvt. Ltd. (2020)**
  https://drive.google.com/file/d/1YvspMZ96eQ65Thf8x-zpnJ4YkIs6vTq7

- **Oral Presentation, Quantum Foundations Summer School – Bhaktivedanta Institute, Kolkata and Centre for Development of Advanced Computing, Patna (2025)**
  https://drive.google.com/file/d/1oBL_DLF-EK2SLvV0NNZ6MQzWgdlCJiWX

- **The Unknowable and the Counterintuitive: International Exchange Program on Science and Religion – Santa Clara University, California; St. Xavier's College, Kolkata (2024)**
  https://drive.google.com/file/d/17gJxogT5uOt6qLX1p55A-Vj9p7WZD-LF

- **Young Member – The New York Academy of Sciences (2020-2022)**
  https://www.credly.com/badges/cc3a3d4a-6164-4baf-b5dd-09cee1cb8ac1

- **Introduction to Complexity – Santa Fe Institute (2024)**
  https://www.complexityexplorer.org/courses/185-introduction-to-complexity/certificates/4053598210.pdf

- **Editorial Board Member, Horizon 2025 – St. Xavier's College, Kolkata**
  https://drive.google.com/file/d/146I8_2VcUOAkWHGszOuxqIolxxBNCUEr

- **Physics behind Biology: International Colloquium 2025 – St. Xavier's College, Kolkata**
  https://drive.google.com/file/d/1lL_r5ErP-oOFyatK6nMYJQWzOHVs4Oau

SKILLS AND INTERESTS

- **Areas of Interest in Physics** – Quantum mechanics, Statistical mechanics, Stochastic processes, Nonlinear dynamics, Biological physics, Complex systems
- **Hard skills** – Python, Monte Carlo simulations, LaTeX, Academic writing and editing
- **Soft skills** – Research, Science communication, Creativity and innovation, Team management, Public speaking
- **Interests beyond academics** – Writing, songwriting, music production, content creation (YouTube)
- **Languages** – English, Hindi, Bengali

CV last updated in April 2026