श्रद्धावान् लभते ज्ञानम्
ESTD. 1881

CITY COLLEGE

DEPARTMENT OF CHEMISTRY

CHEMAZINE

EXPLORE • EXPERIMENT • EXCEL

> *“Chemistry is the art of understanding matter and the science of transforming the world.”*

2026

"Learning gives creativity, creativity leads to thinking, thinking provides knowledge, knowledge makes you great."

- Dr. A.P.J. Abdul Kalam

Dr. Arindam Rana
HOD, Department of Chemistry
City College, Kolkata.

From the HoD's Desk

CHEMAZINE, a love of the students. have come up again – this time with a new batch of students along with the old ones from 2003 – 2023. The old boards were changed to the new one by the generous gift of gratitude by those old students.

It's heartwarming that we have seen a series of gifts of Almirahs, Stopwatches, Water Distillation units, modern Burette stands, Hot Oven, Digital Water Bath, pH Meter, 2-Ton AC, etc. as well as the reclaiming of a termite-stricken room and many more accessories. They came from P. C. Chandra Group, My Children Foundation on behalf of L B Specialities, Students of 2003-2023 home & abroad & of 1982-1987.

Oldies wrote on their memories, present students threw light on the Chemical aspects of War, and students are proud to put up alumnus Prof. Sundar Gopal Ghosh of IIT Chennai & Dr, Biswajit Panda. Prof. Ghosh synthesized the first ever BoronOsmium analogue of Ferrocene while Dr. Panda, who was a Faculty here, has now an organic reaction in his name.

Let CHEMAZINE shine bright as ever with the newer ideas from the new students.

Dr. Arindam Rana,
HoD, Chemistry, City College

Chemistry, Memories & Mentorship: A Conversation with Dr. Biswajit Panda

Some journeys begin in a classroom and return to inspire the next generation. Dr. Biswajit Panda, a proud alumnus of the Department of Chemistry, City College, has walked that remarkable path. Today, as an esteemed Organic Chemistry professor, he continues to guide students with the same curiosity and dedication that once defined his own student life. Through this interview, he shares cherished memories, valuable experiences, and heartfelt reflections on his journey from student to mentor.

1. Do you remember your very first day of walking into City College as a teacher? What did it feel like?

Yes, I remember my first day at City College very clearly. I had returned from abroad early that morning (05.05.2015) and arrived at City College at 9:30 a.m., officially joining the institution at exactly 11:00 a.m. Walking onto the campus of this old heritage institution in North Kolkata as a teacher was both exciting and humbling. Until then, I had known North Kolkata mostly through classic Bengali films, with their iconic wooden windows, elegant architecture, and old-world charm. Seeing that atmosphere in real life was a memorable experience. That day marked the beginning of a new chapter in my life. I felt a mixture of enthusiasm, responsibility, and a little nervousness. However, the warm and welcoming atmosphere of the college, along with the eagerness of the students, quickly made me feel at home.

2. Who was the first colleague who made you feel truly welcomed here—and are they still in touch?

I was fortunate to receive a warm welcome from many colleagues in the Department of Chemistry as well as other departments. Their support during my initial days helped me settle into the new environment with confidence. The friendly conversations, guidance on academic and administrative matters, and willingness to help created a sense of belonging from the very beginning. I remain in regular contact with many of them.

3. What was your first impression of City College's chemistry students—did they surprise you in any way?

My first impression of the chemistry students was that they were curious, sincere, and eager to learn. Although many came from diverse educational and socio-economic backgrounds, they showed remarkable enthusiasm for understanding scientific concepts. What surprised me most was their willingness to ask thoughtful questions and their genuine interest in participating in laboratory work and academic discussions. During the COVID-19 period, I remember Bikramjit from Ghatal, Paschim Medinipur, attending my online class from the rooftop, and the ground floor of their house was completely flooded.

4. Has any student ever said something to you—in class or after—that genuinely moved you or changed how you teach?

Yes, there have been several such moments over the years, but one that has stayed with me was when a student told me, "Sir, your classes made me believe that chemistry is not something to memorize but something to understand and enjoy." Those words were deeply meaningful because they reflected the very philosophy I try to follow as a teacher.

5. Have you ever felt emotionally attached to a particular batch or group of students? What made them special?

Every batch has its own unique identity and leaves behind cherished memories. However, there are certain groups of students with whom I developed a particularly strong bond. Their enthusiasm, obedience, and willingness to learn created a nice classroom environment. If I had to name the batch to which I feel the strongest emotional attachment, it would be Subhraneel's batch. The students in that batch were exceptionally sincere, disciplined, and always willing to help one another. Their unity, kindness, and genuine care for each other were truly remarkable and remain among my most cherished memories. Whenever I think of that batch, I become emotional and feel a deep sense of connection with them. Many students from different batches have left a lasting impression on me. Some of them include Sunonda Santra, Manoj Ghosh, Saurjadipta Basu, Gautam Patra, Debayan Rana, Swarnavo Samanta, and many others.

6. Was there ever a moment when a student was struggling—not just academically but personally—and you stepped in? How do you look back on that?

Yes, there have been occasions when students faced personal difficulties that affected their academic performance and confidence. In such situations, I always believed that my role extended beyond that of a classroom teacher. Whenever possible, I tried to provide that support while respecting their privacy and dignity. Looking back, I feel that these moments were among the most meaningful aspects of my career, reminding me that education is as much about helping students, not only just teaching them in the classroom.

7. Did any student ever come back years later and say something that made all those years of teaching feel truly worthwhile?

Yes, that has happened, and those moments are among the greatest rewards of being a teacher.

8. When did it finally hit you that you were actually leaving—was there a specific moment?

It was not a single dramatic moment but a gradual realization that an important chapter of my teaching life at City College was coming to an end. Owing to personal circumstances, I had been seeking a transfer to a college closer to my home for quite some time. Eventually, I learned that another faculty member was also looking to transfer to a college in Kolkata. We therefore decided to apply for a mutual transfer, and the process moved forward accordingly.

At this point, I would like to express my sincere gratitude to Dr. Arindam Rana, Head of the Department of Chemistry, for his constant support and invaluable assistance throughout the transfer process. I am deeply grateful to Dr. Shital Prasad Chattopadhyay, Principal of City College, for his constant support, encouragement, and guidance throughout my tenure at the college. His leadership and kindness have been a great source of inspiration, and I sincerely appreciate all the help and support he extended to me during my time at City College.

9. Is there anything you wish you had said to a student or colleague but never did?

One thing I wish I had expressed more often is a simple "thank you." To my students, I would like to say that they have taught me as much as I have taught them. Their curiosity, questions, and enthusiasm have continually challenged me to become a better teacher. To my colleagues, I would like to express my heartfelt appreciation for their friendship, cooperation, and continuous support over the years.

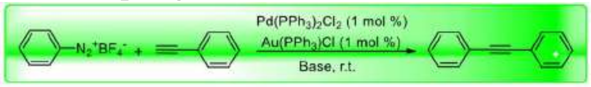
10. If you could spend one last ordinary day at City College—just a regular teaching day—what would you want it to look like?

I would want it to be just like any other fulfilling day at City College. I would begin by greeting my colleagues, walking into a classroom filled with students, and teaching a topic that encourages discussion rather than simply covering the syllabus. I would spend time in the laboratory interacting with students, answering their questions, and motivating the students for doing research in their future. Between classes, I would enjoy informal conversations with colleagues over a cup of tea, exchanging ideas and laughter. I would end the day by walking through the campus once more, appreciating the familiar surroundings that have been an integral part of my life for so many years. Sometimes, it is the ordinary moments that become the most extraordinary memories.

11. What part of City College will you carry inside you, even at your new place?

I will carry with me the people and the values that define City College. The warmth of my colleagues, the curiosity and energy of my students, and the culture of learning, respect, and academic commitment will always remain with me.

First Sonogashira Coupling of Arene Diazonium Salts



Dr. Biswajit Panda is an accomplished organic chemist and former Assistant Professor in the Department of Chemistry, City College, University of Calcutta. He completed his Ph.D. at IIT Kharagpur under the guidance of Prof. Tarun K. Sarkar and later carried out postdoctoral research at National Taiwan University. His research focuses on organic synthesis, catalysis, and the development of innovative synthetic methodologies.

One of his most remarkable scientific achievements is the first Sonogashira-type crosscoupling of arenediazonium salts, published in the Royal Society of Chemistry journal Chemical Communications in 2010. This pioneering work introduced a novel Pd–Au dual catalytic system and laid the foundation for what is now widely referred to as the Panda– Sarkar Coupling, recognizing the contributions of Dr. Biswajit Panda and Prof. Tarun K. Sarkar.

As students of City College, we are immensely proud to have been taught by a scientist whose research has earned international recognition. His dedication to teaching and research continues to inspire young chemists to pursue innovation and excellence in the field of organic chemistry.

The uploaded page also highlights that this was the first Sonogashira coupling of arene diazonium salts and shows that Google identifies the transformation as the Panda–Sarkar coupling, named after Biswajit Panda and Tarun K. Sarkar.

with Dr. S. Ghosh

Inspiring Generations: A Conversation with Dr. S. Ghosh

Every remarkable scientific journey begins with curiosity, determination, and a strong foundation. Dr. S. Ghosh's journey is a testament to this belief. From being a dedicated Chemistry student at City College to becoming a Professor at the Indian Institute of Technology (IIT) Madras, he has built an inspiring career through perseverance, passion for research, and academic excellence. In this exclusive interview, Dr. Ghosh reflects on his student life, the challenges that shaped him, his research in inorganic chemistry, and his message for the next generation of aspiring scientists.

Q1. What inspired you to pursue Chemistry as your major during your time at City College?
Ans: My interest in chemistry began during my school days at KDI, Katwa, Burwan. I was fascinated by the periodic table, how elements are arranged so logically and how their properties and reactions are interconnected. Learning reaction mechanisms further deepened my curiosity. That early exposure sparked a lasting passion for chemistry, which eventually led me to choose it as my major.

Q2. How did your experience at City College shape your academic and research interests?
Ans: City College played a pivotal role in shaping my academic direction. Although I enjoyed all branches of chemistry, I was particularly drawn to inorganic chemistry. Inspiring teachers, especially Shri Manabendranath Bishnu, strengthened my fundamentals and encouraged me to think critically. Their mentorship laid the foundation for my future research interests.

Q3. What challenges did you face while transitioning from City College to IIT, and how did you overcome them?
Ans: One of the biggest challenges was the language shift. I had studied physics and mathematics in Bengali and only chemistry in English, so when I joined IIT Bombay as a research scholar, communicating confidently in English was difficult. At City College, I also had limited opportunities for academic discussions or debates. However, joining IIT introduced me to friends from different regions of India with diverse academic backgrounds. Interacting with them gradually improved my communication skills and helped me adapt to the academic environment.

Q4. Could you tell us about your current area of research at IIT and what excites you most about it?
Ans: My research lies in the broad area of inorganic chemistry. After completing my PhD in carbene chemistry, I shifted my focus to boron chemistry, a field rich in unusual bonding patterns and unique molecular architectures. At IIT Madras, my group explores fundamental aspects of boron chemistry, particularly unconventional structures and bonding. I am also interested in designing boron-based molecules that can mimic the simple organometallic systems. One of our research areas involves developing boron complexes for small-molecule activation. The possibility of discovering entirely new molecular frameworks is what excites me the most.

Q5. How has the field of Chemistry evolved since your undergraduate days at City College?
Ans: Chemistry, especially inorganic and main-group chemistry, has progressed tremendously. Techniques, instrumentation, and theoretical tools have advanced, allowing us to study molecules that were

once considered too unstable or complex. In India, research in organometallic and main-group chemistry has grown significantly, contributing valuable discoveries to the global scientific community.

Q6. What role do you think interdisciplinary approaches (like combining Chemistry with Physics or Biology) play in modern research?
Ans: Interdisciplinarity is essential in today's scientific landscape. Many important problems, ranging from clean energy to drug discovery, require insights from chemistry, physics, biology, and even engineering. When these disciplines converge, they enable new perspectives, innovative methodologies, and transformative breakthroughs.

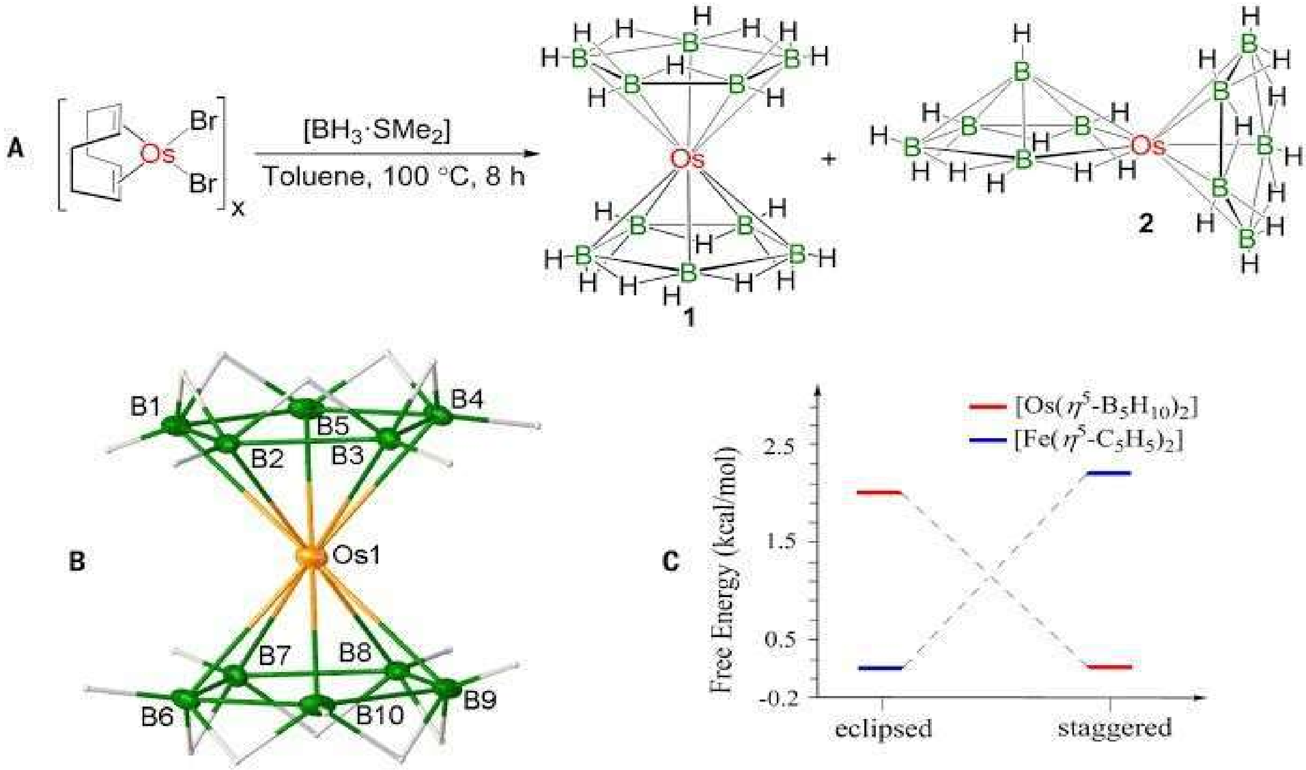
Q7. What advice would you give to current City College Chemistry students who dream of joining IIT or pursuing research?
Ans: Stay focused on your studies, not just chemistry, but all foundational subjects. Be disciplined, attend classes regularly, and make an effort to understand concepts deeply. Most importantly, believe in yourself. With dedication and consistent effort, achieving your goals is very much within reach.

Q8. How can undergraduate students start building a strong research profile early on?
Ans: Today, there are many opportunities for undergraduates to get research exposure. Students can reach out to professors at IITs and other research institutes to request short-term projects or internships. This early experience helps develop scientific thinking and clarity about future research interests. I personally mentor several undergraduate students from across the country who aspire to pursue research careers.

Q9. What skills or habits helped you the most in your academic journey from college to becoming a professor?
Ans: Hard work, consistency, curiosity, and discipline have been the pillars of my journey. I focused on understanding concepts rather than memorizing them, maintained steady study and research habits, and always remained open to learning from mentors, colleagues, and students. These qualities helped me navigate challenges and grow as a scientist.

Q10. Looking back, how do you feel when you visit City College today, and what message would you like to share with its students?
Ans: Visiting City College always fills me with a sense of gratitude and nostalgia. It reminds me where my journey began. My message to students is this**: Dream big and work wholeheartedly toward those dreams. Don't fear failure, learn from it, improve, and keep moving forward. Stay focused, think strategically, and never stop striving for your goals.**

Dr. Sundargopal Ghosh: A Landmark Discovery in Modern Organometallic Chemistry



The City College family takes immense pride in celebrating the remarkable achievement of our distinguished alumnus, **Dr. Sundargopal Ghosh**, whose pioneering research has been published in one of the world's most prestigious scientific journals, *Science* (Vol. 392, Issue 6796, April 23, 2026). His groundbreaking work, titled **"$[Os(\eta^5\text{-}B_5H_{10})_2]$: A Carbon-Free Analog of Ferrocene,"** represents a major milestone in the field of inorganic and organometallic chemistry.

Ferrocene, discovered in the early 1950s, revolutionized chemistry by introducing the concept of a "sandwich compound," where an iron atom is positioned between two cyclopentadienyl carbon rings. This discovery transformed modern organometallic chemistry and opened new avenues in catalysis, materials science, and electrochemistry. For decades, chemists across the world sought to create a true carbon-free counterpart of ferrocene, but the challenge remained unsolved.

Dr. Ghosh and his research team successfully achieved this long-standing scientific goal by synthesizing and characterizing **$[Os(\eta^5\text{-}B_5H_{10})_2]$**, the first authentic carbon-free analog of ferrocene. In this extraordinary molecule, the traditional carbon rings are replaced by boron-hydride (B_5H_{10}) rings that sandwich an osmium atom. Using advanced crystallographic and theoretical studies, the team demonstrated that the new compound possesses a unique bonding arrangement, stronger metal-ring interactions, and exceptional structural stability. The research also revealed an unprecedented coordination mode in an isomeric complex, significantly expanding the understanding of sandwich compounds.

This discovery is far more than the synthesis of a new molecule. It represents a breakthrough that broadens the fundamental principles of chemical bonding and opens exciting possibilities for the design of advanced inorganic materials, catalysts, and molecular electronic systems. The work highlights how innovative research can challenge long-held scientific assumptions and create entirely new directions in chemistry.

Publishing in *Science* is an extraordinary achievement, reflecting the global significance and exceptional quality of this research. Dr. Ghosh's contribution has earned international recognition and stands as an inspiration for young scientists and chemistry students.

As proud members of the City College community, we extend our heartfelt congratulations to **Dr. Sundargopal Ghosh** on this historic accomplishment. His dedication to scientific excellence, innovation, and research continues to inspire future generations of chemists. His success is not only a personal milestone but also a moment of immense pride for our institution, reaffirming that City College alumni continue to make impactful contributions to the global scientific community.

We salute Dr. Sundargopal Ghosh for this remarkable achievement and wish him continued success in his pursuit of scientific excellence.

Some of my best memories are from my college days at City College chemistry department. The historic building, the old staircases, bustling streets, endless conversations with friends between classes and the excitement of learning and dreaming about the chemistry made those years truly special. Though time has passed, the memories of old classroom, laboratory and Amherst Street remain close to my heart, filled with laughter, friendship, and unforgettable moments.

ATANU GHOSH
(Batch: 2017)

Today, I am here at the Illumina Centre in Cambridge, a worldleading sequencing company. Being here would not have been possible without the support of the Department of Chemistry at City College.

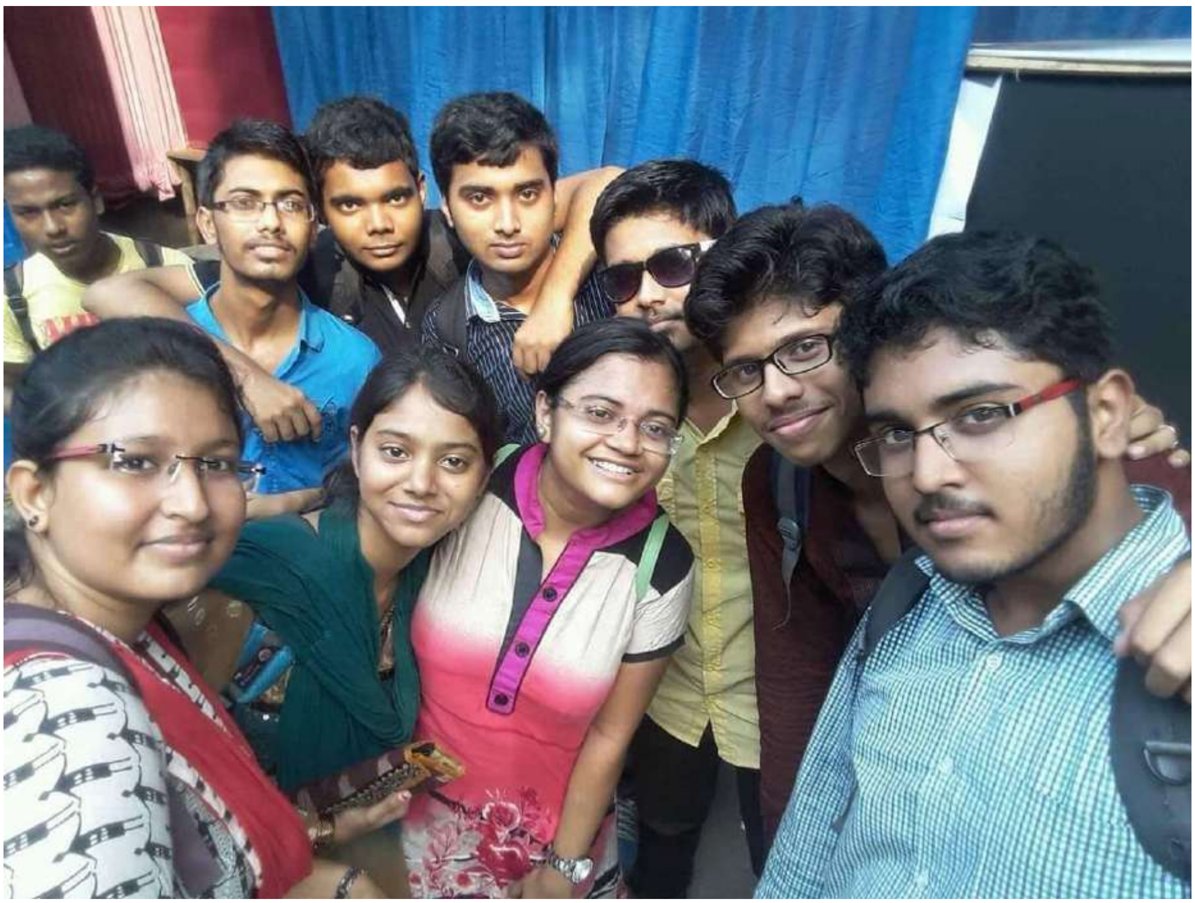
I would like to express my heartfelt gratitude to City College, especially the Chemistry Department, for their guidance and continuous support. The department has always been enriched by inspiring professors like AR Sir, whose contributions are immeasurable. They have guided and shaped many individuals like me, enlightening countless lives that might otherwise have been lost in today’s world.

MITHUN SANTRA
(Batch: 2005)

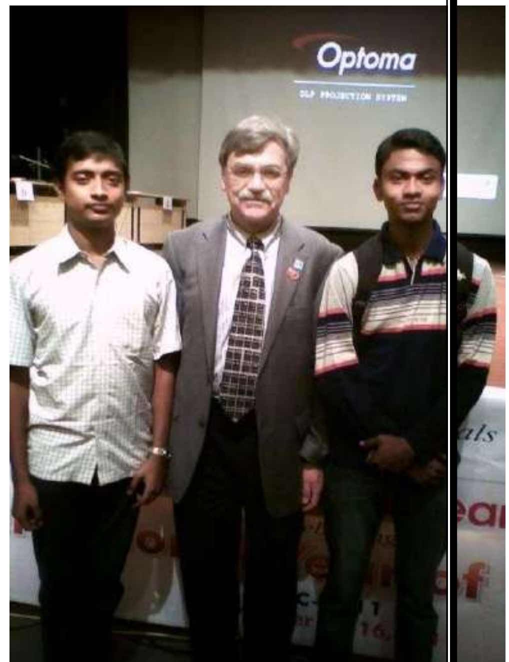
College days shaped me up to be whatever I am today. Thanks to teachers and friends.

Don't be afraid of dreaming big. One needs memory to live. Best memories come from the best people and best people are found at the best places, aim for it and earn it.
Best wishes for juniors, you can't imagine what a beautiful future awaits you.

SOHINI KHAN
(Batch: 2020)



As a proud alumnus of the Department of Chemistry, City College, graduating in 2012, I look back on my college years with immense gratitude and fondness. The department provided not only a strong academic foundation but also the inspiration to appreciate chemistry beyond textbooks and laboratories.



I would like to especially acknowledge Dr. A. Rana, whose engaging teaching style and passion for the subject greatly influenced many of us. His ability to connect chemical concepts with practical applications in everyday life made learning both meaningful and enjoyable.
His encouragement sparked our curiosity and deepened our understanding of chemistry.

Today, as a Manager at Haldia Petrochemicals Ltd., I continue to benefit from the knowledge, analytical thinking, and scientific approach that I developed during my time at City College. I remain grateful to the faculty members who guided us and contributed to our growth. I wish the Department of Chemistry continued success in nurturing future generations of students and inspiring them to explore the fascinating world of chemistry.

ADARSA MONDAL
(Batch: 2012)

My first memory of college is very special to me. On 27th July 2016, around 40 of us joined City College together. It was the beginning of a new journey filled with excitement, dreams, and curiosity.

On the very first day, we enjoyed a lot in the classroom while meeting new friends and teachers. Everything felt new and memorable. All the professors warmly welcomed us and guided us on how to learn chemistry concepts in a proper and practical way. Their words inspired us and gave us confidence for the years ahead.

That first day at City College still remains one of the happiest and most unforgettable memories of my college life.

Name: SOUREN MONDAL
(Batch: 2020)

From a Small Village to a Research Scientist: A Journey Shaped by City College

DR. KHADIMUL ISLAM (Batch: 2014)

When I entered the Department of Chemistry at City College, Kolkata, in 2011, I was a young boy from a small village in Murshidabad carrying dreams much bigger than my confidence. The city was new, the environment was unfamiliar, and the language of higher education seemed intimidating. I still remember my first few days in college. I often felt lost and wondered whether I truly belonged there. At one point, I even considered returning home, convinced that chemistry was not my cup of tea.Thankfully, I stayed.What followed was a transformation that changed the course of my life. The professors of the Chemistry Department did much more than teach a subject—they nurtured confidence, curiosity, and resilience. The mentors of city college (A.G, M.N.B, A.R, S.B, S.S.B, S.K.M, A.K.G and S.B,S) opened our minds to the beauty and depth of chemistry, discipline pushed us to strive for excellence, warmth and accessibility made learning enjoyable and fear-free. Their guidance helped me to discover not only chemistry but also my own potential. The laboratories, classrooms, and corridors of City College became the foundation of my dreams. Despite limited resources, the department provided us with ample opportunities for practical learning and experimentation. For many students from modest backgrounds, those opportunities were invaluable. Beyond academics, the college gave us friendships, laughter, picnics, cricket matches, and countless memories that remain close to my heart even today.

Later, that hesitant village boy completed his Master's degree, pursued doctoral research, from IIT Guwahati, post doctorate and eventually became a Research Scientist at Jubilant Biosys Limited, Greater Noida. Every achievement I have earned carries a piece of City College within it. The lessons learned their continuous guidance, both professionally and personally.

As alumni, we often move far from our campus, but the values and inspiration we receive remain with us forever. City College was not merely an institution in my life—it was the place where my dreams found direction and where I learned that determination can overcome even the greatest insecurities.

To all current students, I leave this simple message: never underestimate your potential. Your background does not define your destination. Believe in yourself, embrace every opportunity to learn, and keep moving forward with perseverance. One day, you will look back and realize that every challenge was preparing you for something greater.

My sincere gratitude and respect to all my teachers and to City College for helping me become the person I am today. Some journeys begin with uncertainty, but with the right guidance, they can lead to destinations beyond imagination.

My time completing my B.Sc. in Chemistry at City College, Amherst Street, from 2019 to 2022 was an incredible chapter of my life. This institution holds a deeply special place in my heart from every aspect, largely because my grandfather (Mr. Ajit Kumar Ghosal) walked those exact same halls decades ago in the 1940s, giving my journey there a beautiful sense of family legacy. During my three years, I made wonderful friends who became a true support system and had the absolute privilege of crossing paths with great mentors like Dr. Arindam Rana and Dr. Pampa Guha, whose guidance shaped my academic experience.

Looking back, I find myself incredibly nostalgic for those days; I deeply miss the familiar buzz of our classrooms, the long hours spent experimenting in the chemistry lab, the endless conversations in the canteen, and the unforgettable energy of our college fests. City College gave me both an education and memories I will cherish forever.

ANIRBAN GHOSAL
(Batch: 2022)

Rupsa Maity actively conducting a chemistry experiment with confidence and accuracy. Her dedication to hands-on learning showcases the enthusiasm and commitment of the B.Sc. Chemistry Batch (2024–2028).

Saheb Roy demonstrating careful laboratory techniques while performing an organic chemistry experiment. His focus and precision reflect the practical skills and scientific discipline developed by the B.Sc. Chemistry Batch (2024–2028).

Public Destinations of Science in Kolkata

Destination 1: Birla Industrial and Technological Museum, BITM 19A Gurusaday Road, Ballygunge, Kolkata, West Bengal 700019.

Destination 2 Sem I Students Skill Development Training on Ceramic Membrane Technology at CG & CRI

Moment and memorise

Date & Time: 9 January 2025 (Thursday),

Venue: City College, Kolkata (Science Department)

Theme & Speakers: Discussion on “বিজ্ঞান ও জনসংযোগ” (Science and Public Communication) with distinguished speakers including Dr. Amal Kumar Ray, Dr. Manaspratim Das, and Dr. Mridulendu Chakraborty.

AI Champ India partnered with City College, Kolkata, to launch the "AI for Everyone" Bridge Course. This academia–industry initiative empowered undergraduate science students and faculty with practical AI skills, aligned with Calcutta University's NEP-based Skill Enhancement Course.

Acivments

Event: APC Ray Memorial Chemistry Olympiad 2.0
Venue: Sister Nivedita University (SNU), Kolkata | **Date:** 29–30 July 2025
Achievement: Team City College secured **3rd Position** in the Olympiad.

Chem photography

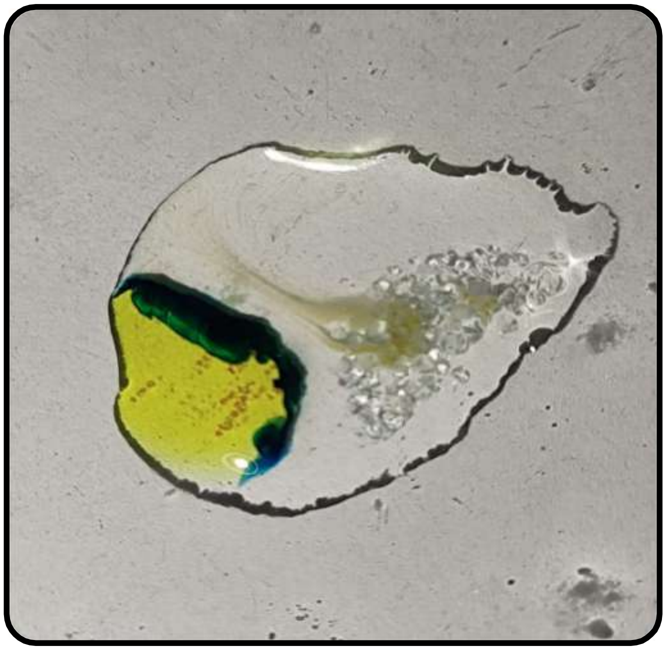


Photo 1: In H_2O , the left one is potassium ferricyanide and the right one is ferrous sulphate

Photo 1: In H2O , the left one is cobalt chloride and the right one is sodium hydroxide

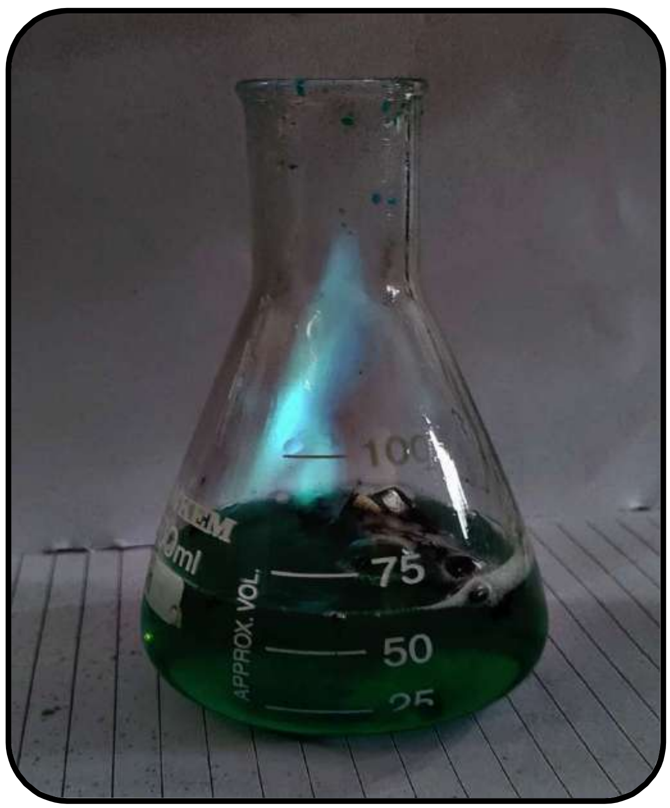


Photo 1: Two spoon CuSO4 , 90ml of dil HCl , aluminium foil Acid-metal reaction involves hydrogen gas Hold the fire near to the hydrogen gas and it will burn with bluish flame by a whistling sound


CSIR..(CGCRI)
Kolkata | 15 May 2026 at 12:03 pm


CSIR..(CGCRI)


CSIR..(CGCRI)
26 May 2026 at 11:54 am

রসায়নের সুর

দেবায়ন রানা, দ্বিতীয় সেমিস্টার

পরমাণুর মায়ায় গাঁথা,
ইলেকট্রনের নৃত্যে মাতোয়ারা ব্যথা।
বন্ধনের ডোরে মিলন সুর,
অণুতে অণুতে জাগে মধুর নূপুর।

অম্লের রাগে ক্ষারের গান,
সমীকরণে বোনা রঙিন প্রাণ।
তাপের ছোঁয়ায়, আলো জ্বলে,
রসায়ন সুর তো বিশ্ব মেলে।

ধাতুর ঝলক, জ্যোতির আলো,
প্রকৃতির বুকে অদ্ভুত ভালো।
গন্ধে রঙে রহস্য খেলা,
কণার ভেতরে বিশ্ব মেলা।

জীবন গড়ার বীজ যে এই,
প্রকৃতি গায় যে সুর কতদূর।
মানুষের হাতে জ্ঞানের নূর,
চির অমর হয়ে বাজে—
রসায়নের সুর।

Chemistry Fun Facts

By Arnab Chakraborty; Semester-II

Absolute Zero, i.e., Zero Kelvin, is impossible to reach.

Heisenberg's uncertainty principle means we can't know both position and momentum exactly. At absolute zero, particles would stop moving, violating this principle—so absolute zero can't be reached

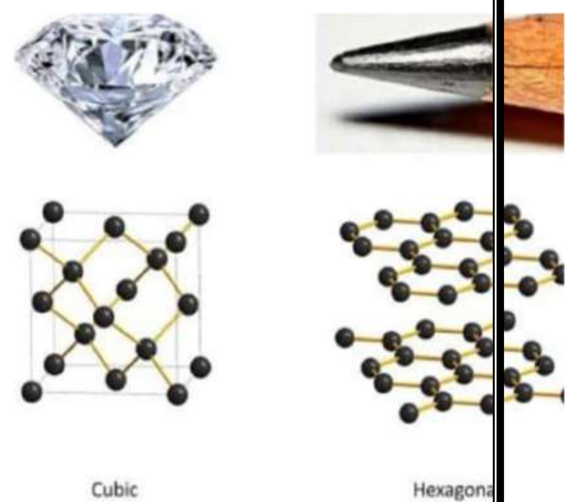
The Sun is not actually burning.

The Sun is a massive ball of hydrogen where nuclear fusion turns hydrogen into helium, releasing energy asper Einstein's equation $E=mc^2$. This energy lights and warms our planet—not from fire, but from fusion.

The Thermodynamics of Making Ice-Cream

Making ice cream involves a lot of physical chemistry! To freeze the mixture, you use salt to lower the freezing point of water, which creates an endothermic reaction, absorbing heat from the surroundings and lowering the temperature enough to freeze the ice cream.

Chemistry Fun Facts



Pencil lead and Diamond

Different forms of the same object

Diamond and graphite are carbon forms with different properties—diamond is hard with a tetrahedral structure graphite is soft, layered, and can become diamond under heat and pressure."

Blue Colour of liquid Oxygen

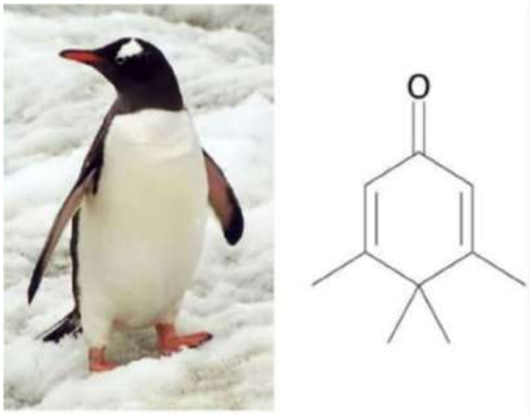
What Colour is Oxygen?

This is due to Oxygen becoming paramagnetic when it condenses into liquid or solid phase. The unpaired electrons originate a “magnetic asymmetry” in the molecules. This creates a absorption band in the visible spectrum (very much as why water is blue), which absorbs red light, resulting in a blue colour.

Make Elephant Toothpaste

Elephant Toothpaste is a rapid decomposition of hydrogen peroxide (H_2O_2) Catalyzed by potassium iodide (KI) or another catalyst. The reaction breaks H_2O_2 into water and oxygen gas: **$2H_2O_2 \text{->} 2H_2O+O_2$** The released oxygen gets trapped in soap, creating a large, foamy “toothpaste-like” eruption.

Chemistry Fun Facts



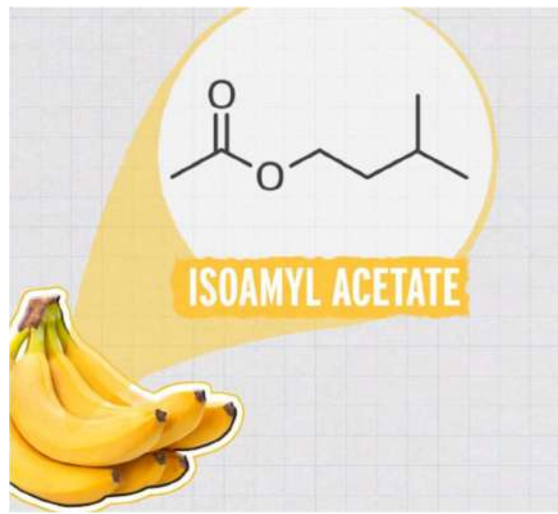
Penguin　　Penguinone

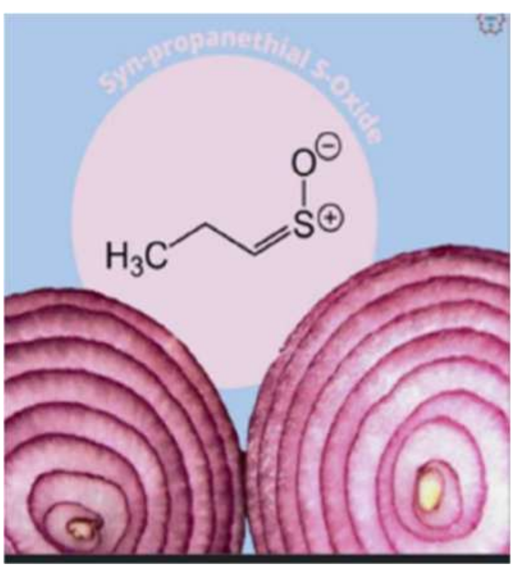
Penguinone

Penguinone (C10H14O) contains a Ketone group as its “head” a functional group that can undergo many organic reactions. This molecule looks like it must be native to Antartica, but it actually has some biological activity useful for medicine.

The Chemistry Behind the Smell Of Bananas

The smell of bananas comes from isoamyl acetate, an ester formed by the reaction of isoamyl alcohol and acetic acid. It gives bananas their sweet, fruity aroma.





Why Do Onions Make You Cry?

When you cut an onion, it releases a sulfur-containing gas called syn-propanethial-S-oxide. This gas reacts with the moisture in your eyes to form a very dilute sulfuric acid. This mild acid irritates the sensitive nerve endings in your eyes, causing them to sting and produce tears to wash the irritant away. That’s why onions make you cry.

Artistic Expressions

Artwork 1(By Saheb Roy, Semester II): Drug abuse is a disorder that involves the use of illegal, recreational drugs or over-the-counter medications in ways other than recommended or intended.

Artistic Expressions

Artwork 2 (By Ishita Basak, Semester II): The Alchemy of Existence — sounds mystical and transformative,portraying that life itself is a chemical and spiritual experiment. It connects the imagery of chemistry with the idea of emotional or existential evolution.

অদৃশ্য সমীকরণ

দেবায়ন রানা,

সবে মাত্র কলেজে ভর্তি হয়েছে সৌরভ। প্রথম বর্ষের রসায়ন ক্লাসেই সে সবচেয়ে বেশি মুগ্ধ হয় ল্যাবরেটরির দিকে তাকিয়ে। কাঁচের টেস্ট টিউব, বুনসেন বার্নারের নীল শিখা, আর নানা রঙের সলিউশন তার চোখে যেন রঙিন জগৎ।

প্রফেসর রানা একদিন লেকচারে বললেন—

“রসায়ন মানে কেবল মুখস্থ সমীকরণ নয়। প্রতিটি বিক্রিয়ার পেছনে একটা গল্প আছে। যদি গল্পটা বুঝতে পারো, তবে সমীকরণ মুখস্থ করতে হবে না।”

সেই কথাটা সৌরভের মাথায় ঘুরতে লাগল।

পরের সপ্তাহে প্রথম ল্যাব ক্লাস। সৌরভের হাতে দিলেন এক অজানা সলিউশন। কাজ— কোন ধাতব আয়ন আছে তা খুঁজে বের করা।

সে প্রথমে ফ্লেম টেস্ট করল। আগুনে দেখা গেল হালকা বেগুনি আভা। সৌরভ মনে মনে হিসেব কষল—

“বেগুনি রঙ মানে তো পটাশিয়াম!”

কিন্তু প্রফেসর আবার ইঙ্গিত দিলেন—

“একটা টেস্ট কখনো শেষ সত্যি নয়, সব সময় দ্বিতীয় প্রমাণ চাই।”

তখন সৌরভ অ্যাসিড যোগ করল, আর অন্য একটি বিক্রিয়া পরীক্ষা করল। ফল মিলল ঠিকই— সত্যিই সেটা পটাশিয়াম সল্ট।

সেদিন সৌরভ প্রথমবার বুঝল, রসায়ন কেবল সংখ্যা, সূত্র আর বইয়ের ভেতর বন্দি নয়। এটা আসলে একটা রহস্যের খেলা— যেখানে প্রতিটি পরীক্ষাই গোয়েন্দাগিরির মতো, প্রতিটি ফলাফলই একটা নতুন সূত্র।

ল্যাব থেকে বেরিয়ে সে ডায়েরিতে লিখল—

“সমীকরণ কাগজে লেখা থাকে, কিন্তু আসল রসায়ন লুকিয়ে থাকে আগুনের রঙে, সলিউশনের গন্ধে, আর সেই অদৃশ্য বন্ধনে যা আমাদের প্রতিদিন বাঁচিয়ে রাখে।”

“সমীকরণ কাগজে লেখা থাকে, কিন্তু আসল রসায়ন লুকিয়ে থাকে আগুনের রঙে, সলিউশনের গন্ধে, আর সেই অদৃশ্য বন্ধনে যা আমাদের প্রতিদিন বাঁচিয়ে রাখে।”

কলেজ জীবনের সেই দিনগুলো আজও হৃদয়ের এক অমূল্য সম্পদ। ক্লাসরুমের হাসি, বন্ধুদের সঙ্গে আড্ডা, শিক্ষকদের স্নেহ, বিভিন্ন অনুষ্ঠান আর একসঙ্গে কাটানো অসংখ্য মুহূর্ত আজ স্মৃতির পাতায় অমলিন হয়ে আছে। সময় অনেক দূর এগিয়ে গেছে, কিন্তু সেই বন্ধুত্ব, সেই ভালোবাসা আর সেই নির্ভার দিনগুলোর উষ্ণতা আজও মনকে নস্টালজিয়ায় ভরিয়ে তোলে।

স্মৃতির অ্যালবামের এই ছবিগুলো শুধু কিছু মুহূর্ত নয়, আমাদের জীবনের এক অমূল্য অধ্যায়। প্রথম ছবিতে প্রজেক্টের ফাঁকে বন্ধুদের সঙ্গে হাসি-ঠাট্টা আর নির্ভার আনন্দ, দ্বিতীয় ও তৃতীয় ছবিতে শিক্ষকদের প্রতি শ্রদ্ধা ও ভালোবাসায় ভরা শিক্ষক দিবসের উদযাপন। আর চতুর্থ ছবিটি আমাদের বিজ্ঞানচর্চার প্রথম বড় অনুপ্রেরণা—IACS, কলকাতায় “The Saga of Indian Science”-এ অংশগ্রহণ। ড. অরিন্দম রানার হাত ধরে সেই জাতীয় বিজ্ঞান দিবসের অভিজ্ঞতা আজও আমাদের স্বপ্ন, কৌতূহল ও পথচলার প্রেরণা হয়ে আছে।

সুনন্দ সাঁতরা
(ব্যাচ: ২০২০)

একটি জীবনের সবথেকে গুরুত্বপূর্ণ বয়স আঠারো। নতুন উদ্যম, নতুন প্রেম, নতুন ভালোলাগা আর নতুন নতুন ভাবনা। যেমনটা আমারও ছিল। অন্যরকম কিছু করার উদ্যম। প্রেম বলতে রসায়ন আর কবিতা। এই দুই প্রেয়সিকে নিয়ে আমার কলেজ জীবন শুরু। সিটি কলেজের চৌকাঠে এসে যখন দাঁড়িয়েছি তখন আমি নিতান্তই এক গ্রামের ছেলে। শহুরে জীবনের কোলাহলে বড্ড বেমানান। কিন্তু কলেজের বিশাল বিশাল স্তম্ভ, গ্যালারি, পুরানো দিনের মেদুরতা আমাকে অবাক করেছিল। আমি সেই প্রথম অনুভব করেছিলাম একটি রসায়নের পরীক্ষাগারের চেহারা। এরপর ধীরে ধীরে ভালোবাসার জন্ম। কলেজের প্রতি, কলকাতার প্রতি। এর কৃতিত্ব অবশ্যই কলেজের অধ্যাপকদের এবং আমার বন্ধুদের।

দেখতে দেখতে রসায়ন বিভাগ হয়ে গেল আমাদের ঘর, কলেজ আমাদের বাড়ি। শুরুর দিকে আমাকে খুব বেগ পেতে হয়েছিল। একেই রসায়নের মত বিষয় তার উপর সমস্তটা ইংরাজিতে। সব ঠিক মাথায় ঢুকত না। কিন্তু সাহস ছিল মনে, চেষ্টা করে গেছি। যখন যেমন বিপদে পড়েছি হাত ধরেছেন স্যারেরা। ভালবাসতে শিখিয়েছেন রসায়নকে। এখানে বিশেষ করে বলতে হয় ডঃ অরিন্দম রানা স্যারের কথা। তিনি আমাদের উৎসাহিত করছেন। নতুন কিছু করার সাহস জুগিয়েছেন। বিষয়ের বাইরে গিয়ে দিয়েছেন জীবনের পাঠ। এখনো খুব মনে পড়ে A.K.G স্যার, M.N.B স্যার, S.B. স্যারদের কথা। তাদের পড়ানোর কথা, তাদের শেখানোর কথা।

আমরা যে শুধু রসায়ন পড়েছি তা নয়। আমরা দেওয়াল পত্রিকা করেছি, অনুষ্ঠান করেছি, পিকনিক করেছি, সেমিনারে গেছি, হুল্লোড় করেছি। স্যারেরা সবসময়ই আমাদের সমর্থন করেছেন। আমার কাছে কলেজের সেই দিন গুলো আলোর মতো, খুব আবেগের। আজ আমি একজন স্কুল শিক্ষক। ক্লাসে রসায়নকে সহজ করে বোঝানোর চেষ্টা করি। এই পথটুকু এগিয়ে যাওয়ার যে পাথেয়, সে তো আমার কলেজ থেকে পাওয়া, আমার অধ্যাপকদের কাছ থেকেই পাওয়া আর পাওয়া আমার অমলিন বন্ধুদের কাছ থেকে। সকলকে আমার শ্রদ্ধা।

নির্মল মন্ডল

(ব্যাচ: ২০১৩)

CONTENTS

EXECUTIVE SUMMARY

Chemical warfare occupies a uniquely disturbing place among the instruments of human conflict: it kills without a visible weapon, wounds across generations, and leaves land uninhabitable long after the guns fall silent. This review traces its arc from the chlorine clouds of Ypres in 1915 through the sarin massacres of Halabja and Ghouta, to the covert Novichok poisonings of the 2010s and the industrial hazards now threatening war-torn Ukraine.

It examines how these agents attack the human body at a molecular level, why they inflict psychological terror disproportionate to their body count, and how their legacy compounds over decades — in the birth defects of Vietnam, the chronic illness of Gulf War veterans, and the billion-dollar remediation bills borne by nations decades after the last shell was fired. It closes by weighing emerging risks — drone delivery, synthetic biology, and the fragility of international law — against the slow, uneven progress made since the 1925 Geneva Protocol toward a chemical-weapons-free world.

INTRODUCTION

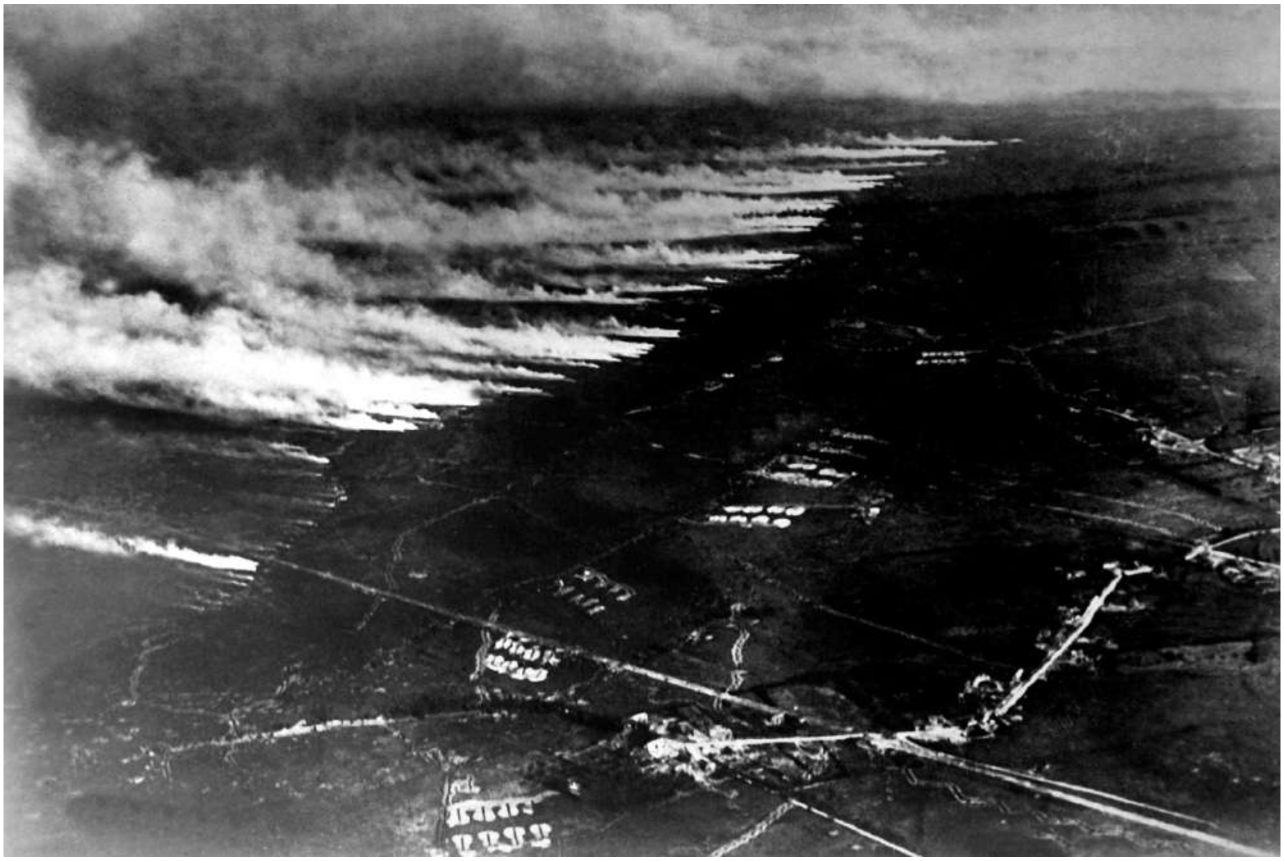
Chemical warfare is called "silent" not because its consequences are subtle, but because its mechanisms of harm are largely invisible and, in many cases, odourless, while being physiologically devastating. Unlike conventional weapons that rely on blast or fragmentation, chemical agents work through biochemical interactions at the cellular and molecular level. Once introduced into the body — through inhalation, skin contact, or ingestion — they interfere with respiration, neural transmission, and cellular metabolism from within.

Toxicologically, these agents fall into four broad families. Choking agents such as chlorine and phosgene damage the alveolar-capillary membrane, flooding the lungs with fluid. Blood agents block cellular respiration at the mitochondrial level, starving tissue of usable oxygen even when the blood itself is saturated with it. Nerve agents inhibit acetylcholinesterase, the enzyme that normally clears the neurotransmitter acetylcholine, causing uncontrolled and ultimately fatal nerve firing. Blister agents such as sulfur mustard alkylate DNA and proteins directly, producing burns, blindness, and long-term mutagenic damage.

The psychological dimension amplifies all of this. The inability to see or immediately detect exposure breeds uncertainty and dread — a phenomenon historically labelled "gas hysteria," in which people display real physical symptoms driven purely by fear rather than exposure. And because many agents persist in soil and water long after deployment, chemical warfare is rarely a single event: it is a standing liability that outlives the war that created it, quietly degrading ecosystems and public health for decades.

PART I · HISTORICAL PERSPECTIVES

Chapter 1 · The Birth of Chemical Warfare — World War I



First Use at Ypres, 1915

The Second Battle of Ypres marked the first large-scale, deliberate use of chemical weapons in modern warfare. German forces released chlorine gas from thousands of cylinders, timing the attack to favourable winds. The gas formed a dense greenish cloud that drifted across no-man's-land into Allied trenches, where soldiers — without training or protective equipment — suffered immediate disorientation and death. The attack exposed how vulnerable static trench warfare was to atmospheric dispersion of toxins.

Chlorine, Phosgene, and Mustard Gas

Chlorine reacts with moisture in the respiratory tract to form hydrochloric and hypochlorous acid, burning lung tissue — but its sharp smell made it somewhat detectable. Phosgene, introduced to overcome this, is far less irritating at first, allowing deeper, more damaging inhalation before symptoms of pulmonary oedema appeared, often hours after exposure. Mustard gas marked a further shift toward persistence: lipophilic and able to penetrate skin and cell membranes, it damaged DNA directly, causing blistering, and remained hazardous in contaminated ground for days or weeks.

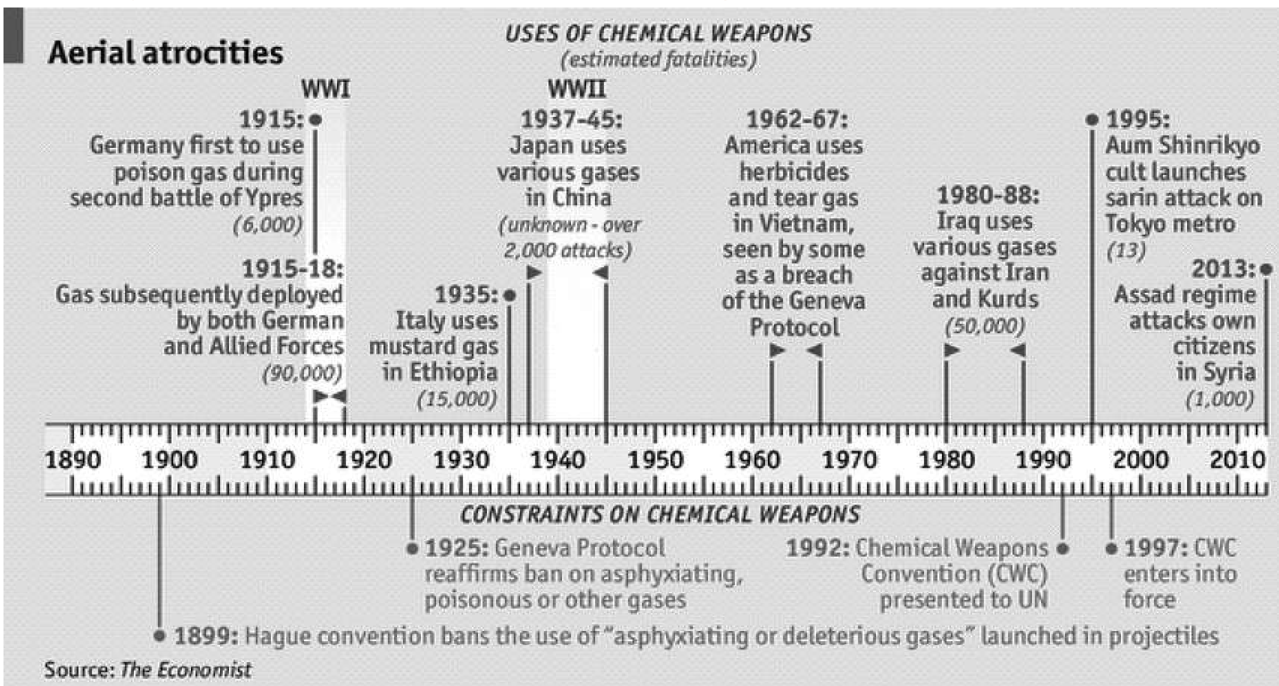
Casualties and the Birth of Chemical Terror

World War I chemical weapons caused over one million casualties. Fatality rates were lower than conventional arms, but injury and long-term suffering were extreme — chronic respiratory disease, blindness, and disfiguring skin damage followed survivors for life. Psychologically, "gas anxiety" and related war-neuroses became widespread, as the constant need to don masks eroded morale as effectively as bullets.

Environmental Legacy in Europe

More than a century later, France and Belgium still bear the scars: millions of unexploded, chemical-filled shells remain buried across the former front lines. As their casings corrode, they leak toxins into soil and groundwater. Certain tracts, known as "Red Zones," remain uninhabitable and unfarmable, a permanent monument to the first industrial use of chemical weapons.

Chapter 2 · Evolution of Chemical Agents — WWII to Cold War



Source: *The Economist*

The Rise of Nerve Agents

The most significant scientific leap in this field was the shift from pulmonary and blister agents to nerve agents — organophosphorus compounds that inhibit acetylcholinesterase. Without this enzyme to clear acetylcholine from synapses, nerves fire continuously, producing pupil constriction, convulsions, paralysis, and death from respiratory failure, even from minute doses.

Tabun, Sarin, and VX

Tabun (GA) was the first nerve agent discovered — highly toxic though less volatile. Sarin (GB) is more volatile, vaporising and spreading quickly to contaminate wide areas. VX, a second-generation agent, is oily and virtually non-volatile, remaining active on surfaces for days and lethal even through minute skin contact.

Cold War Stockpiling and Binary Weapons

Both Cold War superpowers built vast chemical arsenals as instruments of deterrence rather than active use — but storage itself carried real risk of leakage and localized ecological damage. Binary weapons emerged to mitigate this: two comparatively stable precursor chemicals are stored separately within a munition and mix only upon deployment, easing storage and transport risk without reducing the lethality of the final product.

Chapter 3 · The Iran–Iraq War — Largest Modern Use

Iraq's Chemical Weapons Program

Built through the late 1970s and accelerated after 1980, Iraq's chemical arsenal relied on precursor chemicals imported from Western Europe and the United States and processed at facilities in Samarra, Fallujah, and Al-Muthanna. Its stockpile included mustard gas, the nerve agents tabun, sarin, and cyclosarin, and the blood agent hydrogen cyanide — delivered by everything from aerial bombs to long-range artillery and rocket launchers.

The Halabja Massacre, 1988

On 16–17 March 1988, Iraqi aircraft struck the Kurdish town of Halabja with a calculated combination of mustard gas and nerve agents — nerve agents for instant mass lethality, mustard gas to prolong suffering and contaminate the ground. Roughly 5,000 civilians died outright, with total casualties reaching 7,000–10,000; tens of thousands more were left permanently blind or neurologically impaired. The town's low-lying basin trapped the gas cloud at ground level, maximising exposure, and it was later razed under Iraq's Anfal campaign.

Iranian Military Casualties

Iran sustained roughly 100,000 chemical casualties during the war, with 20,000 immediate combat deaths and long-term mortality estimated above 50,000, as survivors continue to die of pulmonary fibrosis and cancer decades later. Overwhelmed field hospitals rarely had the atropine and pralidoxime needed to treat nerve-agent victims in time.

A Failed International Response

Despite UN missions confirming chemical weapons use as early as 1984, the international response was toothless: the United States, viewing Iraq as a counterweight to Iran, continued supplying intelligence and dual-use technology even after Halabja. This impunity directly shaped the 1993 Chemical Weapons Convention (CWC) and the creation of the OPCW — though, as later chapters show, institutions alone cannot substitute for political will.

Chapter 4 · Agent Orange and Vietnam — A Generational Legacy

Operation Ranch Hand, 1961–1971

For a decade, U.S. Air Force C-123 aircraft sprayed roughly 19–20 million gallons of herbicide over South Vietnam, Laos, and Cambodia, covering some 4.5 million acres. Agent Orange — a 1:1 mixture of 2,4-D and 2,4,5-T — was the principal formulation, alongside Agents White, Blue, Purple, Pink, and Green. The manufacturing process for 2,4,5-T inevitably produced the dioxin TCDD, among the most toxic synthetic compounds known, whose consequences were neither anticipated nor acknowledged for decades.

Dioxin Contamination

TCDD binds the aryl hydrocarbon receptor, dysregulating genes that govern cell growth, hormones, immunity, and cell death. Its extreme fat-solubility drives bioaccumulation up the food chain, and in soil it resists degradation with a half-life of 10 to 100 years. Former airbases at Da Nang, Bien Hoa, and Phu Cat remain dioxin "hotspots" today, their contamination having long since spread into rivers, fish, and shellfish.

A Multigenerational Health Toll

The U.S. Veterans Affairs department formally recognises a long list of conditions presumptively linked to Agent Orange exposure, from non-Hodgkin's lymphoma to Type 2 diabetes and peripheral neuropathy. For Vietnamese civilians the scale is far greater: elevated cancer rates, miscarriage, stillbirth, and birth defects — neural tube defects, limb deformities, cleft palate — persist in the children of exposed parents. Vietnam estimates three million citizens affected and over 150,000 children born with serious defects since the war ended, with heritable epigenetic changes documented across at least three generations in animal models.

Environmental Ecocide

Scientists and legal scholars describe the ecological outcome of Ranch Hand as ecocide. Mekong Delta mangroves were nearly eliminated; repeatedly sprayed Central Highlands forests were stripped bare, triggering erosion and invasion by cogon grass that resists natural reforestation. A 2004 lawsuit by Vietnamese victims was dismissed in 2005 on the grounds that Agent Orange did not meet the legal definition of a poison weapon at the time — an omission later addressed, in part, by the 1976 Environmental Modification Convention (ENMOD).

PART II · MODERN CHEMICAL WARFARE

Chapter 5 · Syria's Chemical Tragedy

Ghouta Attack, 2013

On 21 August 2013, rockets filled with sarin struck civilian neighbourhoods near Damascus in one of the deadliest chemical assaults in modern history, killing hundreds instantly and injuring thousands more. Harrowing footage of victims convulsing and gasping for air circulated worldwide, yet political divisions blocked any decisive international response.

Khan Shaykhun, 2017 and Douma, 2018

An April 2017 airstrike released sarin over Khan Shaykhun in Idlib province, killing more than 80 people and proving Syria's chemical arsenal had not been fully dismantled despite prior agreements — prompting U.S. missile strikes but no lasting accountability. A year later, chlorine cylinders dropped on Douma killed dozens more; because chlorine is a widely available industrial chemical, the attack showed how even common substances can be weaponised when sophisticated nerve agents are politically harder to source.

A Pattern of Impunity

Across all three incidents, OPCW and UN investigations confirmed chemical weapons use, yet political divisions — chiefly between Western nations and Russia — blocked enforcement. The repeated failure to sanction perpetrators has undermined the credibility of the Chemical Weapons Convention and, critics argue, emboldened further use.

Chapter 6 · Novichok and Political Assassinations

Novichok denotes a family of organophosphate nerve agents developed under the Soviet-era FOLIANT program. Like other nerve agents, they inhibit acetylcholinesterase, triggering convulsions, paralysis, and respiratory failure even in trace doses, and are notable for extreme persistence on surfaces and in the body.

Skripal (2018) and Navalny (2020)

In March 2018, former double agent Sergei Skripal and his daughter were poisoned with Novichok in Salisbury, UK; both survived intensive care, though a British citizen later died from separate exposure to the same batch. The attack triggered a diplomatic rupture and mass expulsion of Russian diplomats. Two years later, Russian opposition figure Alexei Navalny collapsed mid-flight after Novichok poisoning and was evacuated to Germany for treatment, surviving but reinforcing suspicion of state involvement in silencing dissidents.

Kim Jong-nam, 2017

Kim Jong-un's half-brother was assassinated at Kuala Lumpur airport in February 2017 when two women smeared VX nerve agent on his face, killing him within minutes — a brazen demonstration that one of the most lethal chemical agents known could be deployed in a public airport, bypassing conventional security altogether.

Together these cases mark a disturbing evolution: chemical weapons deployed not on battlefields but as instruments of covert, state-linked political violence — a trend that existing treaties, built around wartime use, are poorly equipped to deter.

Chapter 7 · Ukraine's Chemical Time Bomb

Ukraine's dense network of chemical plants, fertiliser factories, and storage depots — holding an estimated 5.1 billion tons of hazardous materials including ammonia, chlorine, and petroleum products — has turned ordinary industrial infrastructure into a latent chemical hazard. Unlike battlefield chemical weapons, these substances exist in vast quantities, so a single strike, deliberate or accidental, could release toxins on a catastrophic, cross-border scale.

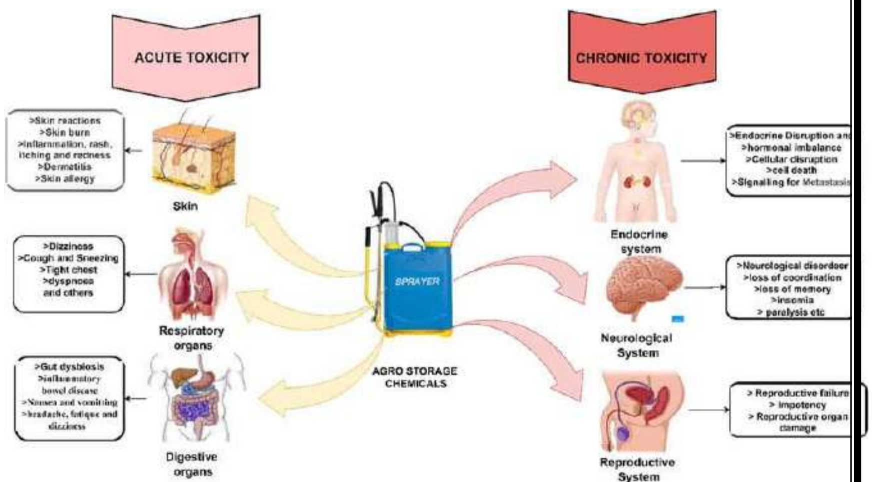
The heavily industrialised and constantly bombarded Donbas region is especially exposed: damaged pipelines and storage tanks constitute what observers describe as a ticking time bomb, capable of triggering a chemical disaster comparable in scale — if not in kind — to Chernobyl, overwhelming hospitals with poisoning and respiratory casualties even without any deliberate use of chemical weapons.

PART III · HEALTH CONSEQUENCES

Chapter 8 · Immediate Effects and Acute Toxicity

Mechanism of Chemical Agents

Acute chemical injury follows the pathway of the agent class involved. Choking agents flood the lungs with fluid by damaging the alveolar-capillary membrane; blood agents shut down cellular respiration at the mitochondrial level; nerve agents flood synapses with acetylcholine, causing convulsions and paralysis; blister agents burn skin, eyes, and airways on contact and continue to damage DNA long after exposure ends.



Nerve Agents vs. Blistering and Choking Agents

Nerve agents act within seconds to minutes and are lethal in microgram quantities, making rapid treatment essential. Blister agents act more slowly — often with a symptom-free latent period — but leave injuries, such as corneal damage and deep burns, that heal poorly and predispose survivors to cancer. Choking agents can appear deceptively mild at first exposure, with fatal pulmonary oedema sometimes developing hours later, a delay that historically cost many soldiers their lives.

Emergency Medical Response

Field response to nerve-agent exposure centres on rapid decontamination and prompt administration of antidotes such as atropine and pralidoxime, which counteract acetylcholine build-up and reactivate the blocked enzyme respectively — though as seen in the Iran–Iraq War, these are frequently unavailable in sufficient quantity during a mass-casualty event. Blister-agent casualties require extensive burn care, while choking-agent victims need close respiratory monitoring even when initial symptoms seem minor.

Chapter 9 · Gulf War Syndrome — Decades of Suffering

Between 250,000 and 300,000 veterans of the 1990–91 Gulf War have reported a cluster of chronic, multi-symptom illnesses — fatigue, joint pain, cognitive difficulties, and gastrointestinal problems — that came to be known as Gulf War Syndrome. Unlike the acute casualties of a direct chemical attack, this is a slow-burning legacy of low-level exposure and its interaction with the human body over years.

Investigators have pointed to several overlapping causes: low-level exposure to nerve agents released when Iraqi chemical weapons depots, notably at Khamisiyah, were demolished by coalition forces; the prophylactic use of pyridostigmine bromide pills intended to protect troops against nerve-agent attack; and heavy pesticide use in theatre. No single cause fully explains the syndrome, and the difficulty of disentangling these factors decades later illustrates how chemical warfare's health toll can remain contested and under-treated long after the fighting ends.

Chapter 10 · Neurological and Cognitive Impacts

War's impact on the brain is as devastating as its impact on the body, and considerably longer-lasting. Nerve agents disrupt the nervous system directly, often causing irreversible injury — impaired motor skills, seizures, and chronic neurological dysfunction that can persist for life.

Beyond direct chemical exposure, the sustained stress and repeated trauma of war conditions themselves impair memory and cognitive function — an effect that reaches well beyond soldiers to touch civilians and children. Post-Traumatic Stress Disorder, marked by flashbacks, anxiety, and emotional instability, frequently persists for years and complicates reintegration into ordinary life, while sustained stress and brain injury raise the long-term risk of depression, anxiety disorders, and neurodegenerative disease.

Chapter 11 · Multigenerational Health Effects

War's health toll does not end when the fighting stops. Vietnam remains the starkest example: toxic chemical exposure during the war has been linked to elevated birth-defect rates that persist across generations, from physical deformities to developmental delays and chronic illness affecting thousands of families decades on. Research suggests health effects can extend to second and even third generations descended from those originally exposed.

Scientists continue to debate how much of this multigenerational burden reflects heritable genetic and epigenetic damage versus ongoing environmental exposure — poor living conditions, malnutrition, and continued contact with residual pollutants — with most evidence pointing to both mechanisms interacting. Women, and particularly women from ethnic minority communities with limited healthcare access, bear a disproportionate share of this burden, facing elevated pregnancy risk with fewer resources to manage it.

PART IV · ENVIRONMENTAL IMPACT

Chapter 12 · Soil Contamination and Agricultural Devastation

Chemical agents behave very differently in soil than conventional munitions, which leave localised debris. Persistent agents and their by-products — from WWI-era mustard gas residue still leaching in France and Belgium's "Red Zones," to TCDD-laden soil at former Vietnamese airbases — can render land unfit for agriculture for generations. In Vietnam, repeated herbicide spraying stripped some upland forests so thoroughly that only invasive, fire-prone cogon grass — locally dubbed "American grass" — could recolonise the bare ground, actively blocking natural forest recovery.

More broadly, bomb craters, compacted soil from heavy military vehicles, and battlefield earthworks degrade soil structure and fertility well beyond any single chemical contaminant, compounding the agricultural cost of conflict long after the front line has moved on.

Chapter 13 · Water Resources and Ecosystem Collapse

Persistent contaminants inevitably migrate from soil into water. Dioxin-bound runoff from former airbases has contaminated rivers and coastal sediment across Vietnam, with fish, ducks, and shellfish becoming long-term vectors of civilian exposure decades after spraying ended. Corroding, buried munitions across former WWI battlefields continue to leach toxins into groundwater. Once in the water column, these substances move up the food chain through bioaccumulation, and the near-total loss of Mekong Delta mangrove forests — among the most herbicide-sensitive ecosystems on Earth — illustrates how chemical contamination can collapse an entire aquatic ecosystem rather than simply poisoning it.

Chapter 14 · Long-Term Environmental Persistence

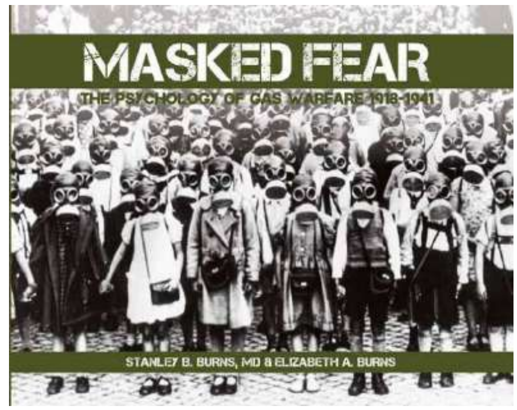
Persistence is what separates chemical warfare's environmental legacy from that of conventional weapons. Dioxin (TCDD) resists microbial breakdown in soil for 10 to 100 years; mustard gas residue can remain hazardous in buried munitions for over a century, as Europe's ongoing WWI shell recoveries attest. Less discussed is the vast tonnage of chemical munitions dumped at sea by multiple nations after both World Wars, whose corroding casings pose a slow-motion, largely unmonitored contamination risk in marine environments to this day.

The cumulative effect across all these pathways is severe and long-lasting biodiversity loss: displaced large mammals, collapsed avian populations, devastated freshwater fisheries, and disrupted soil invertebrate communities that would otherwise drive the nutrient cycling ecosystems need to recover. Unlike a bombed forest, which can regrow within a human lifetime, a dioxin- or mustard-gas-contaminated site can remain actively hostile to recovery for generations.

PART V · SOCIETAL & ECONOMIC CONSEQUENCES

Chapter 15 · The Psychology of Gas Warfare

"Gas Fright" and Terror as a Weapon



Chemical warfare targets the foundations of human composure as much as the body itself. "Gas fright" — a state of collective psychological paralysis triggered merely by the perceived presence of chemical agents — can cause more casualties through panic and breakdown of command than the gas itself. This is by design: unlike conventional weapons, which aim to eliminate a target, gas is deployed to demoralise, forcing troops into hours or days of restrictive masks and suits that induce sensory deprivation, exhaustion, and isolation, eroding the will to fight without a single bullet fired.

Civilian Trauma and Societal Disruption

Civilians, lacking equipment or psychological preparation, suffer even more acutely — chronic anxiety, depression, and PTSD that can be triggered for decades by something as ordinary as a siren or a bank of fog. At a societal level, fear of contamination has repeatedly driven mass migration and refugee crises as populations flee toward "safe" air, clogging transport routes and eroding public trust in a government's basic ability to protect its citizens — a form of psychological pressure capable of paralysing a state more effectively than conventional military force.

Chapter 16 · Economic Costs and Remediation Challenges

The Bill for Decontamination

Environmental restoration after chemical warfare routinely runs into the billions of dollars. Because chemical agents permeate soil, groundwater, and urban infrastructure rather than leaving localised debris, decontamination demands specialised HAZMAT teams, advanced neutralisers, and secure disposal facilities — work so costly and technically demanding that it can span decades, diverting funds from education, healthcare, and infrastructure.

Case Study: Da Nang Airbase

The Da Nang Airbase remediation stands as the benchmark case: an international, multi-year project used Thermal In-Pile Desorption — heating thousands of cubic metres of soil to extreme temperatures — to break down persistent dioxin, at a cost exceeding $100 million for a single site.

Medical Costs and Lost Productivity

Beyond cleanup, survivors' permanent medical needs — lifelong oxygen therapy, ongoing dermatological care for chemical burns, and specialised support for children born with mutagenic birth defects — compound the bill for generations. And because permanent disability prevents many survivors from working, chemical warfare imposes a double economic cost: lost labour productivity alongside rising demand on state disability and welfare systems.

PART VI · THE FUTURE

Chapter 17 · Emerging Threats — Drones and New Technologies

The barriers to chemical weapons use are quietly eroding. Commercial drones offer a low-cost, hard-to-attribute delivery method that sidesteps the need for artillery or aircraft, effectively democratising access to a capability once limited to states with industrial chemical programmes. Advances in synthetic biology raise the further risk that novel toxic compounds could be engineered outside the traditional chemical-industry supply chains that export controls are built to monitor, while non-state actors — from insurgent groups to individual extremists — have repeatedly demonstrated interest in acquiring even crude chemical capabilities.

Chapter 18 · International Law and the Failure of Treaties

The legal framework against chemical warfare has developed largely in reaction to its worst abuses. The 1925 Geneva Protocol banned the use — but not possession — of chemical weapons, a gap that persisted until the 1993 Chemical Weapons Convention established the OPCW with formal verification and inspection powers, the most comprehensive disarmament regime of its kind.

Yet Syria's repeated, well-documented chemical attacks after ratifying the CWC — and the Novichok assassinations conducted by a CWC signatory state — demonstrate that verification mechanisms are only as strong as the political will to enforce them. Sanctions and condemnations have repeatedly proven insufficient deterrents when major powers disagree on attribution or consequences, leaving a persistent accountability gap at the heart of the international regime.

Chapter 19 · Medical Response and Treatment Advances

Medical countermeasures have advanced significantly since the improvised field response of the Iran–Iraq War, with auto-injector antidotes, improved decontamination protocols, and lighter, more effective protective equipment reducing exposure risk for responders and troops alike. Research continues into longer-term treatments for the chronic conditions — respiratory, dermatological, and neurological — that persist in survivors for decades, though funding for this research lags well behind the scale of the problem it addresses.

Chapter 20 · Breaking the Cycle — Future Prevention

Preventing the next Halabja or Ghouta will require strengthening international norms around attribution and consequence, not merely condemnation; investing in more robust and less politically vulnerable verification and inspection regimes; and building public and institutional awareness of chemical warfare's true, multi-decade cost. The history recounted in this review is not one of steady progress — but each treaty, however imperfectly enforced, represents a step toward the possibility of a world where breathing the air is never, again, an act of courage.

CONCLUSION

From the chlorine clouds of Ypres to the sarin rockets of Ghouta and the Novichok-laced doorknobs of Salisbury, chemical warfare has proven remarkably consistent in its core logic across more than a century: it terrorises disproportionately to its body count, it persists in soil and water long after the fighting ends, and it passes its damage down to children who never chose to be exposed. What has changed is the sophistication of the agents and the fragility of the institutions meant to contain them.

The evidence assembled here — from Halabja's tens of thousands of survivors to Da Nang's $100-million cleanup, from Gulf War veterans' chronic illness to Vietnam's third-generation birth defects — makes the case plainly: chemical warfare's true cost is never paid in a single generation, and never fully counted by the states that unleash it. Confronting that reality honestly, rather than treating each new attack as an isolated tragedy, is the first real step toward the "chemical-free future" that international law has promised since 1925 but never fully delivered.

Thank you