CS5027: Fifty Discoveries, Fifty Inventions

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Preface

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Part I

PART 1: LECTURES

1 Science, Mathematics, and Technology

This week's contents focuses on Singapore's history with regards to its scientific and technological advancements.

1.1 Singapore's Past

> "A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill."
>
> – Bush, 1945

When Singapore separated from Malaysia, its focus was put on survival as it was a nation with no natural resources. One such tool that would enable Singapore to survive was through Science: a necessary pre-requisite for industrial and technological advancement.

In February 1966, Deputy Prime Minister Toh Chin Chye[1] announced a proposal for forming a new statutory board: the **Science Council of Singapore**.

1.1.1 Science Council of Singapore (i.e., SCS)

This board was established in 1967 - the board would make reports and suggest recommendations on:

1. Scientific and technological research and developments.
2. Effective training and utilization of scientific and technological manpower in Singapore.
3. Establishing official relations with other scientific organizations.

In 1968, the board suggested establishing a science center in Singapore - this was suggested to the Minister of Science and Technology.

Shortly after, a special committee was appointed to come up with the preparatory work and submit proposals for setting up the center - this committee included:

1. A chairman: Ronald Sng Ewe Min

[1] He was a Physiologist and a Vice Chancellor of the University of Singapore.

2. Three members:

    1. Sng Yew Chong
    2. Rex Anthony Shelley
    3. Bernard Tan Tiong Gie

1.1.1.1 Science and Industry Quiz (i.e., SIQ)

The SCS thought that one way to popularize science and technology over the television would be to combine education with entertainment.

Secondary school students would form teams and participate in the SIQ. Each team would have four members: two members would participate in the quiz programme and the other two on standby.

There are two rounds to the SIQ:

1. **Preliminary Round**

    All competing teams had two sets of question papers: Set A and Set B.

    Set A had 100 questions; Set B had 50 questions. Each team had 15 minutes to answer both sets.

    The first preliminary round was held at the Raffles Institution Hall on 28 July, 1972. 54 Teams competed, but only 12 were selected for the Televised Series.

2. **Televised Series**

    There were three stages - the four Quarter Finals, two Semi-Finals, and a Final.

    Each of the televised series had four rounds. The first round was where each team would have a fixed amount of time to answer as many questions as they could.

    The second round consisted of questions being asked to each individual of a team. The question had to be answered within a minute and with no assistance.

    Round three posed a question to all team members - the team had to answer the question unanimously. The six questions posed in this round enabled problem-solving and teamwork skills.

    The fourth final round was a buzzer-style question triva session.

1.1.1.2 The Innovators

In 1979, the SIQ was replaced by The Innovators.

The Innovators was a series of six programs where JC[2] students would work with Radio Television Singapura producers to produce television programs that had a scientific or technological theme, but focused on innovation.

The top three programs included:

1. "...And Life Goes On"
2. "Food Encounters"
3. "The Miracle Gene"

These three programs were selected by a panel of judges - the student producers were awarded prizes too.

1.1.1.3 Opening of the Science Center

> "While formal educational institutions make sure we are raising a nation of "science literate people", Science Centre Singapore takes this to the next level.
>
> We make science accessible and engaging, creating an environment where Singaporeans are empowered to advance their own learning and, hopefully, are inspired to do something incredible with their futures.
>
> Admission (just to the Science Centre) is \$6 for adults and \$4 for children."
>
> – Science Center's justification

The Science Center aimed to be a place where "Science befriends and transforms the minds of millions".

Figure 1.1: Entrance to Singapore's Science Center

It also aimed to promote interest, learning, and creativity in science and technology via imaginative and enjoyable experiences (that contribute to Singapore's human resources).

[2]**JC** is short for **J**unior **C**ollege!

1.1.1.3.1 Redeveloping the Science Center

> "Many people whom I have spoken to remember the Science Center fondly, and can even name specific exhibits that have inspired them. The new Science Centre gives us an opportunity to do even more – to help our young learn through play and fun, to inculcate a love and wonder for science and technology among Singaporeans and to kindle a passion for lifelong learning and inquiry."
>
> – Mr. Koh

The above was mentioned by Koh Boon Hwee during 12 November, 2014.

1.1.2 National Science and Technology Board (i.e., NSTB)

This was formed in October 1990 (after the passing of the bill); and the enactment of the Science and Technology Board act the following month.

The NSTB was a statutory board under the **M**inistry of **T**rade & **I**ndustry (i.e., **MTI**).

The NSTB developed Singapore into a center of excellence in certain fields of science and technology to enhance national competitiveness in industrial and service sectors (i.e., industry-driven research and development).

1.1.2.1 A*STAR

On 5 January 2002, the NSTB was reorganized and renamed to the Agency for Science, Technology and Research (i.e., A*STAR).

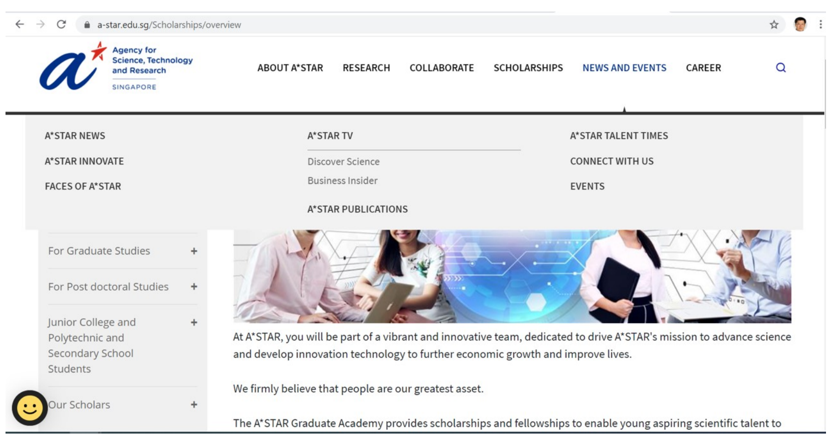


Figure 1.2: A*STAR's Homepage

A*STAR aimed to promote mission-oriented research that advances scientific discovery and technological innovations.

The agency got a portion of the national science and technology's budget as a show of support. Its facilities are currently located at Biopolis and Fusionopolis (at one-north).

1.1.2.1.1 A*STAR's Mission

A*STAR aims to develop Singapore's science, technology, and engineering capabilities to boost Singapore's economic growth via the three ways:

1. Developing the manpower required for the science and technology sectors.
2. Pioneering research and development to drive innovation and enhance the Singapore's knowledge-based economy.
3. Monetizing results in research and development.

Regarding the final point, A*STAR's commercialization arm manages its intellectual property and also helps apply its research to industry.

1.1.3 Lee Kong Chian Natural History Museum (i.e., LKCNHM)

The LKCNHM - formerly known as the **R**affles **M**useum of **B**iodiversity **R**esearch (i.e., **RMBR**) - was opened on 18 April, 2015 by Dr. Tony Tan Keng Yun: the president and chancellor of the National University of Singapore.

The museum strives to be a leader in Southeast Asian biodiversity in research, education, and outreach.

Mrs. Della Lee[3] donated enough money to enable LKCNHM to purchase three dinosaur skeletons.

1.1.4 NUS High School of Mathematics and Science

The school's mission was to shape the future of education in mathematics and science by producing future-ready pioneers, humanitarians, and innovators for the world.

The school's motto is: Experiment. Explore. Excel.

[3]She was Lee Seng Gee's - the Lee Foundation's chairman - wife.

1.1.5 Singapore National Academy of Sciences (i.e., SNAS)

In 31 July, 1967, scientists collectively formed the SNAS - a scholarly and professional body. The SNAS was meant to become the equivalent of the UK's Royal Society or the USA's National Academy of Sciences.

The SNAS was formed with the following objectives:

1. Promoting the advancement of science and technology in Singapore
2. Discussing scientific, technological, and macroeconomic problems (especially those that concern the nation)
3. Representing members' scientific opinions and fellows of the academy

1.2 Singapore's Return on Investment

This sub-section discusses some of Singapore's results with regards to its investment in science and technology.

1.2.1 Trends in International Mathematics and Science Study (i.e., TIMSS)

The TIMSS is developed and executed at the international level by the **I**nternational Association for the **E**valuation of Education **A**ssessment (i.e., **IEA**).

Rank (Grade 4)	Country	Average Score
1	Singapore	587
2	Chinese Taipei	557
3	Hong Kong SAR	554
4	Japan	548

Rank (Grade 8)	Country	Average Score
1	Singapore	567
2	Chinese Taipei	561
3	Japan	554
9	Hong Kong SAR	530

Figure 1.3: Singapore's TIMSS Results in Science

The TIMSS happens once every four years (the latest one was in 2019) - Singapore has partook in every study.

1.2.1.1 Scope of the TIMSS

The TIMSS gauges the mathematics and science knowledge of fourth and eighth graders (i.e., primary four and secondary 2 respectively). However, some countries only participate at the eighth-grade level.

The TIMSS allows for an international benchmark in three bands and along two dimensions - content and cognitive domains:

1. Average is higher than the US'
2. Average score is not measurably different from the US'
3. Average score is lower than the US'

Results may wildly differ between countries, but the reasons are attributed to students' attitudes, educational aspirations, school climates (e.g., violence in schools), school resources, and safety.

1.2.2 Programme for International Student Assessment (e.g., PISA)

The PISA is a study done once every three years and is run by the **O**rganization for the **E**conomic **C**ooperation and **D**evelopment (i.e., **OECD**).

Singapore's 15-year olds were ranked first in mathematics, science, and reading in 2015 (i.e., Singaporean students were the best in the world when it comes to working in teams to solve problems).

Hence, Singaporean students are very well equipped for the future's opportunities and challenges - they have a high ability to work well independently and together.

In 2018, Singapore came in second place in all three categories (China took first place).

1.2.3 Times Higher Education (i.e., THE) University Rankings

In 2019, NTU and NUS were ranked 51 and 23 on the THE world university rankings.

Subject	2019 Rank	2018 Rank	Institution
Architecture / Built Environment	8	10	NUS
Chemistry	7	7	NUS
Chemistry	9	11	NTU
Communication and Media Studies	8	12	NTU
Computer Science and Information Systems	10	10	NUS
Engineering – Chemical	7	9	NUS
Engineering – Civil and Structural	10	21	NTU

STEM in red

Figure 1.4: QS Rankings for NTU and NUS in 2019

The **Q**uacquarelli **S**ymonds (i.e., **QS**) rankings ranked NTU and NUS at 12 and 11 respectively - SMU was ranked at 500. Both NTU and NUS were ranked at 11 in the QS rankings in 2020 - SMU was at 477.

1.2.4 President's Science and Technology Award (i.e., PSTA)

The PSTA recognizes individuals with creative ideas who have made significant contributions to Singapore.

So far, over 60 men and women who have been singled out for this.

1.2.5 International Olympiads

This following sub sub-section lists Singapore's performances in the International Olympiads:

1. **Math**

59TH INTERNATIONAL MATHEMATICAL OLYMPIAD (IMO)

2. For starters, the Singapore team won **two Gold medals, three Silver medals and one Bronze medal** at the IMO held in Cluj-Napoca, Romania, from 3 to 14 July 2018. The IMO challenged students to apply high-level problem solving skills and present rigorous proofs to support their solutions. Singapore was placed 8th in a field of 107 countries/territories, featuring a total of 594 participants.

Gold medallists	• Ng Yu Peng, Hwa Chong Institution • Lee Ker Yang, Raffles Institution
Silver medallists	• Joel Tan Junyao, NUS High School of Mathematics and Science • Lucas Boo Tse Yang, Raffles Institution • Cheng Puhua, Raffles Institution
Bronze medallist	• Shi Cheng, Hwa Chong Institution
Led by	• Associate Professor Wong Yan Loi, Department of Mathematics, National University of Singapore • Mr Thomas Teo Teck Kian, Raffles Institution

Figure 1.5: Singapore's Performance in the International Math Olympiad (i.e., IMO)

The first math olympiad (i.e., IMO) was held in 1959 in Romania with 7 countries' participants. Over the years, 100 counries from five continents have participated.

The competition is overseen by the IMO board - they also ensure that each host country upholds the traditions of the IMO.

2. **Informatics**

30TH INTERNATIONAL OLYMPIAD IN INFORMATICS (IOI)

8. The Singapore team secured **1 Gold medal, 2 Silver medals and 1 Bronze** medal at the IOI held in Tsukuba, Ibaraki, Japan from 1 to 8 September 2018. During the competition, students faced challenging computational problems which tested their ability to design and implement efficient algorithms and data structures. Singapore was placed joint 9th in a field of 87 countries/territories with 341 participants.

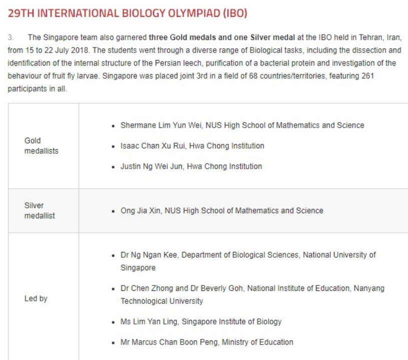
Gold medallists	• Gabriel Goh Kheng Lin, NUS High School of Mathematics and Science
Silver medallists	• Jacob Teo Por Loong, NUS High School of Mathematics and Science • Jeffrey Lee Chun Hean, NUS High School of Mathematics and Science
Bronze medallists	• Teow Hua Jun, Hwa Chong Institution
Led by	• Dr Steven Halim, School of Computing, National University of Singapore • Dr Daren Ler Shan Wen, National Junior College

Figure 1.6: Singapore's Performance in the International Olympiads in Informatics (i.e, IOI)

The IOI is an annual competitive programming competition for secondary school students - the first IOI happened in 1989 in Pravetz, Bulgaria.

The contest consists of two days of computer programming and problem-solving in algorithms.

3. **Biology**



29TH INTERNATIONAL BIOLOGY OLYMPIAD (IBO)

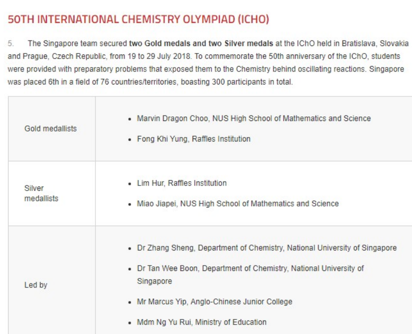
3. The Singapore team also garnered **three Gold medals and one Silver medal** at the IBO held in Tehran, Iran, from 15 to 22 July 2018. The students went through a diverse range of Biological tasks, including the dissection and identification of the internal structure of the Persian leech, purification of a bacterial protein and investigation of the behaviour of fruit fly larvae. Singapore was placed joint 3rd in a field of 68 countries/territories, featuring 261 participants in all.

Gold medallists	• Shermane Lim Yun Wei, NUS High School of Mathematics and Science • Isaac Chan Xu Rui, Hwa Chong Institution • Justin Ng Wei Jun, Hwa Chong Institution
Silver medallist	• Ong Jia Xin, NUS High School of Mathematics and Science
Led by	• Dr Ng Ngan Kee, Department of Biological Sciences, National University of Singapore • Dr Chen Zhong and Dr Beverly Goh, National Institute of Education, Nanyang Technological University • Ms Lim Yan Ling, Singapore Institute of Biology • Mr Marcus Chan Boon Peng, Ministry of Education

Figure 1.7: Singapore's Performance in the International Biology Olympiad (i.e., IBO)

The IBO is a competition that tackles Biological problems and deals with Biological experiments (i.e., testing them). The IBO challenges and stimulates participants to expand their talents and to promote participants' careers as scientists.

4. **Chemistry**



50TH INTERNATIONAL CHEMISTRY OLYMPIAD (ICHO)

5. The Singapore team secured **two Gold medals and two Silver medals** at the IChO held in Bratislava, Slovakia and Prague, Czech Republic, from 19 to 29 July 2018. To commemorate the 50th anniversary of the IChO, students were provided with preparatory problems that exposed them to the Chemistry behind oscillating reactions. Singapore was placed 6th in a field of 76 countries/territories, boasting 300 participants in total.

Gold medallists	• Marvin Dragon Choo, NUS High School of Mathematics and Science • Fong Khi Yung, Raffles Institution
Silver medallists	• Lim Hur, Raffles Institution • Miao Jiapei, NUS High School of Mathematics and Science
Led by	• Dr Zhang Sheng, Department of Chemistry, National University of Singapore • Dr Tan Wee Boon, Department of Chemistry, National University of Singapore • Mr Marcus Yip, Anglo-Chinese Junior College • Mdm Ng Yu Rui, Ministry of Education

Figure 1.8: Singapore's Performance in the 30th International Chemistry Olympiad (i.e., IChO)

The IChO is an annual Chemistry for a nation's most talented high-schoolers. Nations send a team of four students who are tested on their Chemistry knowledge and skills in a five-hour laboratory practical and five-hour written theoretical examination that are both held on different days.

31ST INTERNATIONAL YOUNG PHYSICISTS' TOURNAMENT (IYPT)

4. Competing against 31 other countries/territories, the Singapore team emerged **overall champion** at this year's IYPT held in Beijing, China, from 19 to 26 July 2018. The IYPT is organised around "physics fights", that mimic discussions at research conferences, where participants present their research and provide constructive feedback on the work of other teams.

Team members	• Fu Xinghong, Raffles Institution • Jerry Han Jiatao, Raffles Institution • Hu Yongao, Raffles Institution • Liu Haixuan, Raffles Institution • Russell Yang Qi Xun, NUS High School of Mathematics and Science
Led by	• Dr Koh Teck Seng, School of Physics and Mathematical Sciences, Nanyang Technological University • Mrs Lim Siew Eng, Raffles Institution • Mr Chan Khai Mun, Ministry of Education

Figure 1.9: Singapore's Performance in the International Young Physicists' Tournament (i.e., IYPT)

5. **Young Physicists' Tournament**

   The IYPT (sometimes called the "Physics World Cup") is a team-oriented competition for secondary school students.

   Participants present their solutions to scientific problems they have prepared over several months and then discuss their solutions with other teams.

6. **Astronomy and Astrophysics (i.e., IOAA)**

   The IOAA promotes interest in astronomy and similar subjects by developing "international contacts" between different schools to promote Astronomy and Astrophysics in schools.

1.2.6 Singapore's Scientific Pioneers

The book shown above contains information on 25 individuals who laid foundations for Singapore's scientific achievements.

All of these scientists were born prior to Singapore's independence, but have made exceptional contributions to Singapore's engineering, medical, educational, and scientific sectors.

Some of these people include:

1. **Benjamin Henry Sheares**

   He was the father of Obstetrics and Gynaecology in Singapore. He has a procedure named after him and was one of the top graduates of the King Edward VII College of Medicine.

   He was also Singapore's second president - he also has a bridge named after him: the Benjamin Sheares Bridge (which is one of Singapore's most famous landmarks).

Figure 1.10: A Book on Singapore's Scientific Pioneers

2. **Shih Choong Fong**

   Shih was the president of NUS from 2000 to 2008 and also the founding president for King Abdullah University of Science and Technology (i.e., KAUST) in from 2008 to 2013.

   Shih got a PhD from Harvard in 1973 and led the Fracture Research Group at the GE Corporate Research Lab in the US. In 1981, he joined Brown University. He was appointed University Professor by NUS in 2013 and was inducted into the Honorary Membership by NUSS in 2001.

3. **Tay Eng Soon**

   Soon was more well-known as a politician. He was a minister of state in the Ministry of Education from 1980 until he died in 1993.

   Soon worked hard to develop polytechnics and ITEs.

   His speciality was in nuclear energy and nuclear power.

Figure 1.11: The Shears Bridge in Singapore

1.3 What is Science?

> "Science is a voyage of intellectual exploration, and an expression of the human spirit."
>
> – Henry Stommel, 1989

In 1834, William Whewell[4] (1794 - 1866) coined the term "scientist"[5].

He was also the master of of Trinity College at Cambridge; he was also a founding member and a president of the British Association for the Advancement of Science.

1.3.1 Scientific Worldview

The world is seen as such by a scientist:

1. The world is understandable
2. Scientific ideas can change
3. Scientific knowledge is everlasting
4. Science cannot answer everything
5. Science is an enterprise

Science is a blend of logic and imagination - logic is used to understand why things happen while one's creativity is used to recognize the meaning of something unexpected.

1.3.1.1 The World is Understandable

Stuff that happens in this world have a consistent pattern that can be seen through close observation.

By using one's intellect along with instruments, people can find all sorts of patterns.

The universe is a system where the basic rules are the same.

1.3.1.2 Scientific Ideas can Change

New observations can challenge existing theories, in which case, new theories may be needed to explain the observation.

Science is humanity's attempt at explaining how the universe works.

Testing, improving, and discarding theories is an ongoing process in Science.

[4] He was a philosopher of science and a Cambridge University historian

[5] Prior to this term, scientists were known as "men of science" or "natural philosophers"

1.3.1.3 Scientific Knowledge is Everlasting

Modifying ideas (instead of rejecting them) is a norm in science. Powerful constructs survive and grow more precise so that they are more widely accepted.

Einstein did not reject the Newtonian law of motion, but only showed them to be a limited application with a more general concept.

1.3.1.4 Science Cannot Answer Everything

Many beliefs fall into this category (e.g., supernatural forces, true purpose of life, etc).

In some cases, science may even be seen as irrelevant by people hwo have certain beliefs (e.g., fortune tellers)

1.3.1.5 Science is an Enterprise

Science is a complex, social activity that involves many individuals of many backgrounds.

Scientific research is also competitive in that researchers compete for funding - committees meet up to decide which topic(s) should be focused on.

1.3.2 Components of Science

Science has certain elements:

1.3.2.1 Scientific Enquiry

Science demands evidence; scientists focus on collecting accurate data (which are verified by others).

1.3.2.2 Making Observations

To make observations, scientists must use:

1. Their five senses
2. Instruments that enhance those senses
3. Instruments that go beyond the human senses

1.3.2.3 Attitudes

Scientists need to be willing to work hard, to have courage, and to embrace openness (i.e., be willing to change).

1.3.3 Ways of Observation

Scientists…

1. Observe passively (i.e., watch things happen without interefering)
2. Make collections (i.e., collecting samples)
3. Actively probe the world (e.g., conducting clinical trials, etc).

Otherwise, they also…

1. **Explain and Predict**

   Scientists use observations to construct explanations for them.

   These hypotheses should also fit additional observations.

2. **Identify and Avoid Bias**

   Scientific evidence can be biased in how scientists choose to report those facts (or the kind of data collected to begin with).

   A scientist's nationality, sex, age, and other factors may cause them to look for one kind of evidence or interpretation.

   A possible safeguard against this is to have many different people involved working on the same problem.

3. **Realize that nobody is omniscient (i.e., all-knowing)**

   No scientist had the right to decide for themselves what is "true".

   Scientist whose observations do not align with mainstream ideas may encounter vigorous criticisms - these scientists may also have difficulty garnering support for their research.

1.3.4 Creative-Failure Methodology

> "A basic truth that the history of the creation of the transistor reveals is that the foundations of transistor electronics were created by making errors and following hunches that failed to give what was expected."
>
> – William Shockley

William Shockley - inventor of the transistor - started with a concept of the tubeless radio and used trial and error to make his invention.

1.3.5 Communication and Organization in Science

Science can be communicated in a variety of ways, some of which include:

1. **Communicating with the Public**

   Science is too important for the public to stay in the lab.

   Many scientists too feel a need to inform the public about potentially dangerous misconceptions or to counter misinformation from numerous quarters.

Science is also organized into content disciplines - it is a collection of scientific fields (that provide a foundation of research).

Different fields in science also spill into one another (e.g., Biochemistry, Biophysics, etc).

1.3.6 A "Right" Way to Perform Science

There are ethical principles to conducting science - competition has led to unethical practices such as:

1. **Scientists withholding information and falsifying findings**

   These violations damage science, the scientific community, and the funding agencies.

2. **Treating live subjects**

   For instance, human subjects should only be used for a study if they consent to it. Part of this also means disclosing the risks and intended benefits of research.

3. **Scientists as Experts and Advisors**

   Scientists partake in public affairs as specialists and as citizens.

   Scientists help the public and its representatives to help understand what most likely happened.

1.3.7 Why is Science so Important?

Science is so important (and specialised) that the President of the United States has a 25-member panel, known as the “National Science Board” to serve as advisors to him and the Congress on policy matters related to science and engineering, and education in both fields.

The National Science Board has its members drawn from industry and academia. Vannevar Bush was the first Presidential Science Advisor, and also head of the Office of Scientific Research and Development (OSRD). He oversaw most of America’s scientific research during World War II.

1.3.8 Science in Courtrooms

An increasing number of legal disputes involve the principles and tools of science. Properly resolving those disputes matters not just to the litigants, but also to the general public – those who live in our technologically complex society and whom the law must serve.

The decisions of the judges should reflect a proper scientific and technical understanding so that the law can respond to the needs of the public

1.4 Mathematics and Science

Mathematics is the science of patterns and relationships For some, especially professional mathematicians, the essence of mathematics lies in its beauty and its intellectual challenge these people talk about “elegant” solutions to mathematical problems

For scientists and engineers, the value of mathematics lie in its ability to solve problems that originate in the world of experience

Mathematics also find application in “non-technical”, fields, e.g., business, music, politics, sports, and social sciences

1.5 Technology

Technology extends our abilities to change the world: to cut, shape, or put together materials; to reach farther with our hands, voices, and senses.

We use technology to try to change the world to suite us better The changes may relate to survival needs such as food, shelter, or defense, or they may relate to human aspirations such as knowledge, art, or control.

But the results of changing the world are often complicated and unpredictable.

They can include unexpected benefits, costs, or risks.

1.5.1 Is it Practical?

Engineering combines scientific enquiry and practical values In its broadest sense, engineering consists of construing a problem and designing a solution for it.

Engineering shares many characteristics with science, but engineering affects the social system and culture more directly than scientific research.

1.5.1.1 There is No Perfect Design

There is no perfect design as accommodating one constraint leads to conflict with another.

All technologies involve control, e.g., in an iron (or an air-conditioned room, or a rice cooker), the temperature is controlled within a preset range.

Control typically requires feedback, logical comparisons, and a means for activating change

1.5.1.2 Side Effects

Technologies have side effects   what is one side effect of X-ray? personal computers? mobile phones? the Internet? photocopy machines? the automobile? social media?

Systematic risk analysis is used to minimise the impact of side effects (e.g., the side effect of X-ray is cancer)

There may also be unintended benefits / consequences:

1. **Suntan lotion**

   The main ingredient, titanium dioxide, mixed with water, results in hydrogen peroxide. This kills phytoplankton that nourishes fish and ultimately poisons the rest of the food chain.

Technology can also fail too (e.g., crashing of the space shuttle).

1.5.2 Issues in Technology

Issues have also emerged   overuse of fossil fuels, pollution, global warming, new bacterial strains that are resistant to antibiotics, digital divide, deforestation, extinction of plants and animals, strain on the soil and water systems, and more.

1.5.2.1 Pseudoscience

In prescientific times, any attempt to harness nature mean forcing nature against her will, Nature had to be subjugated, usually with some form of magic, or by means that were “above” nature – that is, supernatural.

Science does the exact opposite, it works “within” nature’s laws. The methods of science have largely displaced reliance on the supernatural.

The old ways persist, full force in primitive cultures, and they survive in technologically advanced societies too, usually disguised as science.

1.5.2.1.1 No Science! Column

In his book, Flim-Flam!, James Randi reported that more than 20,000 practising astrologers in the United States serve millions of credulous believers.

Science writer Martin Gardner reports that a greater percentage of Americans today believe in astrology and occult phenomena than did citizens of medieval Europe.

Few newspapers print a daily science column, but nearly all provide daily horoscopes.

1.5.2.2 Science Denialism

> Denialism refers to “the employment of rhetorical arguments to give the appearance of legitimate debate where there is none, an approach that has the ultimate goal of rejecting a proposition on which a scientific consensus exists”.

– CS5027 Course Material

Mbeki Aids denial 'caused 300,000 deaths'

South African president's refusal to accept medical evidence of virus was major obstacle to providing medicine, say Harvard researchers

Figure 1.12: A Consequence of Thabo Mbeki’s Science Denialism

Thabo Mbeki’s (the second president of South Africa) denial of science has led to the deaths of many people.

2 The Innovation Process

This week's lecture focuses on the following pieces of content:

1. Stoke's research quadrants
2. Cha-cha-cha theory of scientific studies
3. Types of innovation
4. Characteristics of innovation
5. Seven sources of innovation
6. Innovation case studies

2.1 Stoke's Research Quadrants

Research is the main way by which knowledge is produced.

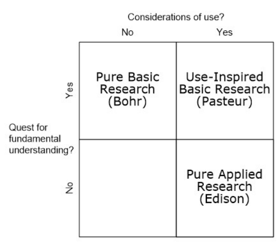


Figure 2.1: Stokes' Model of Research Quadrants

Stokes' 1997 model of research quadrants can be used to justify the kind of research that scientists conduct. A scientist is used to represent a particular kind of research[1].

2.1.1 Bohr's Quadrant

Research here is done for the sake of discovery (i.e., for knowledge purposes).

There is no attention to the research's practicality

[1]The bottom left quadrant has no scientist - that kind of research is non-existent.

2.1.2 Edison's Quadrant

> "Edison never allowed himself or those working with him in Menlo Park five minutes to consider the underlying side of the significance of what they were discovering in their headlong rush toward commercial illumination.
>
> The value and even the mark of true science consists, in my opinion, in the useful inventions which can be derived from it."
>
> – Gottfried Wilhelm Leibniz

Research in this quadrant is done for the sake of applications. When Thomas Edison invented the light bulb, he wasn't interested in the science behind the device, but the potential applications and revenue that could be generated from the light bulb.

2.1.3 Pasteur's Quadrant

This quadrant was a mix of both Bohr's and Edison's quadrants: research in this quadrant was a mix of both practical applications and discovering new knowledge.

Pasteur not only studied the disease that was ruining southern France's silkworm industry, but also anthrax, rabies, and fermentation and brewing in the beer industry.

2.2 Cha-Cha-Cha Theory

This theory states that scientific discoveries can be categorized into three types: **cha**rge, **cha**llenge, and **cha**nge.

CATEGORIES OF DISCOVERY

Problem that needed solving	Discovery	Discoverer	Category of discovery
Movement of stars, Earth, and Sun	Gravity	Newton	Charge
Structure of C_6H_6	Benzene structure	Kekulé	Challenge
Clear spots on petri dish	Penicillin	Fleming	Chance
Constant speed of light	Special relativity	Einstein	Challenge
Preventing heart attacks	Cholesterol metabolism	Brown & Goldstein	Charge
Crystals of D- and -L tartaric acid	Optical activity	Pasteur	Chance
Atomic spectra that could not be explained	Quantum mechanical atom	Bohr	Challenge
How DNA replicates and passes on coding	Base pairing in double helix	Watson & Crick	Challenge
Reagent "stuck" in storage cylinder	Teflon	Plunkett	Chance
Why offspring look like their parents	Laws of heredity	Mendel	Charge

Figure 2.2: Examples of Charge, Challenge, and Chance Discoveries

Charge solves problems that are obvious (e.g., cure malaria), but whose solutions must be seen from a novsel perspective.

Challenge discoveries are discoveries that arise from an accumulation of facts that cannot be explained by current science. A new concept or theory may be needed to explain the discovery.

Chance discoveries are discoveries that arise out of chance (e.g., Pasteur's discovery of optical isomers).

2.3 Types of Innovation

> "Innovation distinguishes between a leader and a follower."
>
> – Steve Jobs

> "Leave the beaten track occasionally and dive into the woods. Every time you do so you will be certain to find something that you have never seen before."
>
> – Bell Labs' Motto

An **innovation** is a series of activities that begin when an idea is conceived. This idea then undergoes a series of research, development, engineering, design, market analysis, management decision making, and so on before ending at product realization.

Innovations are like creations and exploitations of new flowers.

> "Innovations, like flowers, start from tiny seeds and have to be nurtured carefully until they blossom, then their essence has to be carried elsewhere for the flowers to spread.
>
> Innovations can grow wild, springing up weed-like despite unfavourable circumstances.
>
> And some conditions - soil, climate, fertilizer, the layout of the garden - produce larger and more abundant flowers."
>
> – Professor himself

Innovations can be broadly divided into several categories:

1. **Product Innovations**

   This is the introduction of a good or a service that is new or is significantly improved in some way (i.e., technical specifications, components and materials, incorporated software, user friendliness, or other functional characteristics).

   Such innovations can be based on new ideas and technologies (or a combination of existing and new ideas and technologies).

2. **Process Innovations**

   These are the implementation of a new or significantly improved production or delivery method (which often includes changes in techniques, equipment, and / or software).

   Such innovations are often made to decrease unit costs, to increase quality, or to produce or deliver significantly improved products.

   These innovations also deal with the steps in making a product.

3. **Service Innovations**

Figure 2.3: Service Kiosks at McDonalds'

   These are intangible methods of serving users at a new level of performance - for instance, new service concepts.

4. **Radical Innovations**

Figure 2.4: The MP3 Logo

   These are big and major changes in products.

   The MP3 audio system is one major example. Prior to the invention of MP3, music was listened to communally.

5. **Incremental Innovations**

   These apply existing knowledge to improve products.

Figure 2.5: Transition from Mentos Mint Candy to Mentos Caramels

2.3.1 Innovation as Work

Innovation is the work of knowing, not doing. It's also an effort to purposeful, forced change in an enterprise's economic or social position.

> "I am not pleading with you to make changes. I am telling you you have got to make them – not because I say so, but because old Father Time will take care of you if you don't change. Advancing waves of other people's progress sweep over the unchanging man and wash him out. Consequently, you need to organise a department of systematic change-making."
>
> – Charles F. Kettering

Innovation requires knowledge, ingenuity, and boldness. If a person lacks persistence and commitment, then talent, knowledge, and ingenuity will not be useful.

> "Businessmen go down with their businesses because they like the old way so well they cannot bring themselves to change. One sees them all about - men who do not know that yesterday is past, and who woke up this morning with their last year's ideas."
>
> – Henry Ford

Innovation is a specific function of entrepreneurship, whether that be in the form of an existing business, a public service institution, or a new venture started by an individual.

2.3.2 Characteristics of Innovation

Kanter (1998) suggested the following traits of most, if not all innovations:

1. **Uncertainty**

   Sources of innovation may be unpredictable - the goal of innovation may have little to base itself off of.

   Innovations make progress in spurts in unforseen moments.

2. **A Long Journey**

   The costs of innovation may overrun and the results are highly uncertain.

   Analysts have estimated that it may take years for a business to see any returns on their innovations.

3. **Knowledge-Intensive**

   The innovation process generates new knowledge and in doing so, uses human intelligence and creativity. This learning curve is steep.

   Efforts during innovation are vulnerable to leaving because of the loss of knowledge and experience (i.e.,

4. **Controversial**

   Innovations are always competitive - they provide an alternative course of action.

   On several occassions, an innovation may be a threat to peoples' interests (whether that "interest" be a salesperson receiving high commissions or whatnot).

   Political problems are often the primary cause for the failure of new venture departments in corporations.

5. **Imperialistic**

   An innovation is also capable of crossing boundaries.

   There is also evidence that the best ideas or interdisciplinary (i.e., they benefit from broader perspectives and from information outside of the idea responsible for the innovation).

2.3.3 Example #1: Scrabble

In 1931, Alfred Mosher Butts was a young, out-of-work architect who was seeking a means of making money.

Butts was interested in anagrams and crossword puzzles (i.e., his source of inspiration) - after further analysis, he found that games of his generation fell into one of three categories:

1. Number-based games
2. Move-based games
3. Word-based games

Figure 2.6: People Playing Scrabble

He eventually created a game that used a grid and words. Butts wanted his game to have both skill and luck (with a stronger emphasis on skill). Butts also realized that of the 26 characters in the alphabet, that not all of them were used frequently.

To find out the relative frequencies, he painstakingly studied the front pages of the New York Times, doing letter-by-letter counts (i.e., innovation is knowledge-intensive).

This enabled Butts to assign values to each letter in his game.

From 1932 to 1938, Butts made the sets by hand and gave them to friends; most game manufacturers in the US turned down Butts' idea.

In 1943, Butts met marketing genius James Brunot - Brunot made some refinements to Butts' game.

Eventually, Brunot and his wife made an agreement with Selchow & Righter, a much more established game manufacturer to make the game (as Brunot could not keep up with game production himself).

Figure 2.7: The Irish Scrabble Association

By 1954, more than 4 million sets of the game had been sold; the game was also available in other languages (e.g., Spanish, Italian, French, etc).

In 1972, Selchow & Righter purchased the game and trademarked "Scrabble".

Hasbro now supports the National Scrabble Association (It was formerly Coleco, but they went bankrupt).

2.3.4 Example #2: Barbie Dolls

Figure 2.8: A Barbie Doll Holding a Plastic Video Recorder

In 1956, American businesswoman Ruth Handler was vacationing in Switzerland until she came across Bild Lilli: a prostitute doll with long legs and heavy makeup.

The first barbie doll came out in 1959.

2.4 Sources of Innovation

There are *seven* sources, some of which are inside or outside a company:

2.4.1 Inside a Company

These include:

Figure 2.9: A Bild Lilli Doll

Figure 2.10: A Stack of Post-it Notes

1. **Unexpected**

   Spencer Silver was trying to create a super strong adhesive, but instead discovered a weak adhesive that sticks to paper and can be lifted off without tearing the paper

   Silver told his colleague Art Fry about the new adhesive.

   Fry was singing in a church choir and had bookmarked his hymnal with little pieces of paper but when it was time to sing until they fell out. Fry thought that Silver's adhesive would be the ticket for a better bookmark.

   Fry went to work the next day, ordered a sample of the adhesive and began coating it on paper, carefully coating only the edge of the paper so that the part protruding from his hymnal wouldn't be sticky. Fry also realized that the bookmark could also be a note.

   In 1978, 3Mers descended on Boise, Idaho, with samples for what would later be called the "Boise Blitz". Boise was selected because it wasn't too big a city.

   Samples were handed out, and 3M discovered that more than 90% of the people who tried them would buy them.

   At the request of 3M marketers, Shirley Tholander (secretary to Lew Lehr, chairman of the 3M board) sent a letter to her executive secretary peers at Fortune 100 companies and enclosed a product sample.

2. **Incongruities**

   An **Incongruity** is an incompability - something that appears very different to the point of change.

   In 1912, Charles Franklin Kettering invented the electric starter.

   Before the electric starter, this boost was provided by a crank at the front of the car. Women and men of smaller stature had trouble working the crank without help. In addition, the crank was dangerous to operate, and some drivers were injured while cranking the car – this became a source of innovation.

   The impetus for the electric starter came from a realisation of the incongruity between the demographics of car buyers versus the demographic composition of the world at large.

   Without an easy way to start the car, car manufacturers were only selling to half[2] the population!

3. **Process Needs**

   SBS Transit's Iris NextBus and PostBox are good examples.

[2]The world has 50% men and 50% women.

4. **Industry Market and Structures**

   Industry structures can change, creating tremendous opportunities for innovation.

   In the past, photographic film needed to be "processed" in a dark room.

   In the digital world, processing can be self-serviced.

2.4.2 Outside a Company

These include:

1. **Demographic Changes**

   The graying of many societies is a demographic change that is looming.

   One impact of this will be the increasing need for robots to do routine housework (and so on).

2. **Changes in Public Perception**

   ***C**irque **d**u **S**oleil* (i.e., **CdS**) capitalised on the changes in public perception on the use of animals in circuses (in addition, the cost of the animals and their training, medical care, housing, insurance, and transportation was very high).

   Traditional circus shows have a series of unrelated acts, but each Cirque du Soleil creation has a theme and story line, somewhat resembling a theater performance.

3. **New Knowledge and Scientific Discoveries**

   There is a protracted time span between the emergence of new knowledge and its distillation into usable technology.

   Then there is another long period before this new technology appears in the marketplace in products, processes or services.

   To become effective, innovation of this sort demands not one kind of knowledge but

2.5 Innovation Case Study #1: Shipping Containers

The shipping container was invented by Malcolm Purcell McLean. MacLean was also responsible for founding pan-Atlantic services.

Figure 2.11: A Shipping Container

2.5.1 Prior to the Shipping Container's Fruition

Armies of ill-paid and ill-treated workers called **longshoremen** would help unload and load supplies onto merchant ships. The whole (un)loading process would take a day - shipping costs were hence expensive (i.e., a four-thousand mile voyage for a shipment might consume about 50% of its costs for just two ten-mile movements).

> "In the first forty months of World War II, the U-boats sank 2,177 merchant ships totalling 11,045,284 tons, while the number of merchant ships lost to all other causes was negligible in comparison."
>
> – Syrett, 1993, page 1.

Many German "U-boats" (i.e., submarines) also sank many merchant ships during the Battle of the Atlantic.

In response to this, the US navy built more than 2400 "liberty ships" between 1941 and 1945. These ships were small enough to avoid being sunk so that little cargo would be lost if the ship was sunk.

After the war, the US navy sold about 450 "liberty ships" to their merchant lines. However, these "liberty ships" were cramped and had odd dimensions - longshoremen needed to figure out how to fit cargo in these conditions. These "liberty ships" wasted time and money from the shipowners' perspectives.

2.5.1.1 More About Longshoremen

Longshoremen were individuals who saw themselve as tough, independent men who were doing a tough job. They had reputations as brawlers and drinkers.

The work that they did was brutal and physically dangerous, so much so that there were many injuries, and in some cases, fatalities.

Figure 2.12: Longshoremen Loading Bananas onto a Merchant Ship

Longshoremen would also work in all sorts of weather conditions and would also compete among themselves for work. This entire process meant kickbacks, flattery, and begging. Because of this, their income was irregular and longshoremen would be loyal to their co-workers, not the company that they were working for.

Strikes were also frequent due to poor pay and poor working conditions. In Britain alone, these strikes led to 1 million man-days lost between 1948 to 1951 and another 1.3 million in 1954. These strikes also led to two major problems:

1. Pilfering: longshoremen would end up stealing the cargo that they were supposed to load.
2. Resistance to anything that might eliminate jobs.

2.5.2 McLean's Background and Starting His Own Trucking Company

MacLean was born in Maxton, North Carolina. His mother first taught him how to do business by giving him eggs to sell on commission.

McLean graduated from high school in 1931 and started working at a grocery store to stock shelves. He eventually became the manager of a gas station in a nearby town.

McLean learned that drivers were being paid $5 an hour just to transport gas to the station.

2.5.2.1 McLean Trucking Company

In March 1934, McLean started the McLean Trucking Company. In 1935, he started off with two trucks and a truck trailer. He also employed nine truck drivers who owned their own rigs.

In 1940, he owned about 30 trucks and grossed about $230,000.

In 1945, he owned 162 trucks and in 1946, made a revenue of about $2.2 million.

In 1953, McLean noticed that the highways were becoming increasingly congested. He was also concerned that domestic ship lines were allowed to buy war-surplus cargo ships for a low price from the government.

In September 1955, McLean sold off his trucking company for about $14 million!

Figure 2.13: An Image of the Ideal-X

2.5.3 McLean's First Container Ship

On 26 April, 1956, 58 aluminium truck bodies were loaded aboard an ageing tanker **Ideal-X** that was moored in Newark, New Jersey. Ideal-X then sailed into Houston.

On 1 April, 1964, the **P**ort of **S**ingapore **A**uthority (i.e., **PSA**) was formed to take over the functions, the assets, and the liabilities of the Singapore harbor board.

2.5.3.1 What is a Shipping Container?

A **shipping container** is an aluminum or a steel box that held up by rivets and welds - it has a wooden floor and two enormous doors at both ends.

The container cheapened transportation costs; it was also a part of a highly efficient and seamless system for shipping cargo across the world.

The container could also be loaded onto the Ideal-X in seven minutes (i.e., using a crane). The railroad and trucking business attempted to compete with McLean's shipping containers. Between April and December, 44 voyages were created; consequently, the tanker's capacity increased from 58 to 60 containers (before it increased to 62 containers).

2.5.4 New York's Decline

McLean's containers made New York ports obsolete. During the 1920s, the trucking industry had already made New York's ports obsolete.

In 1952, traffic leading to piers was so bad that pier-bound vehicles were banned from the Twelfth Avenue.

2.5.5 Social Impact of Shipping Containers

When the industry fled New York, the number of manufacturing jobs fell.

The Brooklyn Navy Yard closed in 1966, and Brooklyn residents abandoned the borough in droves. Brooklyn's population fell by 14% between 1971 and 1980.

Figure 2.14: A Group of People on Segways

2.6 Innovation Case Study #2: Segways

Kamen (i.e., the inventor of the segway) was at a local mall and was watching a man struggle to get his wheelchair over a curb. He was disturbed by what he saw. He thought: “we can put people on the moon and travel to the depths of the ocean, but we cannot get a wheelchair over a curb?”

The more he thought about the limitations faced by people in wheelchairs - no eye-level conversations, no trips to the beach or anywhere else without sidewalks, no reaching the top shelf at the grocery, no possibility of defeating the absolute barrier of stairs - the more he became offended as an engineer

2.6.1 Kamen’s Invention

Figure 2.15: The iBOT Project Started by Kamen

Fred-iBOT was a wheelchair that could roll through gravel and sand, go up curbs, and even climb stairs. It would change the lives of many.

The project was funded by Johnson & Johnson, but did not take off likely due to cost issues.

2.6.2 About Dean Kamen

He was born in Rockville Center, Long Island, New York, in 1951. He attended college at Worcester Polytechnic Institute in Massachusetts.

He also owned a business, Independent Prototype, and did a project for Cordis, a medical company, through which he met the founder, William Murphy. He made about $60,000 a year

Bart, a medical student at Harvard, suggested that he work on a drug-infusion pump.

From there, Kamen started a new company - AutoSyringe - where he designed the first portable insulin pump (which freed diabetics from their condition's limitations).

2.6.2.1 Starting a Family Business

Kamen's brother, Mitch and Mitch's friends became assemblers for the pump.

His mother tested circuit boards and kept the books.

His father drew the illustrations for the manual.

He enlisted the help of Worcester Polytechnic's students and professors to help him improve the design of his inventions.

Kamen also moved to New Hampshire to evade New York's high taxes.

Eventually, Kamen would sell the pump to Baxter Healthcare for about $30 million in 1982 (when Kamen was 31 years old).

Kamen would then go onto buy an airplane, a helicopter, and an island in Long Island Sound. He then founded his own R&D company DEKA (i.e., short for DEan KAmen).

Kamen's first spinoff company Teletrol installed climate control systems for large industrial and commercial buildings

2.6.3 Kamen's Attitude Regarding Failure

> "In study after study, of composers, basketball players, fiction writers, ice-skaters, concert pianists, chess players, master criminals," writes the neurologist Daniel Levitin, "this number comes up again and again.
>
> Ten thousand hours is equivalent to roughly three hours a day, or 20 hours a week, of practice over 10 years .... No one has yet found a case in which true world-class expertise was accomplished in less time. It seems that it takes the brain this long to assimilate all that it needs to know to achieve true mastery."
>
> – Dean Kamen

In 1987, Baxter Healthcare approached Kamen to improve its kidney dialysis machine - it was noisy, expensive, heavy (180 lb) and bulky!

Kamen urged his engineers not to limit themselves to what they thought was feasible, and he did not hold failures against his engineers if they learned something along the way.

His philosophy was that no experiments was useless.

2.7 Innovation Case Study #3: Bonsack Machine

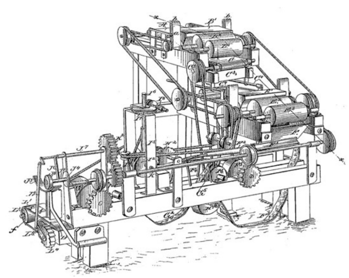


Figure 2.16: A Sketch of a Bonsack Machine

During 1876, **A**llen and **G**inter (i.e., **A&G**) were employing hundreds of girls as rollers. This was a problem as not only was it difficult to oversee such a vast amount of workers, but there would also be inconsistencies with the quality of labor.

A&G then offered a price of $75000 to anybody who could invent an automatic cigarette rolling machine.

2.7.1 James Albert Bonsack

On September 4, 1880, Bonsack - a teenager tinkerer - got a patent for his invention. His machine could turn out about 200 to 212 cigarettes per minute (roughly 40 to 50 workers' output).

2.7.1.1 Bonsack's Machine's Performance

A&G ultimately rejected the machine for the following reasons:

1. They feared that cigarettes were traditionally hand-crafted.
2. They feared that the machine would be too efficient, leaving them with mountains of unsold cigarettes.
3. Overall managerial timidity associated with the handling of the dismissals of unneeded workers.

Washington Duke and his son, James Buchanan Duke, decided to install Bonsack's machine in their factories. In 1889, Duke & Sons sold a billion cigarettes, and in 1890, formed the American Tobacco Company,

The machines brought about a tremendous reduction in the cost of manufacturing cigarettes.

By 1884, the Bonsack Machine was producing from 100,000 to 120,000 cigarettes per day, the equivalent of the production of forty to fifty hand workers.

Duke, like other producers, initially overcame any popular prejudice against the machines in a very simple way: he used them in the greatest secrecy and the public remained unaware of their widespread application for years.

The Duke company began to produce most of its cigarettes by machine in 1885, encountering little of the consumer resistance its rivals had anticipated. Duke's application of the Bonsack Machines revolutionized the business of making cigarettes; the profits of the Duke company rose during subsequent years.

This was also what happened to Leica.

3 The Metric System

> "There is madness in not striving to reduce the gap between rich and poor. This gap is more dangerous than nuclear bombs. When people do not have enough to eat, and this will soon be the case of eight out of ten human beings, their revolt can prove impossible to check. Developed countries have to be very attentive to the plight of poor countries."
>
> – President François Mitterrand, 1989

The **metric system** is a universal system of measurements that strives to bring order and reason to the exchange of goods and information.

Figure 3.1: A Statue of a Blindfolded Woman Holding a Scale

Such a system is important as it represents fair exchanges with exactness (hence why the scale is often a symbol of justice).

3.1 Decimal Division

All measurements are divided decimally, hence making calculations easier in the metric system.

Yet, imperial units (e.g., BTU, miles, horsepower, etc.) are still widely used in certain industries.

10 mm = 1 cm
10 cm = 1 dm
10 dm = 1 m
10 m = 1 dam
10 dam = 1 hm
10 hm = 1 km

The same prefixes apply to all units, e.g., time, area, volume, etc.

Figure 3.2: Measurements in the Metric System

3.1.1 Currency

Pre-decimal British currency was difficult to remember. In those days:

1. 1 shilling = 12 pennies
2. 1 pound = 20 shillings (or 240 pennies)

Prices would be writen in shillings and pounds - for instance, an item that costs nine pounds and four shillings might be marked as "9/4" in shops or written as "9s 4d".

Farthing = ¼d
Half penny = ½d
Penny = 1d
Threepence = 3d
Sixpence = 6d
Shilling = 1/-
Florin = 2/-
Half Crown = 2/6
Crown = 5/-
Crown = £¼

Figure 3.3: More Terminologies in Pre-Metric System British Currency

The "s" was Latin for *solidus* and the "d" Latin for *denarius*.

On February 15, 1971, both the United Kingdom and Ireland decimalized their currencies. The shilling was abandoned and the pound subdivided into a hundred "new pence" with the symbol "p". February 15 was also known as **decimal day**.

3.1.2 Arabic Numerals

These numerals were common in 1500; in 1585, Flemish mathematician Simon Stevin showed how fractions could be explained with Arabic numerals using a decimal point method called "De Thiende".

"De Thiende" was translated into

3.1.3 Spreading of Metric System

In 1656, Robert Wood suggested that the pound sterling be divided into what he called "tenths, hunds and thous".

Gabrile Mouton - a Parish priest with a good working knowledge of astronomy and mathematics proposed the following units based on the size of the Earth:

1. **mille**

   This was the length of a minute.

2. **geometric foot**

   This was a thousandth of a mile.

3.2 Pre-French Revolution

Bad harvests in 1787 and 1788 led to riots in Rennes, Besançon, Orléans, Lyon, Aix-en-Provence, and Marseille (i.e., all cities in France).

People were ransacking shops, assaulting merchants, hijacking convoys, and also tearing down barriers. Furious mobs also destroyed 40 customs post in the 18-mile wall surrounding Paris.

Because of this, France was bankrupt - the king didn't know what to do and debts rose in England's favor.

3.2.1 8 August, 1788

King Louis XVI summoned the *Estate General* - something that hadn't been done in 175 years (i.e., not since 1614).. The *Estate General* represents the three general orders of French society: clergy, nobility, and commoners.

There only about 500000 clergy and nobility in the *Estate General* and about 27 million commoners.

Nonetheless, Louis XVI ordered the *Estate Geneal* to form a *cahiers de doléances*, a notebook of grievances. One of the items was a reform of weights and measures.

3.2.2 Formation of the National Assembly

On June 17, 1789, the deputies of the third estate (i.e., the nation) were locked out of the meeting hall at Versailles. They thought that that was Louis XVI's way of forcing them to disband.

Instead, the deputies had a meeting at a nearby tennis court - they swore to never disband until France had a written constitution.

3.2.3 14 July, 1789

Louis XVI let his finance minister Jacques Necker go. Necker was sympathetic to the third estate and was hailed as a reformer by the people.

On the same day, a large crowd bursted into the *Invalides* (i.e., old soldiers' home and weapons depot) and carried 30,000 muskets and fire cannons. They also raided the bastille for gunpowder - by the end, the *Invalides* was theirs (with about 170 casualties).

3.2.4 5 and 6 October, 1789

A crowd of women (i.e., fishwives, stallkeepers, harlots, and seamstresses) marched towards the Versailles with weapons (e.g., cudgels, scythes, etc.) and demanded bread.

On the next morning, they found an open side gate and burst into the palace. With the heads of two guards impaled on a spike, they escorted the royal family to Paris and left them in the Tuileres Palace.

3.2.5 21 June , 1791

Louis XVI and Marie Antoinette slipped out of the Tuileres in servants' disguise for a 200-mile dash to Austrian territory (that was overseen by Marie's brother). However, a postmaster identified Louis and the couple was arrested and bought back to Paris. Both people were found guilty of treason.

On 21 September, 1792, the monarchy was abolished.

Louis XVI was beheaded on 21 January, 1793 - his body was dumped in an anonymous grave.

Marie Antoinette was beheaded on 16 October, 1793; her body was taken to a graveyard behind the *Church of Medeline*. However, the gravediggers were on a lunch break.

This opportunity gave Marie Groscholtz (later known as Madame Tussaud) enough time to make a was figure of her face.

3.2.6 France's Measurement Situation

> "Contemporaries estimated that under the cover of some eight hundred names, ancient regime France contained a staggering 250,000 different units of weights and measures."
>
> – Alder, 2002, p. 3

Many quantities were named as such because of their origins from human needs and interests.

The Greeks and Romans used fingers as a base measurement - a "foot"'s length is about the same as a human foot. The cubit foot was about as long as an arm's bend at the elbow to the tip of the middle finger. Because of this, the following measurements were fashioned:

1. 1 foot = 16 fingers
2. 1 cubit = 24 fingers

Anthropometric measures also reflected the amount of labor that a person could do in one sitting. Coal was measured in charge and was equivalent to about $\frac{1}{12}$ of a miner's daily output. Arable land was measured in "homme" or "journee" to estimate the amount of land that a peasant might be able to plough in a day.

3.3 Implications of the Metric System

There were many different kinds of implications (to different disciplines) when the metric system was introduced.

3.3.1 Religious Implications

> "You shall do no unrighteousness in judgment regarding measures in length, weight, or quantity. You shall have honest balances, honest weights, an honest ephah, and an honest hin: I am the LORD your God, who brought you out of the land of Egypt."
>
> – Leviticus, 19:35-36

3.3.2 Scientific Implications

Scientists argued that such a system should also proclaim universal measures (just as how the French revolution would also proclaim universal rights for all).

Scientists also derived the fundamental unit from the measure of the word itself.

3.3.2.1 Fundamental Unit

The “unit of length” was defined as one ten-millionth of the distance along the meridian through Paris from the North Pole to the Equator.

The “meter” would be eternal as it was taken from the Earth itself (which was believed to be eternal). It was also equally belong to all people of the world as the Earth also belonged to each individual equally.

An alternative idea was that a fundamental unit of length could also be derived from the length of a pendulum beating one second. This was an idea that dated back to the 17^{th} century when Galileo demonstrated that the period of a pendulum’s beat was determined by its length.

However, the length of a one-second pendulum was also sensitive to the latitude at which it was measured, because gravity varied slightly with latitude. The equator may have been a suitable choice, but it was also quite remote from scientific nations; hence, the second most natural location would be 45° of north latitude - at the outskirts of Bordeaux in south-west France. However, the idea did not meet with international approval.

3.3.2.1.1 Refinements to the System

Auguste-Savinien Leblond - a French mathematician - coined the word “meter” (which came from the Greek word “metron”) for the fundamental unit of length.

Greek prefixes were used for multiple measures of the meter and Latin prefixes for submultiples. This idea was proposed by Claude Antoine Prieur.

For a brief period of time, these prefixes scared people, so they were replaced with ordinary names (e.g., “decimeter” would used to be called a *palme*).

3.3.3 Meridian Expedition

The **meridian** is an imaginary north-south line on the Earth’s surface that connects both geographic poles. It is used to indicate longitude.

In June 1792, two astronomers - Jean-Baptiste-Joseph Delambre and Pierre-François-André Méchain - went in opposite directions from Paris to measure a piece of the meridian arc that ran from Dunkirk to Barcelona through Paris.

They did this to establish a common standard of measure that people of all sorts could use it.

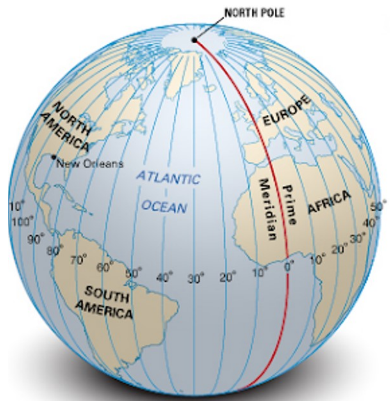


Figure 3.4: The Meridian on the Globe

3.3.3.1 Geodesy

Geodesy is the science of measuring and understanding Earth's properties - its shape, its gravity, its orientation in space - as well as how these properties change over time.

Via GPS, many geodesists can measure the movement of a site 24 hours per day, seven days a week.

Geodesy on a smaller scale is called **surveying**.

3.3.4 Standard for Mass

Antoine Lavoisier and the crystallographer René-Just Haüy worked on the ***grave*** - the kilogram as it was previously called - as a cubic decimeter of rainwater weighed in a vacuum at the melting point of ice (i.e., 0°C).

In 1799, the chemist Lefèvre-Gineau would define the "gram" as a cubic centimeter of rainwater in a vacuum at the temperature of maximum density.

3.3.5 First International Scientific Conference

Two months before Méchain and Delambre finished their measurements, foreign representatives arrived in Paris to attend the Congress on Definitive Metric Standards. This happened on 28 November 1798.

The instruments used for the preliminary work was inspected and tested in field observations. The representatives were asked to propagate the new system in their own countries.

3.3.5.1 Adopting the Meter

When the meter was introduced in France, it caused confusion. The system disrupted norms and opened local markets to outside competitions. Even physicians were afraid that they would have to re-learn all their dosages.

Napoleon Bonaparte refused to learn the system - he insisted that the weights he got be restated in *poids de marc* (i.e., old-style pounds) as he could not “think” in the new units.

Eventually, a legislation passed in 1873 that would mandate the metric system mandatory throughout France and its colones from 1840 onwards.

3.3.6 World Metrology Day

The meter convention was signed on 20 May, 1875 by representatives from the following nations:

1. Argentina
2. Austria
3. Belgium
4. Brazil
5. Denmark
6. France
7. Germany
8. Italy
9. Peru
10. Portugal
11. Russia
12. Spain
13. Sweden and Norway
14. Switzerland
15. Turkey
16. USA
17. Venezuela

This day also mandated the establishment of a permanent *International Bureau of Weights and Measures* (i.e., *BIPM: Bureau International des Poids et Mesures*) to be located in Sèvres, France.

This annivesary is now known as **World Metrology Day**.

Figure 3.5: A Watch in Decimal Time

3.4 Decimal Time

This was based on the idea of dividing the day into tens. One day would have 10 decimal hours, an hour 100 decimal minutes, and a decimal minute 100 decimal seconds.

This was an idea that got introduced during the French revolution during October 5, 1793.

Watchmakers would design prototype clocks that pointed to “V o’clock” at midday and at “X o’clock” midnight.

Other alternatives were also proposed:

1. Joseph Charles François de Rey-Pailhade suggested dividing the day into 100 parts, each called cé, for “centiday”.
2. Henri de Sarrauton defined the hour as the fundamental unit and divided it into 100 decimal minutes.

However, decimal time was dropped shortly after for the following reasons:

1. It had no significant advantage over the previous system
2. People would become confused
3. People were too used to the old timing system
4. Making new clocks and watches would be too costly
5. Watchmakers would be unable to dispose of their old stock

3.4.1 Definitions of Time

At the 13th official meeting in 1967, the committee adopted the following definition:

> "The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom"
>
> – The committee

In 1972, the committee would then introduce the **leap second** to take care of small irregularities in the rotation of the Earth.

3.5 Decimal Currency and Angles

Prior to the decimal system, French currency was denominated in *livre tournois*, and after that, *livre*.

The decimal *Franc* was established as France's national currency by the French revolutionary convention in 1795 as a decimal unit of 4.5 grams of silver. The Franc was the Western world's first brush with decimalized currency.

3.5.1 Decimal Angles

A 400° circle would not only ease calculations, but also unify astronomy and navigation.

In a world where the quarter meridian was ten million meters long, each degree would measure a hundred kilometers (hence simplifying maps and helping sailors).

3.5.2 Consequences of Measuring Mix-Ups

In September 1999, the Mars Climate Orbiter - a USD 125 million, 338 kilogram robotic space probe launched by NASA to study Martian climate and atmosphere - burned up and broke into pieces after 10 months of travel.

The navigation team at the Jet Propulsion Laboratory used metric systems, while Lockheed Martin Astronautics in Denver, Colorado provided acceleration data in inches, feet, and pounds.

4 ANSI Standards for Abstracts (Z39.14) and Authorships

4.1 ANSI Standards for Abstracts (Z39.14)

The **A**merican **N**ational **S**tandards **I**nstitute (i.e., **ANSI**) is the voice for US standards and conformity assessment system. The ANSI empowers members and constituents to strengthen the US' position in the global economy while also assuring the health and the safety of consumers and the environment.

The ANSI oversees the creation, the propagation, and the use of thousands of norms and guidelines that impact businesses in almost every sector.

The ANSI is also active in **accreditation**: assessing the competence of organizations and their adherence to standards.

4.1.1 Guidelines for Abstracts

Basic content must be easily identifiable by readers and users. Authors and editors can also help do the aforementioned via starting a document with a meaningful title and a well-prepared abstract.

However, authors should also bear in mind that people may only selectively read parts of the paper (i.e., not just the abstract).

4.1.2 What is an Abstract?

An **abstract** is a brief, objective representation of a document or an oral source's contents. Its purpose to allow readers to identify what a document will be about, to determine a document's relevance to their motives, and to decide what it is that they will need to read from the document.

The purpose of ANSI Z39.14 is to guide authors and staff of service access services on how to prepare an abstract that is as useful as possible.

ANSI Z39.14 applies to all abstracts regardless of author(s), publication location, or publication style (e.g., oral presentations and written documents).

4.1.3 Definitions Used in ASNI Z39.14

The document uses some terms that may be unfamiliar to the layperson:

1. **Abstract**

   A brief and objective representation of a document or an oral presentation.

2. **Annotation**

   A brief explanation of a document and its contents (usually as a note).

3. **Critical Abstract**

   An uncommon form of an abstract that contains evaluations on the significance of a kind of material or a material's presentation. These abstracts are written by domain knowledge experts.

4. **Document**

   An item (printed or otherwise) that an abstract can be done up for.

5. **Slanted Abstract**

   An abstract that represents a portion of a document for the benefit of an audience.

6. **Structured Abstract**

   An abstract that is structured via headings.

7. **Summary**

   A brief restatement within a document that contains findings and conclusions.

8. **Synoptic**

   A concise, original publication of key results from a previously unpublished paper.

4.1.4 Writing an Abstract

ANSI Z39.14 covers many portions of writing an abstract:

1. **Location of an Abstract**

   In a journal, the abstract should be placed at the top of the first page between the title and the beginning of the text.

   In separately-published documents, the abstract should be placed between the title page and the text.

   Abstracts in separate chapters should appear under each chapter title on the first page of its text.

2. **Sentences**

   Complete sentences should be used. The kind of document should not be stated in the first sentence of an abstract.

3. **Active Verbs**

   Active voice should be used whenever possible. Passive voice may be used for indicative and for informative statements (for which the receiver of the action should be emphasized).

4. **Vocabulary**

   Unfamiliar jargon should be avoided.

5. **Non-Textual Material**

   They should only be included when necessary and when no other alternative is possible.

4.1.5 Kinds of Abstracts

There are two main kinds:

4.1.5.1 Informative Abstracts

Informative abstracts are used for documents for experimental investigations, inquiries, or surveys. The abstracts of these documents state the document's purpose, methodology, results, and conclusions.

The structure of an informative abstract may be changed depending on the kind of document and its audience.

In a **structured abstract** (i.e., a structured informative abstract), major points of text are shown in several, labelled paragraphs instead of one.

4.1.5.2 Indicative Abstracts

Indicative abstracts are used for less-structured documents (e.g., editorials, essays, opinions, or descriptions) or for lengthy documents (e.g., books, directories, and lists).

Such abstracts are used for documents that do not have information pertaining to methodologies or results. However, the abstract should still describe the purpose or the scope of discussion or descriptions within a document.

The abstract may also discuss any crucial background information.

4.2 Authorship

The earliest *named* author in history was the Mesopotamian princess *Enheduanna* who - more than 4000 years ago - signed her name on clay tablets that had songs made in honor of Inanna: the goddess of love and war.

4.2.1 Kinds of Authorship

There are numerous kinds:

4.2.1.1 Single Authorship

Authorship was historically a solitary profession. However, this stereotype of authors being alone ignores the fact that many scholarly literature is the byproduct of many peoples' works.

Gradually, authorship has expanded to include contributions of all kinds (i.e., even those that have little written contributions).

However, authorship should still be given to those who have substantially contributed to the work and who have a shared responsibility for the results.

4.2.1.1.1 Substantial Contributions

Contribution can exist in four different kinds:

1. Conception or design
2. Data collection or processing
3. Analysis and interpretation of the idea
4. Writing substantial sections of the paper

4.2.1.2 Co-Authorship

This is when a work has many authors. These authors need not have written something in order to become an author.

4.2.1.3 Hyperauthorship

This refers to a massively-co-authored paper.

4.2.1.4 Sub-Authorship Collaboration

This is reflected in the acknowledgement status of a document.

Acknowledgements are complex in that authors can thank colleagues for ideas, funding agencies for support, spouses for support, and so on.

There are six categories of acknowledgements:

1. Conceptual
2. Editorial
3. Financial
4. Instrumental / technical
5. Moral
6. Reader

4.2.1.5 Gifting and Ghosting

Some individuals' names can be included as co-authors even though they have not done anything to contribute to the paper - these are **gift authors**.

Otherwise, authors may also have made material contributions, but do not get mentioned. These people are called **ghost authors**.

4.2.2 How Should Authorship Go?

Authorship order should always go in terms of contribution to the project.

Senior team members should lead conversations among authors to determine the amount of contribution by individual

4.3 Current Stance on ChatGPT

Publishers and preprint servers by *Nature*'s news team agree that AIs such as ChatGPT do not fulfill the criteria for a study author as they cannot take responsibility for the content and the integrity of scientific papers.

5 Health Literacy

> "...we believe that the case is closed – supplementing the diet of well-nourished adults with (most) mineral or vitamin supplements has no clear benefits and might even be harmful."
>
> – Articles in assigned readings

The articles shown in the course readings address the role of vitamin and mineral supplements

5.1 Supplements for Primary Prevention

CS5027 presents three case studies:

1. **Fortman and colleagues**

   After reviewing three trials of multivitamin supplements and 24 trials of single or paired vitamins that randomly assigned more than 400000 participants, Fortman found that there was no correlation between supplements and mortality, cancer, or cardiovascular diseases.

2. **Grodstein and coworkers**

   After a 12-year follow up, Grodstein found that there was no difference multivitamin and placebo groups in overall cognitive performance or verbal memory.

3. **Lamas and associates**

   They assessed the benefits of a high-dose, 28-component multivitamin supplement in 1708 men and women who had a previous myocardial infarction (i.e., heart attack).

   After a median follow-up period of 4.6 years, Lamas found that there was no difference in recurrent cardiovascular events with multivitamins with placebos.

The overall message is that there is no clear benefit of multivitamins - in fact, such supplements may contain harmful ingredients that may increase mortality. Most supplements do not prevent chronic disease or death - hence, their use is not justified (i.e., they should be avoided).

6 Story of Biology

About 3.8 billion years ago, certain molecules collided with one another to form larger, more complex molecules that ultimately formed large and intricate structures called **organisms**. This story of how organisms formed is called **Biology**.

The history of science and shows that no one science is isolated from another. For instance - genetics has progressed due to mathematics, biochemistry, and even computer science (i.e., bioinformatics).

6.1 What is Biology?

The word Biology is derived from the Greek words "bios" (meaning "life") and "logos" (meaning "study" or "knowledge"). Hence, **Biology** is the study of living organisms.

It also involves many other techniques such as Chemistry, Physics, or Mathematics.

Biology also overlaps with Medicine to a great extent.

6.1.1 Characteristics of Living Organisms

All living organisms will share the following characteristics:

1. **Movement**

   All living organisms exhibit some form of movement.

2. **Reproduction**

   All living organisms come from pre-existing generations and can give birth to the following generation.

   Reproduction can take many forms (i.e., asexually or sexually). DNA - among many other molecules - are involved in reproduction. DNA contains "instructions" for cellular structures and ultimately, for the *whole* organism.

3. **Sensing**

   All living organisms will have some sort of response towards stimuli from the outside world.

   These responses can be slow or fast.

4. **Respiration**

   Everything that an organism does is governed by chemical processes (that consume energy). The energy to do work often comes in sugars, amino acids, and other biochemical processes - during which produces ATP.

5. **Excretion**

   Biochemical reactions often result in the production of toxic waste products - these products are disposed via a method called **excretion**.

   Plants often store their waste.

6. **Nutrition**

   Organisms obtain energy from food or from other sources - these sources provide energy that is needed for purposes such as cell growth, cell maintenance, and cell repair.

   Autotrophs take in simple, inorganic substances to turn into complex organic substances - these organisms are sometimes called *producers*. Plants - along with algae and phytoplankton - are the most familiar kind of autotrophs. Most autotrophs use photosynthesis to produce their own food.

   Heterotrophs take in ready-made substances - these organisms are known as *consumers*. Dogs, birds, fish, and humans are examples of heterotrophs; they occupy the second and third levels in a food chain.

   Detrivores (e.g., worms, fungi, and insects) obtain nutrition via consuming **detritus**: dead organic matter.

   The **food chain** is a diagram that contains three trophic levels: autotrophs (first level), herbivores (second level), and carnivores and omnivores (third level).

7. **Growth**

   Organisms grow by taking outside substances and incorporating it into its internal structure in a process called **assimilation**.

6.1.2 Divisions of Biology

Traditionally, there were two: Zoology (the study of animals) and Botany (the study of plants). Over time, the following divisions appeared:

1. **Microbiology**

   This is the study of microorganisms - this division can be divided into two more subdivisions: bacteriology and virology.

2. **Anatomy**

   This is the study of plants' and animals' structures.

3. **Biochemistry**

   This is the study of chemical processes that underlie plant and animal life.

4. **Cell Biology**

   This is the study of cell function and structure.

5. **Ecology**

   This deals with the relationships of organisms and their environments.

6. **Evolution**

   This deals with how organisms evolve over time.

7. **Genetics**

   This is the study of genes, genetic variation, and heredity among living organisms.

8. **Entomology**

   This studies insects.

9. **Ornithology**

   This studies birds.

10. **Herpetology**

    This studies reptiles.

11. **Mycology**

    This studies fungi.

12. **Ichtyology**

    This studies fish.

13. **Malacology**

    This studies molluscs.

14. **Paleontology**

    This studies fossils and what they tell us about the ecologies of the past, about evolution, and about our place (as humans) in the world.

6.2 The Sun

Almost all life on Earth depends on the sun to survive.

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2 \tag{6.1}$$

Plants and some microbes use the sun's light to perform photosynthesis. In the above photosynthesis equation, light energy is used to combine carbon dioxide with water to form a mole of glucose.

In most plants, the *leaf* is where photosynthesis occurs: the **palisade cells** are where most photosynthetic activities occur. **Chloroplasts** are photosynthetic organelles - their job is to absorb light for photosynthesis.

6.2.1 Chlorophyll

Chlorophyll is a pigment that absorbs and reflects specific wavelengths of light - these are also "light harvesting complexes".

The most common kinds of chlorophyll are Chlorophyll A and Chlorophyll B. What separates them is their absorption spectrum.

6.2.1.1 Discovery of Chlorophyll

Chlorophyll was found in 1817 by Joseph Bienaimé Caventou and Pierre Joseph Pelletier.

70 years after the discovery of Chlorophyll C, Harold Strain and Winston Manning found Chlorophyll D in 1943.

Chlorophyll F - the latest chlorophyll discovery - was found by scientists at the University of Sydney by professor Min Chen's group.

6.2.1.2 Tree Loss Rates

15.3 billion trees are cut down each year - the tree-to-person density ratio is about 422:1 for now.

The global amount of trees has fallen by 46% since the start of human civilization.

6.3 Origins of Life

> "It is often said that all the conditions for the first production of a living organism are present, which could ever have been present. But if (and Oh! what a big if!) we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, etc., present, that a protein compound was chemically formed ready to undergo still more complex changes, at the present day such matter would be instantly devoured or absorbed, which would not have been the case before living creatures were formed."
>
> – Darwin in a letter to Joseph Dalton Hooker, 1871

80 years later, Harold Clayton Urey used research on planetary conditions to show how interactions between the atmosphere and the oceans may have produced a "primordial soup".

In 1953, Stanley Lloyd Miller - inspired by a lecture given by Urey - wanted to cook up the "soup" in a lab. Miller was skeptical - he gave Urey a budget of under 1000 dollars.

6.3.1 Urey-Miller Experiment

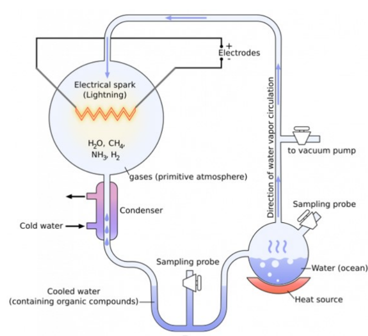


Figure 6.1: The Urey Miller Experiment

In this experiment, a flame boils the "ocean water" to simulate evaporation. The steam travels through an atmospheric flask that contains hydrogen, methane, and ammonia.

An electric spark at 60000 volts produced lightning while a second glass condensed the vapor and made it “rain” back down.

Within less than a week, the clear liquid darkened - Miller analyzed the soup and found five amino acids. He published his results in May 15, 1953 and he made global headlines.

6.4 Spontaneous Generation

> “Insects come into being spontaneously”
>
> – William Harvey (Exercitationes de Generatione Animalium, 1651)

Spontaneous Generation is the idea that living organisms can originate from non-living organisms.

Back in the days, it was believed that frogs, eels, mice, and other such organisms could arise spontaneously.

6.4.1 Francesco Redi’s Experiments

In 1668, Redi carried out some experiments to show that maggots come from fly eggs, not rotting meat.

At that time, it was believed that maggots in rotting meat was evidence of spontaneous generation.

Redi placed jars of meats in open air - one of them was covered in a fine muslin cloth. Redi saw that while flies of that particular jar would never get to the meat, they would still lay eggs on the cloth, hence disproving spontaneous generation as their origin.

However, Redi still thought that some insects like gall flies arose by spontaneous generation.

6.4.2 Pasteur’s Work

He carried 20 sterilized, sealed flasks high up in the Swiss Alps and opened them there.

Another set of flasks were also brought to the dusty streets of Paris. Only one flask in the Swiss Alps produced convincing proof of Pasteur’s position.

Pasteur’s work is recognized today as crucial in large scale effective control of disease.

If organisms spontaneously generated in decaying organic matter or other places, it would be very difficult to stop their natural formation unless one of the necessary ingredients, which was only hypothesized and never confirmed, was removed.

6.4.2.1 Pasteur's Swan Neck Experiment

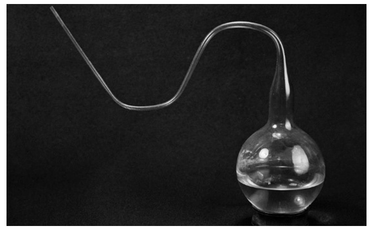


Figure 6.2: Image of Pasteur's Swan Neck Flask

Pasteur's experiment went as such:

1. Nutrient broth was poured into two flasks: an open necked flask and a swan necked flask.
2. Both broths were boiled to kill existing microbes
3. The broths were then left open and allowed to cool

In the end, microbes in the air reached the opened flask, but were caught in the layer of moisture in the swan-necked flask's neck. The former flask turned cloudy while the latter remained clear.

Pasteur's swan-necked design allowed air to pass into the flask, but the curved neck trapped any airborne microbes that might contaminate the broth.

6.4.3 Practical Implications

If only life begets life, then it is only a matter of preventing life from reaching the organism which one wants to prevent from becoming contaminated.

This is the purpose of sealing food in air tight containers or for destroying the organisms which spread disease by methods that are strong enough to destroy most microorganisms, but not their host (e.g., cooking).

This technique is the ordinary and primary method used today to control germs, and thus disease.

The spontaneous generation controversy continued for several years after the work of Pasteur with scientists who advocated grasping at every possible straw to save it. A London physician, Henry Charlton Bastian (1837–1915) published a two-volume work entitled *The Beginning of Life* where he cited difficulties with Pasteur's experiments.

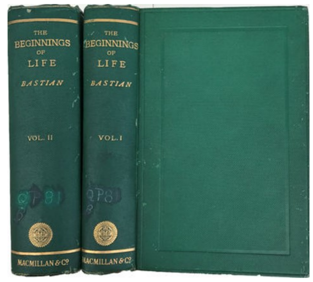


Figure 6.3: Bastian's *The Beginning of Life*

6.5 Taxonomy

This is science of naming, describing and classifying organisms and includes all plants, animals and microorganisms of the world.

Using morphological, behavioural, genetic and biochemical observations, taxonomists identify, describe and arrange species into classifications, including those that are new to science.

In the past 250 years of research, taxonomists have named about 1.78 million species of animals, plants and micro-organisms, yet the total number of species is unknown and probably between 5 and 30 million.

6.5.1 Species Problem

> "No other species displays such diversity as the dog."
>
> – Karen Lange, *Wolf to Woof*

All dogs belong to the species *Canis lupus familiaris*, yet there are still many species.

The establishment of kennel clubs in the 1800s accelerated the process of artificial selection by encouraging new breeds. Most breeds established since 1900 were created for the sake of appearance.

6.5.2 Why Study Taxonomy?

Taxonomy helps us provide unique names for species and help us ensure that two different people are talking about the same organism. The Latin "scientific" name is given as a *unique universal identifier*.

6.5.2.1 Modern Taxnomic Process

Taxonomists begin by sorting specimens into sets that they think represent species.

They then go through the specimens to see if a specimen already has a name or not[1].

These comparisons may also involve external characteristics, DNA analysis, or internal structure analysis too.

If no match is found, then a description has to be written, including ways that the species can be distinguished from other species. A new name (and one that is properly formatted) must also be formed.

This entire process can be length - it can take *years*.

6.5.3 Carolus Linnaeus

> "Now the Lord God had formed out of the ground all the wild animals and all the birds in the sky. He brought them to the man to see what he would name them; and whatever the man called each living creature, that was its name. So the man gave names to all the livestock, the birds in the sky and all the wild animals."
>
> – Genesis 2:19-20

Carolus Linnaeus was born at Stenbrohult, in the province of Småland in southern Sweden on 23 May 1707.

In 1727, he studied medicine at the University of Lund, and a year later, he transferred to the University of Uppsala, where he spent time collecting and studying plants.

At the time, training in botany was part of the medical curriculum, for every doctor had to prepare and prescribe drugs derived from medicinal plants.

6.5.3.1 Expedition to Lapland

In 1732, Linnaeus made an expedition to Lapland, the northernmost region of Sweden, with the objective of finding new plants, animals, and possibly valuable minerals.

In 1735, he completed his medical degree at the University of Harderwijk, and published the first edition of his classification of living things, the *Systema Naturae*.

Returning to Sweden in 1738, he practiced medicine (specializing in the treatment of syphilis) and lectured in Stockholm before being awarded a professorship at Uppsala in 1741.

[1] This may be done through reading guides, reading descriptions from 200 years ago, or borrowing specimens from museums and whatnot.

At Uppsala, he restored the University's botanical garden (arranging the plants according to his system of classification), made three more expeditions to various parts of Sweden, and inspired a generation of students.

He was instrumental in arranging to have his students sent out on trade and exploration voyages to all parts of the world: nineteen of Linnaeus's students went out on these voyages of discovery.

His most famous student, Daniel Solander, was the naturalist on Captain James Cook's first round-the-world voyage, and brought back the first plant collections from Australia and the South Pacific to Europe.

Anders Sparrman, another of Linnaeus's students, was a botanist on James Cook's second voyage.

Another student, Pehr Kalm, traveled in the northeastern American colonies for three years studying American plants.

Yet another, Carl Peter Thunberg, was the first Western naturalist to visit Japan in over a century. He not only studied the flora of Japan but taught Western medicine to Japanese practitioners.

Still others of his students traveled to South America, southeast Asia, Africa, and the Middle East. Many died on their travels.

6.5.3.2 Swedish Economy

Linnaeus was also deeply involved with ways to make the Swedish economy more self-sufficient and less dependent on foreign trade, either by acclimatizing valuable plants to grow in Sweden or by finding native substitutes.

Unfortunately, Linnaeus's attempts to grow cacao, coffee, tea, bananas, rice, and mulberries proved unsuccessful in Sweden's cold climate.

6.5.4 Comparisons Between Kingdoms

Character	Plantae	Animalia
Body organisation	Simple, organ systems like excretory, sensory, nervous, etc., absent	Well-developed and organ systems like excretory, sensory, nervous, etc., present
Mobility	Absent, organs of locomotion are not present	Present due to occurrence or organs of locomotion
Growth and development	Indefinite	Definite as body grows to certain size and then stop
Nutrition	Autotrophic, through either photosynthesis or absorption	Heterotrophic through ingestion

Figure 6.4: Comparisons Between Features in the Animal and Plant Kingdom

> "A few years ago Miss [Agnes] Joaquim, a lady residing in Singapore succeeded in crossing *Vanda hookeriana* and *Vanda teres*, two plants cultivated in almost every garden in Singapore."
>
> – Henry Nicholas Ridley (1855 - 1956)

Singapore's national flower (i.e., the *Papilionanthe*) was bred by breeding two common household orchids together.

6.5.5 Ernst H. Haeckel

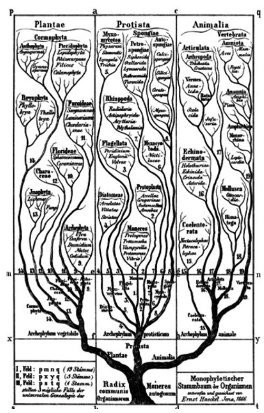


Figure 6.5: Three Kingdoms in the Taxonomy

The two-kingdom classification was adopted for a very long period in history of biological sciences.

However, invention of microscope during the 16^{th} century made it possible to explore the living world, which was not earlier possible to explore through the naked eye.

This exploration revealed an altogether new world of microorganisms sharing features of both plants and animals.

For example, Euglena are single-celled flagellated microorganisms that feature both plant and animal characteristics.

On the other hand, fungi have plant-like features such as immobility, irregular shape and indefinite growth but also posses heterotrophic mode of nutrition, a characteristic feature of animals.

Therefore such microorganisms could not have appropriate placement in two-kingdom classification.

In order to classify these microorganisms, Ernst H. Haeckel, in 1866, proposed a three-kingdom classification in which he added a new kingdom – *Protista*.

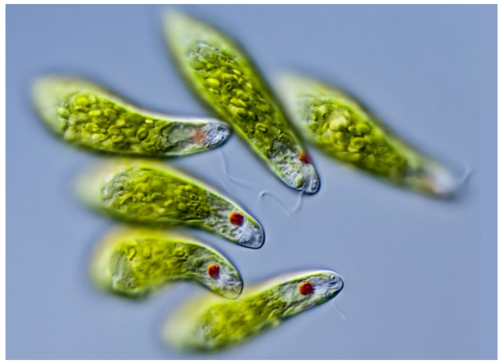


Figure 6.6: Bright Field Microscopy on a Protist

In this new kingdom he included all simple microscopic living organisms such as bacteria, microalgae, protozoa, fungi and sponges.

6.5.6 Robert Whittaker

Robert Whittaker worked on the area of classification, and developed three-kingdom, four-kingdom, and five-kingdom classification systems.

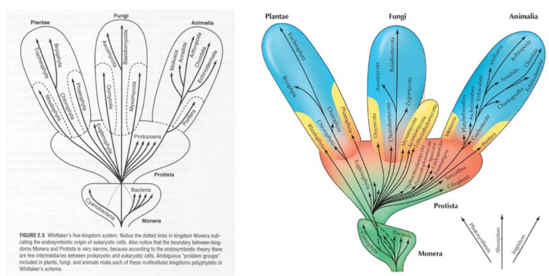


Figure 6.7: Whittaker's Five-Kingdom Classification System

His five-kingdom classification system, which he published in 1969, is featured in many biology textbooks.

The five kingdoms defined by him were named Monera, Protista, Fungi, Plantae and Animalia.

6.5.6.1 Carl Richard Woese's Domains

In 1990, Carl Richard Woese (1990) suggested further rectification in system of classification.

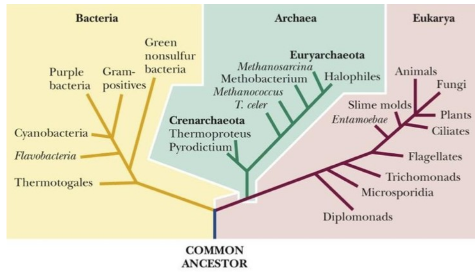


Figure 6.8: Woese's Domains

Relying on the information gathered with the help of various techniques of molecular biology about different prokaryotes he proposed a revision.

In this classification, a new level – the domain – was introduced as the top category.

This taxonomic system is known as a three-domain classification that includes domains – Bacteria, Archaea and Eukarya.

6.6 Anatomy

Democritus of Igisistratos or Athinocratos or Damasippos was born in Abdera, Thrace, Greece around the 80th Olympic Games, 460 to 457 BC. Serafini states 470 BC as the year he was born.

Among his students he had Mitrodorou of Chios, whose student was in turn Hippocrates from Kos. Democritus is also mentioned as being the teacher of Hippocrates who later treated him as a patient.

He came from a rich family. Later in his life, the people of Abdera tried Democritus in public and he was charged for spending the fatherly fortune.

When he read them his works Great décor and On vulvar explaining that he spent the money on that, he was cleared.

Democritus is considered an erudite and a scientist with multiple interests, one of the most famous Greeks of his time, whom Sextus Empiricus compared with the voice of God Zeus. He is referred to as polyhistor (he who has a great and varied learning) and gelastinos (he who laughs at everything).

6.6.1 Democritus' Stance on Anatomy

Democritus' views regarding the issue of human nature and anatomy are depicted in a letter he sent to Hippocrates of Kos.

The accuracy of his knowledge regarding the anatomy of the human body is explained by the plethora of dissections he had carried out, which results from his own writings.

However, historians' opinions on whether Democritus actually practiced cadaver dissection are contradictory. French historian Bouillet (1883) wrote:

> "Democritus dedicated long hours to dissection; his successors accused him of living in graves. True it was not, because he was never able to dissect human bodies".
>
> – Bouillet

Galen has left what has been called an abominable testimony, that Democritus used human parts and blood. Galen's testimony therefore is in favour of the possibility that Democritus had actually practiced human dissections.

6.6.2 Aristotle

Aristotle was born in Stagira, on the peninsula of Chalcidice in 384 BC.

Later, he became the tutor of Alexander the Great, who was then 12. In about 336 BC, Alexander departed on his Asiatic campaign, and Aristotle, who had served as an informal adviser since Alexander ascended the Macedonian throne, returned to Athens and opened his own school of philosophy, the Lyceum.

Alexander wrote books on zoology, astronomy, botany, poetry, drama, metaphysics, physics, ethics and other topics.

While Plato distrusted the sphere of the senses, Aristotle did not. Like Plato, Aristotle conceded the role of the intellect in the acquisition of learning, but he regarded the senses as no less significant.

This to him, the physical cosmos was as vital as the spiritual, and was equally deserving of study.

Not surprisingly, Aristotle wrote a number of volumes devoted specifically to physics and biology (e.g., *De Animalia*, or *On the History of Animals*).

6.6.2.1 Aristotle's Views on Taxonomy

> "Animals may be characterised according to their way of living, their actions, their habits, and their bodily parts."
>
> – Aristotle

Aristotle was interested in categorising all life-forms. Many consider him the inaugurator of systematic taxonomy in the style of Linnaeus.

Using behaviour and native habitat as a guide, he divided all beasts into land animals, animals that always live in the water (e.g., fish), and animals that live periodically in the water, but reproducing on land (e.g., otter, alligators, and beavers).

Aristotle's classification system had two principal divisions, the **Genos** and the **Eidos**. Genos signified broad categories of animals, such as a mammal, while Eidos referred to specific kinds of animals within the Genos, such as cats, horses, tigers, and so forth.

Alexander the Great sent him most of the material he needed for his studies.

Although his theories and specific classifications have altered considerably, several of the fundamental tenets still influence contemporary biology.

6.6.2.2 Aristotle's Views on Reproduction

Aristotle distinguished between sexual and asexual reproduction. The latter, he believed occurred via "spontaneous generation".

In line with later thinking, Aristotle believed spontaneous generation occurred primarily in more primitive animals, such as fleas and mosquitoes, which could arise, spontaneously from decaying substances.

Aristotle was the first to realise that that mother and the father were of equal weight in the creation of a new organism.

6.6.2.3 Aristotle and the "Vital Force"

Aristotle concluded that the heart controlled the flow of blood and was also the source of "animal heat" – the conviction that an undetectable, non-physical "force" keeps animals alive.

What distinguishes animate from inanimate matter, such as a rock, is precisely that the latter does not have the "vital force" while the former does.

In 1928, Friedrich Wöhler demolished the concept of vitalism when he synthesized urea (CH_4N_2O) in his laboratory.

6.6.3 Galen of Pergamum

Galen was born in 131 in the city of Pergamum in Asia Minor. Although born a Greek, he later moved to Rome, fell in love with Roman culture, and even altered his name to the more Roman Claudius Galenus.

After his philosophical training, Galen began to study medicine, first in Corinth, and later in Alexandria.

He returned to Pergamum in 158, becoming a court physician at the city's school for gladiators. He then headed for Rome, where he began teaching science. There, he gained a reputation in medicine and became the personal physician of Marcus Aurelius.

Galen also treated quite ordinary people – not only the wives, children, and slaves of the rich, but the peasants he encountered in the countryside, friends of friends he met in the street, and the miscellaneous patients who walked or were carried to the clinic he operated in his home. He claims have provided his services for free.

Because of this, he became a public figure, known and recognized by many, accosted in the streets, challenged to debate, accompanied everywhere by a crowd of friends, supporters, students, domestic servants, and professional assistants.

6.6.3.1 Galen's Speculations

Galen used the pulse to diagnose illness, although he had no understanding of the circulatory system. He put together an encyclopedia of medical knowledge, relying heavily on Aristotle.

For the circulation of blood, he described the aorta and the primacy veins of dogs, pigs, sheep and other animals.

His discussions of the digestive system are an interesting blend of fact and fiction. He claimed that the stomach had a mysterious force called "transformation power", which allowed it to digest food.

To pursue his anatomical ideas, Galen examined creatures of every imaginable species. He was unafraid to perform vivisection (dissecting a living body), except on human beings.

His descriptions of the circulatory system dispelled the myth that the left chamber of the heart contained air. Although he had no grasp of the importance of oxygen in physiology (Joseph Priestley only discovered oxygen in 1774), he did in a way anticipate this view when he defended the tenet that there was some hitherto undiscovered element in the blood which was the basis of life. Oxygen is, of course, this element.

6.6.3.2 Galen's Misshaps

Galen made mistakes in his anatomy. He maintained (mistakenly) that both veins and arteries carried blood away from the heart, and that the wall between the left and right ventricles were porous, allowing blood to pass between them. He also claimed that the liver was the "seat" of the venous system.

Cultural taboos prevented Galen from dissecting human bodies, forcing him to rely on animals – a deficiency he candidly acknowledged and one that led to numerous errors.

6.6.4 Leonardo da Vinci

Leonardo was born in the village of Vinci, near Florence, in 1452. Many historians surmise that he actually dissected as many as thirty corpses in his youth.

He recorded his commentary in the form of notes and drawings, of which 4,000 pages are still extant.

Leonardo's finely detailed drawings helped others make headway in understanding the muscular and skeletal systems, and the relationship between them.

6.6.4.1 Leonardo's Work in Anatomy

Anatomists in Leonardo's time often dissected unclaimed bodies, such as of drunks and vagrants, and those bodies were more likely to be male.

Studying them would have been obnoxious work because they didn't have any form of embalming, and within two or three days, the body decomposes.

Because of this, Leonardo's illustrations of human anatomy are uncannily accurate with just one major exception: the female reproductive system.

Many of his drawings of the female reproductive system get details wrong.

6.6.5 Andreas Vesalius

Andreas Vesalius (née Andries van Wesel) was born in 1514 in Brussels.

He studied at the University of Louvain (1529 - 1533), then at the University of Paris (1523 - 1536).

While in France, he took lessons from Jacobus Sylvius, an ardent Galenist and famous physician in his own right, who later came to oppose bitterly his student's anatomical discoveries that denied the preeminence of the ancients.

Finally, he transferred to the University of Padua – the premier medical university of the era – to complete his doctorate in December 1537.

6.6.5.1 Vesalius' Dissections

Uniquely for the era, Vesalius insisted on the importance of actual dissection, by both teacher and pupil, when learning anatomy.

His position afforded him time to study the human body. Vesalius began his anatomical studies shortly after assuming his Chair at Padua.

He personally dissected cadavers and encouraged / forced his students to do the same. Bodies typically came from the gallows or fresh graves.

The local magistrate courteously timed Padua's executions around Vesalius' needs.

It was this hands-on engagement that enabled Vesalius to master the subject and make his portentous discoveries. While a professor, he published several texts and a dissection manual for his students that portended his magnum opus.

Vesalius' investigations culminated with his 1543 publication of De Human Corporis Fabrica Septem Libri, or Seven Books on the Fabric of the Human Body. A second edition, significantly revised and dramatically improved, appeared in 1555.

6.6.5.2 Vesalius' Seven Books

His seven books covered the following (in order):

1. The human skeleton
2. Musculature of the human body
3. Vasculature of the human body
4. The human body's nerves
5. The human body's gastrointestinal system
6. The human heart and lungs
7. The brain

It was 663 pages, with 83 plates containing 420 illustrations, of which the "muscle men" remain the best known.

Scholars have debated for centuries who actually created the figures, with the artists Titian (c. 1488/90-1576) and van Calcar (c. 1499-1546) as leading contenders.

Most medieval and early modern anatomy texts lacked any illustrations and relied on written description to portray the human body.

Vesalius' images, in addition to their artistic beauty, illuminated the subject of anatomy for students and facilitated its mastery.

Their seamless integration within the text set a new standard for the field. Moreover, he initiated a trend, furthered by subsequent anatomists such as Fallopio, Eustachi, and Albinus, who likewise filled their works with gorgeous and useful images, a practice continued by Netter and other modern anatomists.

6.6.6 Plastination

Figure 6.9: von Hagens with Two Plastinated Bodies

In July 1977, Gunther von Hagens was working as a research scientist at the University of Heidelberg's Institute of Pathology and Anatomy.

Looking at specimens embedded in plastic – the most advanced preservation technique then available – he wondered why the plastic was poured around bodies rather than into them.

He came up with the idea of vacuum-impregnation, whereby bodily fluids are drained and soluble fat are extracted and replaced with resins, silicon rubbers and epoxies – a process taking a year.

> "In the beginning, I thought plastination would mainly contribute to improving medical teaching.
>
> But the huge subsequent lay interest inspired me to create public exhibitions – not to shock people, but capture their imaginations."
>
> – Gunter von Hagens

He named the process **plastination**. After a year of intense research, and hundreds of experiments, he filed the first patent for plastination, a technique now used in 400 medical schools and universities worldwide, in March 1978.

6.6.6.1 Public Displays

The first Body Worlds exhibition, featuring whole body plastinates, was shown in Japan in 1995.

The displays feature healthy and diseased body parts as well as skinned, whole corpses in assorted poses – a rider atop a horse, a pregnant woman reclining.

In 2018, von Hagens is suffering from Parkinson's disease, and has requested to be plastinated when he dies, and become a permanent part of the Body Worlds exhibition.

The Body Worlds exhibition was held in Singapore in 2003 and in 2009.

The "The Cycle of Life" exhibit was excluded from the Singapore exhibition because it included copulating cadavers.

Critics have denounced von Hagens' work as disrespectful to the dead, others are appalled that dead bodies are used to make money. There was also controversy about the origin of his specimens. He has stated that the bodies of executed Chinese prisoners has not been used.

6.7 William Harvey and the Heart

William Harvey was born in Folkestone, Kent on 1 April 1578. His father was a merchant. Harvey was educated at King's College, Canterbury and then at Cambridge University.

He then studied medicine at the University of Padua in Italy, completing his studies in 1602.

Harvey married Elizabeth Browne, daughter of Elizabeth I's physician, in 1604. In 1607, he became a fellow of the Royal College of Physicians and, in 1609, was appointed physician to St Bartholomew's Hospital.

Through his teachings and observations, Harvey began to develop a new theory to explain how blood flowed through the body.

He conducted thorough research, including numerous dissections of human beings and as many as 40 animal species.

Harvey pored over the results before compiling them and publishing his groundbreaking *Exercitatio anatomica de motu cordis et sanguinis in animalibus (On the Motion of the Heart and Blood in Animals)* in 1628.

Only about 70 pages long, it became a gigantic milestone.

6.7.1 Heart Transplantation

The most controversial and famous operations of the twentieth century – human heart transplantation – was first performed by the South African surgeon Christiaan Neethling Barnard on 3 December 1967.

Popular twentieth-century histories often single out this surgical endeavour as a great or defining moment in world history, as important as the moon-landing of 1969. On par with space travel, it has been frequently used to symbolise human ability and medical achievement.

The first heart transplants were as much media as medical events.

On the afternoon of Saturday, 2 December 1967, a car collided with a mother and daughter who were crossing a Cape Town road. The mother died instantly and her daughter, Denise Darvall, was left critically injured and unconscious. A motorist passed by the scene, unaware that the accident was irrevocably going to change her own family's life.

She was on her way to visit her husband, dentist Louis Washkansky, who was in the nearby Groote Schuur Hospital suffering from end-stage cardiac disease. By 6 the next morning, Denise Darvell's heart was beating inside Louis Washkansky's chest. Christiaan Barnard, from the Groote Schuur Hospital, had led a team in conducting the first ever human-to-human heart transplant.

> "The young Republic of South Africa is rightly very proud of the magnificent feat achieved by a medical team at Groote Schuur Hospital in performing the first successful transplant of a human heart. The claim "successful" can be used even at this early stage because to date, it is a feat which makes medical history, no matter how short the further survival of the patient might be."
>
> – South African Medical Journal

Louis Washkansky died on 21 December 1967, eighteen days after receiving the heart of Denise Darvall.

6.7.2 Gaspare Tagliocozzi

In 1597, Gaspare Tagliacozzi, a professor of surgery at the University of Bologna, published *De Curtorum Chirurgia per Insitionem*, an illustrated guide that documented for the first time a technique for performing a rhinoplasty, or nose job.

> "We restore, repair, and make whole those parts which nature has given but fortune has taken away, not so much that they delight the eye, but that they buoy up the spirit and help the mind of the afflicted."
>
> – Tagliacozzi

Figure 6.10: A Patient After a Nose Job

Tagliacozzi improved the reconstructive surgery methods that had been developed in Italy in the 1400s and 1500s to repair noses which had been amputated, usually in war.

6.7.2.1 Ridiculing Tagliacozzi's Grafts

The Catholic Church judged that he had been tampering with the will of God and excommunicated him. Grafts became an object of ridicule. In 1909, the *Boston Medical and Surgical Journal* noted that by the eighteenth-century rhinoplasty "sank into disuse and in course of time began to be considered impossible or fabulous."

In the subsequent centuries, reconstructive techniques improved, but the principle remained the same. Tissue used to repair a wound had to be taken from the patient's own body. Otherwise, the immune system would attack and destroy it!

6.7.2.2 "Uniqueness" of Individuals

> "The singular character of the individual entirely dissuades us from attempting this work on another person. For such is the force and power of individuality, that if anyone should believe that he could accelerate and increase the beauty of union, nay more, even achieve even the least part of the operation, we consider him plainly superstitious and badly grounded in the physical sciences."
>
> – Tagliacozzi

The Venetian adventurer Nicolò Manuzzi (1639– 1717) settled in India and left a travelogue manuscript, published much later, in which he records that he had seen many natives with restored noses.

Manuzzi had acquired some surgical skills and was asked to repair a nose but to use a slave donor for the skin.

Manuzzi replied that "it would be of no avail, for being another's flesh it would not unite".

> "Concerning homoplastic transplantation (allografts) of organs such as the kidney, I have never found positive results to persist … whereas in autoplastic transplantation (autographs) the results was always positive. The biological side of the question has to be investigated very much more and we must find out by what means to prevent the reaction of the organism against a new organ."
>
> – Alexis Carrel to Theodor Kocher

No one, though many experiments have been reported, has yet succeeded in keeping an animal alive for any great length of time which carried the kidney or kidneys of another animal after its own kidneys were removed.

The outlook is by no means hopeless and the principles of immunity, which yield such brilliant results in many other fields, would seem to ne worthy of being tested in this case.

6.7.3 Cyclosporin

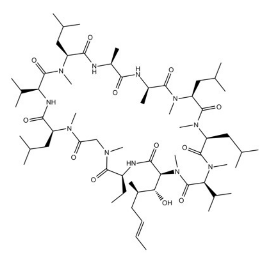


Figure 6.11: Structural Formula of Cyclosporin

In 1969, Sandoz biologist Hans Peter Frey, collected a soil sample which contained the fungus *Tolypocladium inflatum* (*Beauveria nivea*), from Hardangervidda, a national park in Norway. Sandoz encouraged employees to collect such samples on business trips and holidays to search for new antibiotic drugs from fungal metabolites.

The immunosuppressive effect of cyclosporine was discovered on 31 January 1972 by employees of Sandoz (now Novartis), in a screening test on immune suppression designed and implemented by Hartmann Stähelin.

The extraordinary commercial success of cyclosporin is due to its immunosuppression and absence of cytotoxicity.

Among 170 liver transplants between 1967 and 1980, Thomas Starzl's team reported only a 30% 1-year survival rate. Roy Calne's series of 130 liver transplants between 1968 and 1983 achieved similar results.

It was apparent that acute and chronic rejection of the donor liver by the host immune system remained a major clinical problem that was limiting the efficacy of liver transplantation.

In 1978, Calne and others obtained extremely encouraging experimental results using cyclosporin in animal organ grafts, which was followed shortly by introduction into human transplantation.

Three years later, Starzl reported a doubling of the 1-year survival rate of liver transplant recipients to about 60% using cyclosporine and prednisone for immunosuppression after liver transplantation.

Between January 1, 1988 and April 30, 2012, 115,458 liver transplants were performed in the USA alone. The 1-year survival of a liver transplant patient has improved to 85%–88%, and the 5-year survival is 74%.

6.8 Blood Types

Research on blood transfusion began in the 17th century with the English physician William Harvey while carrying out experiments on blood circulation. The very first transfusions were done with animal blood and were fatal to the receivers.

It was only at the very beginning of the 20th century that the Austrian physician Karl Landsteiner (1868-1943) discovered that humans belonged to different blood types, which he coined A, B and C – later to become A, B and O.

In 1902, his colleagues Alfred Decastello and Adriano Sturli discovered the fourth blood type: AB.

In 1907, an American doctor named Reuben Ottenberg successfully transfused blood between two people at Mount Sinai Hospital in New York.

Ottenberg also discovered that people with type O blood are "universal donors", which means that their blood will be accepted by people with any of the four ABO system blood groups.

6.9 Diabetes and Insulin

Diabetes mellitus is a chronic disease where the body does not make or does not use insulin properly, resulting in having too much sugar in the blood.

Sugar comes from the food we eat. The body needs sugar to make energy.

The amount of sugar in the blood of a normal person is closely controlled by a substance called insulin, which is made by the pancreas. People with diabetes either do not produce enough insulin or the insulin produced does not work well. As a result, sugar builds up in the blood.

Diabetes is one of the most studied diseases in the history of medicine.

Diabetes was first described in Ancient Egypt around 1552 BC (the Ebers Papyrus). Ever since then, physicians around the world tried to test and treat the "sugar sickness", as it was called. However, with insulin still unknown, diabetics were doomed to waste away.

Doctors in Egypt, India, and Greece all watched as the patients they desperately tried to save inevitably fell into comas and died. Indian physicians called it madhumeha ('honey urine') because it attracted ants.

6.9.1 Where are the Pancreas?

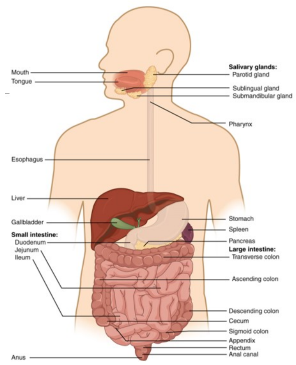


Figure 6.12: Location of Pancreas

The pancreas is a long, flattened gland located deep in the abdomen. The pancreas contains exocrine glands that produce enzymes important to digestion.

The islets of Langerhans create and release important hormones (insulin and glucagon) directly into the bloodstream.

6.9.2 Types of Diabetes

1. **Type I Diabetes**

   Persons with Type 1 diabetes cannot control their blood sugar properly because their pancreas produces little or no insulin. They need insulin injections to control their blood sugars. It usually happens to young people.

2. **Type II Diabetes**

   About 80% of all persons with diabetes belong to this group. They can produce insulin, but their body does not use it effectively. It is often the result poor diet and a sedentary lifestyle.

6.9.3 Statistics in Singapore

About 9% of the adult population in Singapore have diabetes. 90% of people with diabetes are over 40 years old.

Some risks of diabetes mellitus include:

1. Family history
2. Overweight
3. More than 40 years of age

4. Pregnancy
5. Exposure to a trigger mechanism (a virus or chemical substance)

Among the major ethnic groups in Malaysia, Indians (24.9% in 2011 and 19.9% in 2006) had the highest prevalence of T2D, followed by Malays (16.9% in 2011 and 11.9% in 2006) and Chinese (13.8% in 2011 and 11.4% in 2006).

These epidemiologic differences could be due to the genetic makeup, diet, and cultural variants among these major ethnic groups.

6.9.4 Origin of the word "Diabetes"

The term "diabetes" was probably introduced by the Greek physician Demetrius of Apamea or by Aretaeus of Cappadocia (129-199 AD).

Later, the word mellitus (honey sweet) was added by Thomas Willis (Britain) in 1675 after rediscovering the sweetness of urine and blood of patients (first noticed by the ancient Indians).

In 1776, the Liverpool physician Matthew Dobson firstly confirmed the presence of excess sugar in urine and blood as a cause of their sweetness.

Diabetes is a wonderful affection, not very frequent among men, being a melting down of the flesh and limbs into urine. The course is the common one, namely, the kidneys and bladder; for the patients never stop making water, but the flow is incessant, as if from the opening of aqueducts.

The nature of the disease, then, is chronic, and it takes a long period to form; but the patient is short-lived, if the constitution of the disease be completely established; for the melting is rapid, the death speedy. Moreover, life is disgusting and painful; thirst, unquenchable; excessive drinking, which, however, is disproportionate to the large quantity of urine, for more urine is passed; and one cannot stop them either from drinking or making water.

6.9.5 Pre-Insulin Era

Characterised by the efforts of controlling diabetes by means of bizarre pharmacological treatment such as the use of opium or dietary interventions, based on the conviction that diabetic patients should eat extra-portion for compensating their endocrinological and metabolic impairment.

However, some physicians began to notice that it was fasting and not an excess of calories to improve the clinical symptoms of diabetes. They introduced dietary restrictions such as "Bouchardat's treatment" or "starvation diets".

6.9.5.1 Paul Langerhans

In 1869, Paul Langerhans made the first careful and detailed description of the microscopic structure of the pancreas. He described nine different types of cells including small, irregularly shaped, polygonal cells without granules, which formed numerous cell heaps measuring 0.1 to 0.24 mm in diameter, throughout the gland. Langerhans refrained from making a hypothesis as to the nature and importance of these cells. In 1893, the French histologist GE Languesse named these spots "ilots de Langerhans".

In 1875, Langerhans moved to the island of Madeira because of pulmonary tuberculosis, but he did not stop his scientific work.

He continued his zoological studies of the fauna of the Canary Islands and Madeira, and wrote a handbook for travelers to the island.

Langerhans was also interested in his own disease and published two papers on tuberculosis.

In Madeira he practiced medicine in the capital, Funchal, where in 1888 he died of a kidney infection.

6.9.6 Diabetes Cases and Treatments

The below cases were common:

1. **Case 1**

   A man in his late fifties began to have severe pain in one of his toes, causing constant suffering and loss of sleep. Then, it began to turn black. His family doctor confirmed the diagnosis of diabetes which he himself had feared, since a brother and several members of his family had been diabetic.

   A surgeon, consulted in the hope that the gangrenous toe could be amputated, was unwilling to operate. He stated that, with diabetes, healing would fail to occur. The man was bedridden for months as the gangrene extended into his foot. Finally death came to end his suffering.

2. **Case 2**

   A young girl with diabetes in an early stage, was treated with the Allen "starvation diet" then in vogue. Introduced by Dr. Frederick Madison Allen, and promoted by Dr. Elliott Proctor Joslin, dietary restriction of extreme degree was then the chief hope for juvenile diabetics. The results for this girl at first appeared successful, but suddenly diabetic coma developed, and she was gone.

In 1889, two German researchers, Oskar Minkowski and Joseph von Mering, discovered that removing a dog's pancreas (total pancreatectomy) would provoke severe symptoms of diabetes.

They begun the speculation that a mysterious substance produced by the pancreas is responsible for metabolic control.

In 1907 a Belgian investigator Jean de Meyer proposed it be named "insulin".

The discovery of insulin at the University of Toronto by in 1921-22 was one of the most dramatic events in the history of the treatment of disease.

On December 2, 1921, Leonard Thompson, 14, arrived at the emergency of Toronto General Hospital.

He weighed just 30 kg (as he had been on a "starvation diet"), and his life hung by a thread. His diabetes had been diagnosed two years earlier.

Thompson's father let the hospital try Banting and Best's new pancreatic extract for the first time.

On January 11, 1922, Leonard Thompson became the first patient with diabetes to receive insulin injections.

After an impure form of insulin failed to improve Leonard's condition initially, a purer version restored his blood glucose levels back to normal and his symptoms began to disappear.

Two weeks later, on 23 January 1922, Leonard underwent a second series of insulin injections and the results were stunning. His life was, literally, saved by insulin and he became the poster boy of the now commonplace medical miracle.

When Leonard was aged 27, 13 years after his first insulin injections, he died of pneumonia, which was thought to be a complication of his diabetes.

6.9.7 Controversy over Nobel Prize

In 1923, Frederick Banting and John MacLeod were awarded the Nobel Prize for Physiology or Medicine. The prize aroused a lively and debated controversy.

In 1955, the British biochemist Frederick Sanger managed to fully sequence the bovine insulin and discovered its exact composition in terms of amino-acids. For this discovery, Sanger won the Nobel for Chemistry in 1958.

For the discovery of the physical structure of insulin, the English biochemist Dorothy Mary Crowfoot-Hodgkin (1910–1994), a pioneer in the protein X-ray crystallography, was awarded the Nobel Prize in Chemistry in 1964.

6.10 Insect Metamorphoses

Jan Swammerdam was born on 12 February 1637 in Amsterdam. He qualified as a medical candidate in October 1663.

After obtaining his doctorate, Swammerdam concentrated mainly on the study of insects. The purpose of Swammerdam's work on insects and other lower animals was to refute the Aristotelian idea that these were imperfect animals, by systematically contradicting the Aristotelian arguments that they lacked internal anatomy, originated spontaneous generation, and developed through an abrupt metamorphosis.

William Harvey proposed that the insect egg contains so scarce nutrients that the embryo is forced to hatch before completing development.

Then, during the larval life, the animal would accumulate enough resources to reach the pupal stage, which Harvey considered as the perfect egg.

Swammerdam showed that the pupa is not a sort of egg but a transitional stage between the larvae and the adult. He classified insect metamorphoses into four main types.

6.10.1 Types of Metamorphoses

There are four kinds:

1. **Type I**

   Insects that grow without transformation (lice were his example)

2. **Type II**

   In a second type, he included the species that develop the wings progressively and that transform into adults without any intermediate, quiescent stage (as crickets and cockroaches).

3. **Type III**

   Represented by species whose wings develop under the larval cuticle and that undergo a quiescent pupal stage before transforming into adults (as in butterflies and beetles)

4. **Type IV**

   Species that pass the pupal stage under the skin of the last larval stage (represented by flies)

6.10.2 Textbooks on Insects

Although refined and completed with many examples, Swammerdam's categories are essentially the same as the one used today.

Ametabolans, which do not experience morphological transformations along the biological cycle.

Hemimetabolans, which hatch as nymphs with a morphology similar to that of the adult and grow progressively until the adult stage, which gain full flying wings and functional genitalia.

Holometabolans, which hatch as a larva morphologically very different from the adult, then progressively grow through successive moults until the last larval instar, after which they moult into the pupal stage, often quiescent and similar to the adult, and then to the adult stage, with flying wings and fully formed and functional genitalia.

6.11 Vitamins

Gelatin (also called gelatine) is an animal protein prepared by the thermal denaturation of collagen, isolated from animal skin and bones, with very dilute acid. It can also be extracted from fish skins.

Chemically, gelatin is a heterogeneous mixture of single or multi-stranded polypeptides. More about this in a later lecture (on biochemistry)!

For now, let's go back to Paris in the early 1800s. Philanthropists were seeking ways to feed the poor. Chemists discovered that gelatin could be extracted from leftover bones.

So they came up with an idea – people of means could consume the meat, while the poor would receive a gelatin broth. However, the poor revolted against the unappetizing broth.

The authorities appointed a committee, the Gelatin Commission, to evaluate gelatin. After ten years of research, the Commission concluded that gelatin was not a complete food.

By the late nineteenth century, the prevailing dogma held that there were four essential elements of nutrition: proteins, carbohydrates, fats, and minerals.

6.11.1 Cause of Disease: Germ Theory

Germ theory, that diseases are caused by infectious organisms or toxins produced by these organisms became the reigning principle in science.

Louis Pasteur (1822 – 1895) and Robert Koch (1843 – 1910) were influential proponents of the germ theory of disease.

Investigations identified the organisms responsible for anthrax, malaria, tuberculosis, cholera, leprosy, and diphtheria.

Other diseases such as scurvy, beriberi, rickets, and pellagra – considered by some to be infections – continued to baffle scientists.

> "Scurvy and rickets are conditions so severe that they force themselves upon our attention; but many other nutritive errors affect the health of individuals to a degree most important to themselves, and some of them depend upon unsuspected dietetic factors …"
>
> – Frederick Gowland Hopkins

In a speech in 1906, Frederick Gowland Hopkins stated that "… no animal can live upon a mixture of pure protein fat, and carbohydrate, and even when the necessary inorganic material [i.e., minerals] is carefully supplied the animal still cannot flourish."

> "Mice can live quite well under these conditions when receiving suitable foods (e. g., milk), however, as the above experiments demonstrate that they are unable to live on proteins, fats, carbohydrates, salts, and water, it follows that other substances indispensable for nutrition must be present in milk …".
>
> – Nicolai Lunin

Carl Socin, demonstrated that there was an unknown substance in egg yolk that was essential to life, and he raised the question of whether this substance was fat-like in nature.

6.11.2 During the Seige of Paris

> "Since no conscientious chemist can assert that the analysis of milk has made known all the products necessary for life ... we must renounce, for the present, the pretension to make milk. ... It is therefore always prudent to abstain from pronouncing upon the identity of these indefinite substances employed in the sustenance of life, in which the smallest and most insignificant traces of matter may prove to be not only efficacious, but even indispensable ... The siege of Paris will have proved that we... must still leave to nurses the mission of producing milk."
>
> – Dumas

Many infants and toddlers died when the city was cut off from the milk supply of the countryside. Some opportunists tried to manufacture an artificial substitute for cows' milk, but this artificial milk failed to sustain the infants. Many children died.

6.11.3 Vitamins

Discoverers of Different Vitamins

Vitamin A: Frederick Gowland Hopkins

Vitamin C: Albert Szent-Györgyi

Vitamin D: Adolf Windaus

Vitamin E: Herbert McLean Evans and Katharine Scott Bishop

Vitamin B_1: Casimir Funk

Vitamin B_2 (riboflavin): Richard Kuhn and Theodor Wagner-Jauregg

Vitamin B_6 (pyridoxine): Paul György and colleagues

Vitamin B12 (cobalamin): Karl Folkers

Vitamin K: Henrik Dam

Figure 6.13: Scientists who Discovered Vitamins

In 1912, Hopkins showed that young rats did not grow well when fed a basal ration of protein, starch, cane sugar, lard, and minerals. After a small amount of milk was added to the basal ration, they had normal growth. The unknown factors in milk that supported life were found in "astonishingly small amounts" and were termed "accessory factors" by Hopkins.

Casimir Funk (1884 – 1967) proposed the term "vitamine" instead of "accessory food factors" in 1912 for the deficient substances in the food as related to beriberi, scurvy, and pellagra.

In 1913, University of Wisconsin biochemist Elmer McCollum (1879–1967) was able to distinguish two different species of vitamins, which he called "fat-soluble factor A" and "water-soluble factor B."

The announcements by Hopkins, Funk, McCollum and others sparked enormous worldwide interest in this new area of research. Over time, more vitamins were discovered.

7 Story of Chemistry

> "Chemistry is the branch of science which is concerned with materials of every description. It is often called the central science as it overlaps with both biology (biochemistry) and physics (physical chemistry)."
>
> – Lister and Renshaw

Our everyday lives have been transformed by science. Yet many people remain deeply suspicious of science and in particular, of chemistry.

> "It is from chemistry that the dyer acquired all the processes for extracting, toning, and fixing his colours; through it, the starcher, brewer, and distiller controlled their fermentations. It is chemistry that has allowed the cabinetmaker to vary the shades of his veneers, the varnisher to dissolve resins, the tanner to tan leather and soften hides. It is also chemistry that taught so many manufacturers how to remove the grease from wool and to smooth out silks. It alone can add some perfection to all these arts."
>
> – Guyton de Morveau

Chemistry is the study of substances in terms of :

1. **Composition**

   What is a material made out of?

2. **Structure**

   How are elementary particles put together?

3. **Properties**

   What characteristics does the material have?

4. **Reactions**

   What reactions does this material have with other materials?

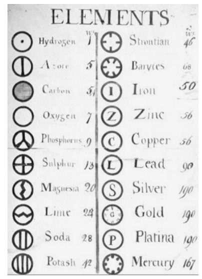


Figure 7.1: Early Chemical Notations by John Dalton

7.1 Chemical Notations

In 1782, Guyton de Morveau stated that, in the interest of science, it was necessary to have "a constant method of denomination, which helps the intelligence and relieves the memory".

Ideally, an element or compound should have a unique name because the proliferation of names for the same substance can lead to confusion.

In 1803, John Dalton, starts using symbols to represent atoms of different elements.

Dalton's symbols were not the ones we use today, but circles containing distinct symbols (a dot for hydrogen, a cross for sulfur), or circles containing letters ("C" for copper,"L" for lead).

He used them singly to represent elements and in combination to show compounds.

Later, Swedish chemist, Jöns Jakob Berzelius simplified the system.

Berzelius organized 47 elements with letters alone, and he based those letters not primarily on the English names, but on the Latin ones.

7.1.1 Jöns Jacob Berzelius

Berzelius wrote a textbook for his students, and in the process, he became convinced that chemistry was in a state of confusion.

In particular, he felt the need for a more helpful method of naming and classifying chemical substances – perhaps resembling binomial nomenclature, the system developed by his fellow countryman, Linnaeus (1707-78).

He published his system in a series of articles published in 1813 and 1814. His system of chemical symbols survived and it remains the basis of chemical nomenclature today.

Having organised the elements, he then tried to create a notation for compounds which revealed their chemical nature.

At first, he indicated the numbers of atoms with superscripts, so that sulphur dioxide was written SO2.

Eventually, the subscript version (SO2) became the standard form. At first, many chemists were not impressed by the Berzelian symbols. By the mid-century, though, they were generally accepted.

7.1.2 IUPAC

The **I**nternational **U**nion of **P**ure and **A**pplied **C**hemistry was formed in 1919 by chemists from industry and from academia.

Its primary aim in chemical nomenclature is to provide a methodology for assigning descriptors (names and formulae) to chemical substances so that they can be identified without ambiguity, facilitating communication.

The origin of the names of some elements (e.g., antimony and iron) is obscure, and lost in antiquity.

7.1.2.1 Origin of Element Names

Element (Symbol)	Origin of the Name
Phosphorus (P)	From Greek mythology, meaning light bearer – white phosphorus emits a greenish glow
Barium (Ba)	From Greek *barys*, meaning heavy
Hydrogen (H)	From the Greek *hydro*, meaning water and *genes*, meaning creator – water is produced when hydrogen combusts.
Radium (Ra)	From Latin, radius (ray), referring to its power of emitting radioactive energy

Figure 7.2: Some Origins of Elements' Names

Element names are based on:

1. An element's properties
2. A mineral that the element is isolated from
3. The place or area of discovery (e.g., Gallium)
4. A mythological character or concept
5. An astronomical object

The origin of words is known as **etymology**. The study of the origin of the names of chemical elements is known as **elementymology**.

7.2 Periodic Table of Elements

In the middle 1800s, elements were being discovered almost every decade.

This profusion of new elements, with an ever-widening range of properties soon began to provoke questions:

1. Precisely how many elements were there?
2. Had most of them already been discovered?
3. Or would there perhaps turn out to be innumerable elements?

These questions led to speculations.

Somehow, amongst all the elements, there must be some kind of fundamental order.

John Dalton had already discovered that the atoms of each element had different weights.

Berzelius had noticed that elements had different electrical affinities.

There were also groups of elements with similar properties:

1. Metals that resisted corrosion
2. Combustible alkali metals
3. Colorless, odorless gases

The Periodic Table is of central importance to chemistry.

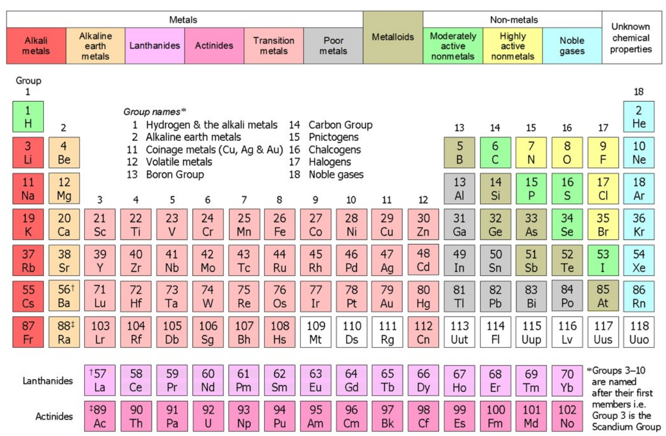


Figure 7.3: The Periodic Table of Elements

It provides a logical framework for recognising patterns in the properties of elements and their compounds. It also allows us to explain trends and similarities in properties in terms of the electronic structures of the elements.

Without the Periodic Table, chemistry would be a hotchpotch of unrelated information about different substances.

7.2.1 Johan Döbereiner

Döbereiner was a professor of chemistry at the University of Jena. He was the son of a coachman, and was largely self-educated. He became a pharmacist, and attended regular local public lectures on science.

He eventually secured a position at the University of Jena, where his lectures were regularly attended by Goethe.

In 1829, Döbereiner noticed that the recently discovered bromine had properties which seemed to lie midway between those of chlorine and iodine. Not only that, it's atomic weight lay exactly halfway between the two.

Döbereiner began studying the list of known elements, recorded with their properties and atomic weights, and eventually discovers another two groups of elements with the same pattern:

1. Strontium (between calcium and barium)
2. Selenium (between sulphur and tellurium)

He looked for further examples, but could find no more. Döbereiner Law of Triads only applied to nine of the fifty-four known elements.
It was dismissed by his colleagues as a coincidence.

7.2.2 Alexandre-Emile Béguyer de Chancourtois

In 1862, de Chancourtois published a paper describing a "telluric screw", which demonstrated that there did indeed appear to be some kind of pattern amongst the elements.

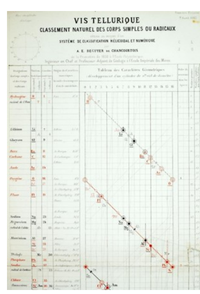


Figure 7.4: Chancourtois' Elemental Screw

The "telluric screw" consisted of a cylinder on which was drawn a descending spiral line. He was intrigued to find that the properties of these elements tended to repeat when they were read of in vertical columns down the cylinder.

It seemed that after every 16 units of atomic weight, the properties of the matching elements tended to repeat when the elements were read off in vertical columns.

De Chancourtois's paper was published, but he used geological terms, and even introduced numerology.

The publishers omitted to include the illustration of the cylinder, rendering the article virtually incomprehensible to all but the most persistent readers.

7.2.3 John Newlands

In 1864, John Newlands came up with his own pattern of the elements.

In his research, Newlands came up with findings that bore a resemblance to those of de Chancourtois. Newlands discovered that if he listed the elements in ascending order of their atomic weights, in vertical lines of seven, the properties of the elements along the corresponding horizontal lines were remarkably similar.

The eighth element starting from a given one is a kind of repetition of the first, like the eighth note in an octave of music. He named this his 'law of octaves'.

Sodium – potassium; magnesium – calcium, chlorine – bromine – iodine

Unfortunately, the properties of some elements especially those of higher atonic weight, simply did not tally. Even so, this is the first solid evidence that there was indeed some comprehensive pattern to the elements.

7.2.4 Dmitri Ivanovich Mendeleev

The Father of the Periodic Table is Dmitri Ivanovich Mendeleev. Mendeleev was born in Tobolsk (in Siberia). He was the 17th child in his family.

His father was the headmaster of the local school, but became blind in the year of Dmitry's birth, leaving the mother to provide for the large family.

Mendeleyev went to school in Tobolsk, and did badly. He learnt Ancient Greek and Latin, and Mendeleyev developed a distaste of high culture which was to last a lifetime.

His brother-in-law (Bessagrin) instilled in him a deep interest in science.

7.2.4.1 The Journey to Moscow

In 1849, when Dmitry was fifteen, his mother set off with her two remaining dependent children, Dmitri and Liza – for Moscow. This meant a laborious 1,300-mile journey.

Maria Mendeleyava was now 57 years old, tired and aged will beyond her years after bringing up her huge family single-handedly, while at the same time running a factory and organizing the welfare of its workers.

But she was determined that Dmitri should receive the education his promise deserved.

In Moscow, they encountered problems enrolling into the university.

Entry from the provinces was according to a quota system, but the province Mendeleyev was from had not been given a quota yet, and so he was denied entry. In addition, they found that Siberian qualifications were not recognised in Moscow.

As a last resort, they set off for the capital, St Petersburg. Fortunately, Maria found that the head of the Central Pedagogical Institute was an old friend of her husband. Mendeleyev was given a place to study mathematics and natural science, and a government scholarship.

7.2.4.2 Being a Top Student

In 1855, Mendeleyev qualified as a teacher, taking the gold medal for the best student of his year. His first appointment was to a teaching post at Simferopol in the Crimea. He arrived to find the Crimean War in full swing, and the school at Simferopol closed for months.

He went back to St Petersburg and was appointed privat Dozent (untenured, unpaid lecturer) in the University of St Petersburg. In 1859, he managed to secure a government grant to study abroad for two years. On the advice of Borodin, he headed first to Paris, and then to Heidelberg.

In 1861, Mendeleyev returned to St Petersburg, taking up a teaching position at the Technical Institute. To his astonishment, he found that Russia simply hadn't heard of the fundamental advances in modern chemistry which were taking place all over Europe.

He started to deliver lectures about these developments, and began attracting attention. He also write a Russian textbook on modern organic chemistry. In 1864, he became a professor, and bought a small estate two hundred miles from St Petersburg.

7.2.4.3 External Work

By 1867, he was being sent as far afield as Baku in the Caucasus to advice on the establishment of an oil industry, and Paris to organise the Russian pavilion at the Exposition Internationale.

At age 32, Mendeleyev was appointed professor of general chemistry at the University of St Petersburg. His lectures were on inorganic chemistry, but his students were hampered by the lack of an adequate textbook.

By early 1869, he had completed the first volume of his projected two0-volume The Principles of Chemistry. This was to be his masterpiece.

The end of the first volume covered the halogen group. The halogens combine readily with potassium.

So the obvious logical step was to start volume two with the alkali metals group, which contained sodium and potassium. By the morning of 14 February 1869, the two chapters were complete. The problem now was what group of elements to deal with next. The structure of the book depended on this. By 17 February, he still hadn't come up with anything.

> "I saw in a dream a table where all the elements fell into place as required. Awakening, I immediately wrote it down on a piece of paper."
>
> - Mendeleev

In his dream, Mendeleyev had realised that when the elements were listed in order of their atomic weights, their properties repeated in a series of periodic intervals. For this reason, he named his discovery the Periodic Table of the Elements.

In his table, where no element fitted into the pattern, he simply left a gap. H predicted that these gaps would one day be filled by elements which had not been discovered.

7.2.4.3.1 Julius Meyer

The German scientist, Julius Meyer, published a paper claiming that he had discovered the Period Table. Mendeleyev was given credit for the discovery of the periodic table because he published first (1 March 1869), whereas Meyer only published the following year.

In addition, Meyer's conclusions were more tentative, and he couldn't fully account for the anomalies in his table.

In 1875, Paul Lecoq de Boisbaudran announced the discovery of gallium. In 1886, Clemens Alexander Winkler discovered germanium.

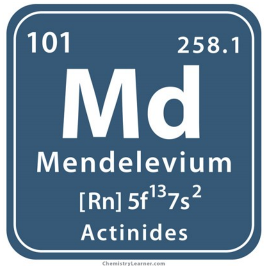


Figure 7.5: Element Symbol for Mendelevium

7.2.4.4 Mendelevium

In 1955, element 101 was discovered by Albert Ghiorso, Bernard Harvey, Gregory Choppin, Stanley Thompson, and Glenn Seaborg at the Lawrence Berkeley National Laboratory in California.

It was named Mendelevium, in recognition of Mendeleyev's achievements.

7.2.5 CAS Numbers

The **C**hemical **A**bstracts **S**ervice (i.e., **CAS**), a division of the American Chemical Society, maintains a registry of chemical substances that assigns each chemical a registry number ("CAS Number") and a unique systematic name.

Every chemical is assigned a CAS Number.

On 8 September 2009, it recorded the 50 millionth substance in the registry.

The CAS Registry is the world's most comprehensive and high-quality compendium of publicly disclosed chemical information. The CAS Registry can be accessed free from Common Chemistry.

CAS numbers have three uses:

1. Searching for physical, chemical, or thermodynamical data on a chemical compound
2. Ordering a chemical compound
3. When looking for safety information (MSDS) on a chemical compound.

Each element is tested using 64-17-5 (i.e., ethanol).

7.3 Washing Soda

Washing soda is the common name for sodium carbonate (Na_2_CO_3_). It is used in the manufacture of soap, detergent, textiles, glass and paper.

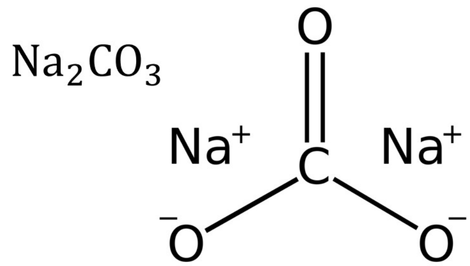


Figure 7.6: Structural Formula for Washing Soda

Nicolas Leblanc invented an industrial process to make pure washing soda.

Before Leblanc, soap was a handmade luxury for the rich and a medicinal salve for the sick. After him, soap became an everyday part of modern life.

It revolutionised personal cleanliness and prevented scabies, an itchy skin disease. When the British government removed its soap tax in 1853, the price of soap dropped and the incidence of scabies plummeted. Soap also reduced the incidence of typhus.

7.3.1 King Louis XVI's Reward and Later Years

Nicolas Leblanc was a poor orphan (his father died when he was nine) who studied chemistry with Jean Darcet, one of France's first chemistry

Louis XVI offered 12,000 livres for the best way to turn common salt into washing soda for the manufacture of soap. For Leblanc, the contest represented a chance at attaining wealth, security, and professional acclaim.

Chemists had long known that sea salt could be transformed into sodium carbonate, and French scientists understood that the two compounds are related. No one could make the process work on a large, industrial scale, though.

At 42, Leblanc took up the challenge.

He knew the first step – mixing salt with sulphuric acid to make sodium sulphate and hydrochloric acid (readily available):

$$2NaCl + H_2SO_4 \longrightarrow Na_2SO_4 + 2HCl \tag{7.1}$$

The challenge was the second step. Leblanc wrestled with the problem for five years between 1784 and 1789, and then stumbled upon the solution. As Leblanc heated his sodium sulphate with charcoal, he added a key new ingredient – limestone (calcium carbonate, $CaCO_3$):

$$Na_2SO_4 + CaCO_3 + 2C \longrightarrow Na_2CO_3 + CaS + 2CO_2 \tag{7.2}$$

Unfortunately for Leblanc, in July 1789, Parisian mobs stormed the Bastille and triggered the French Revolution. The timing could not have been worse. The absolute monarchy was gone, and with it all changes of his winning Louis XVI's prize money.

Jean Darcet confirmed Leblanc's discovery, and recommended it to their patron, the Duke or Orleans. He wrote:

> "I the undersigned, professor of chemistry at the Royal College of France, …, certify that … with the same process, it will be easy to establish a factory."
>
> – Jean Darcet

The Duke of Orleans was visiting London, so in February 1790, Leblanc crossed the English Channel on his first trip outside France. Orleans agreed to invest $8 million in a start-up factory to exploit Leblanc's secret process.

With a year of getting the duke's support, Leblanc opened a small factory at Saint-Denis, and started to transform his laboratory project into a large-scale factor.

Leblanc also applied for a patent. On 19 September 1791, Leblanc became the 14th inventor granted a patent under France's new laws.

> "The last letter received pierced my soul, for I learnt that they have suspended the payment of the pensions and pledges of the people who were attached to me. I cannot tell you how I was affected by that. I put this sorrow among the biggest sorrows that I have suffered."
>
> – Leblanc in wriitng to his mistress

For the next two years, Leblanc struggled to get his factory going amid wartime shortages of sulphuric acid and capital. The Duke of Orleans was arrested, and two days before his execution, he wrote the above to his mistress

Among those affected was Nicolas Leblanc. The Duke of Orleans was executed in November 1793, and Leblanc's factory was seized. The Committee of Public Safety called for patent holders of soda processes to publish their methods:

> "A true republican does not hesitate to relinquish the ownership of even the fruits of his mind when he hears the voice of his country entreating for aid."
>
> – Committee of Public Safety

Leblanc submitted his discovery to the committee, which published a brochure describing his process in minute detail as the French government wanted as many factories as possible to manufacture washing soda.

Within months of the execution of the Duke of Orleans, Leblanc had lost his salary, the factory, and his patent. The revolution had already cost him his chance of winning Louis XVI's prize money. Meanwhile, Leblanc's wife had fallen ill, and he had four children to support.

The government was sympathetic about the loss of his patent, and appointed him to a patchwork of administrative and study posts, most of them unpaid.

On 16 January 1806, Leblanc committed suicide by shooting himself in the head.

7.3.2 Leblanc Pollution

Leblanc's process continued to be used, and produced much pollution, devastating entire communities. For each ton of washing soda made, three quarters of a ton of HCl spewed into the air, poisoning farmland. As HCl poured into the waterways, it combined with sulphur to make H_2S gas, spreading a rotten egg smell for miles around:

$$2NaCl + H_2SO_4 \longrightarrow Na_2SO_4 + 2HCl \tag{7.3}$$

In 1856, the French National Academy of sciences concluded that "scarcely anyone has done so much for industry and received so little reward as did Leblanc."

In 1863, the British Parliament passed the Alkali Act, which forced the Leblanc factories to reclaim 95% if the HCl that they produced. Angus Smith, the Alkali Inspector assigned to enforce the law, demonstrated that industrial towns suffered from higher sulphate levels than did the countryside.

He also coined the term acid rain, and air pollution became a public issue. Bu the 1870s, Leblanc factories emitted less than 0.1% of the HCl they produced. The rest was reclaimed and sold. People started cleaning themselves with soap on a regular basis too. Cheap soap prevented scabies, a disease almost forgotten.

7.4 Sucrose

Sugar cane, a giant perennial grass, *Saccharum officinarum*, originated in tropical southern Asia and was known in the Middle East and China between 8000 and 6000 BC.

Arabs used sugar as a medicine and brought it to the Mediterranean where, grown by peasants, it was expensive luxury. Christopher Columbus brought sugar cane to plant in the Caribbean islands on his second voyage in 1493.

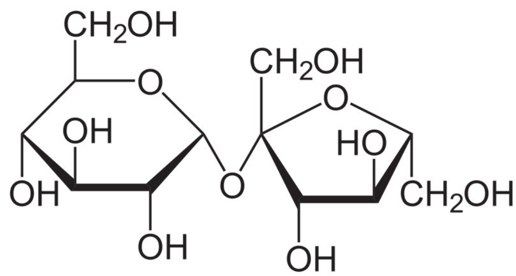


Figure 7.7: Structural Formula of Sucrose

Figure 7.8: Sugar Cane Growing

Spain, England and France grew sugar cane with slave labor on their island colonies, and their product was far cheaper than European sugar cane grown with free labor.

7.4.1 Triple Effect Evaporator

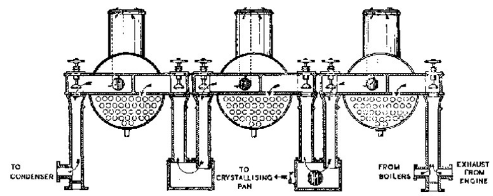


Figure 7.9: A Drawing of a Triple Effect Evaporator

Norbert Rillieux was born on 17 March 1806 to a wealthy white man and his longtime mistress. Norbert's father, Vincent Rillieux, was a cotton merchant and engineer. His mother, Constance Vivant, was a free African American from a rich real estate family in New Orleans.

She herself was the daughter of a white father and a black mother. Norbert Rillieux's birth was registered as "Norbert Rillieux, quadroon libre, natural son of Vincent Rillieux and Constance Vivant." The words quadroon libre, stipulated that Norbert was a free African American with more white ancestry than black.

In the 1820s, Vincent Rillieux sent Norbert to Paris for his education, but more specifically, to master its science and sugar technology. France was vitally interested in sugar, and they were studying the sugar-making process intensively. Scientists had known for roughly 75 years that many plants contain sucrose, and Napoleon had launched a crash programme to make France independent of imported cane sugar.

After Napoleon's defeat, French scientists continued their research, trying to make beet sugar grown by free farmers in France competitive with cane sugar grown by slaves in the New World.

7.4.2 Rillieux's Experiments

Edmund Forstall, a planter and banker in New Orleans, asked Norbert to become the chief engineer of a sugar factory under construction there. In 1833, Norbert left Paris and returned to New Orleans. Norbert quit his job with Forstall almost as soon as it began. Forstall had a disagreement with Norbert's father, and the younger Rillieux honoured his family ties.

Rillieux began to engineer his laboratory into a practical apparatus. He needed a sugar planter to let him build and test his equipment.

Finally, Judah Benjamin and Theodore Packwood offered Rillieux the use of their sugarhouse. They agreed to pay Rillieux $13,500 if his sugar was as good and plentiful as the previous year's crop.

Rilleux's triple-effect evaporator was a tremendous success, and Rillieux travelled around Louisiana installing his machinery. About thirteen of Rillieux's systems were installed before the Civil War.

Racial problems caused Rillieux to permanently to France.

7.4.3 Retirement

German farmers adopted Rillieux's equipment enthusiastically. By 1888, Rillieux systens were refining beet sugar in 30 German, 100 Austrian, and 20 Russian factories.

Rillieux-produced beet sugar added both sweets and meat to European diets. Sugar consumption more than doubled during the last 25 years of his life. Penned livestock could be fed molasses and beet residue.

Rillieux married, and studied Egyptology and hieroglyphics, never returning to Louisiana.

7.5 Clean Drinking Water

Cholera outbreaks can occur sporadically in any part of the world where water supplies, sanitation, food safety and hygiene practices are inadequate.

Overcrowded communities with poor sanitation and unsafe drinking-water supplies are most frequently affected.

Cholera is caused by the bacterium *Vibrio cholerae.*

People become infected after eating food or drinking water that has been contaminated by the faeces of infected persons.

Raw or undercooked seafood may be a source of infection in areas where cholera is prevalent and sanitation is poor.

Vegetables and fruit that have been washed with water contaminated by sewage may also transmit the infection if *Vibrio cholerae* is present.

Improved hygiene and clean drinking water is the solution to cholera.

Queen Victoria's personal physician, John Snow, removed the handle from the polluted Broad Street pump in London to prevent the waterborne disease.

7.5.1 Secret Affairs

Edward Frankland's mother, Margaret Frankland, worked as a maid for the Gorsts, a wealthy family of distinguished lawyers and judges.

The Gorsts' 20-year-old son Edward was living at home, and the two young people had a secret affair.

When Margaret Frankland became pregnant, the Gorsts were horrified as any hint of scandal would destroy the young man's prospects.

His father functioned as the queen's chief legal officer in Lancashire County, and his family was expected to be an unblemished example for all.

An illegitimate child disgraced both mother and father, and the latter was expected to support the child or face the consequences in court.

Edward Gorst set aside an annuity of £1,200 for Margaret Frankland and her child – provided that his identity was never revealed.

He paid Margaret the interest from the annuity, about £60 per year. Eventually, the annuity was probably replaced b a one-time payment of £1,500.

7.5.1.1 Becoming a Pharmacist

Margaret Frankland was banished from the Gorsts' household, and moved back to her family home outside Garstang to give birth and raise her son.

On 18 January 1825, Edward Frankland was born in Churchtown, Lancashire.

The child's name combined his father's first name and his mother's maiden name. Thus the Gorsts were protected from publicity, but the child was not.

To anyone who knew him, Edward Frankland's use of his mother's unmarried name was assign of "bastardy," a Victorian disgrace.

Frankland wanted to become a doctor, but could not afford medical school. So in 1840, when Frankland was 14, she apprenticed him to a pharmacist.

As an apprentice, he worked more than 70 hours a week, wheeling heavy casks of treacle through town and hauling 100-pound sacks up a steep and narrow staircase. To grind a pound of cocoa, he worked a 20-pound pestle continuously for a day. To make ointment, he spent more than 24 days grinding six pounds of mercury into 14 pounds of lard.

7.5.1.2 Friendship with John Tyndall

Frankland's analytical chemistry skills were enough to land him a teaching job. At one of the schools, he befriended a fellow teacher, John Tyndall, who later became a prominent British physicist.

The two men had a mutual pact to wake up at 4:00 a.m. each day and study together. Frankland taught Tyndall chemistry, and Tyndall taught Frankland biology and mathematics.

A year later, Frankland and his friend, John Tyndall left to earn their doctorates from Bunsen in Germany.

After his studies, he returned to England in 1849 to become a professional chemist. Frankland worked on organic compounds containing arsenic, and coined the term "organometallic" to describe this group of compounds.

Frankland became aware that each element has a definite combining power.

Valency, as the principle is called today, is one of the fundamental concepts in chemistry. The valence of an atom equals the number of bonds that an atom has for combining with other elements. Hydrogen has a valence of one.

Frankland sends his report on valency to the Royal Society on May 10, 1850. Unfortunately, the secretary laid the report aside and forgot about it for a year!

In the meantime, August Kekulé ignore Frankland's work, and claimed the valence theory for himself.

In contrast, Frankland's work in organometallic compounds attracted considerable attention, and when the University of Manchester opened, Frankland was appointed its chemistry professor.

7.5.1.3 Transforming Chemistry Education

At age 40, he was appointed to a prestigious professorship to replace August Wilhelm Hofmann at the Royal College of Chemistry. In addition to his regular duties, Frankland was responsible for analysing London's water supply.

Frankland transformed chemistry education by integrating the laboratory into the curriculum. He compiled a list of 109 experiments that students needed to understand, and wrote a textbook that became a standard for chemistry instruction.

Frankland developed the system for writing chemical formulae and for depicting the bonds between the atoms in molecules.

As he synthesised more and more isomers, compounds with the same formulae but different molecular structures, he found traditional formulae confusing – they showed the types and numbers of elements but provided no clue as to how the atoms were arranged inside the molecule.

To solve this problem, Frankland depicted the atoms in functional groups, and drew lines between them to indicate the bonds between the elements.

7.5.1.4 Attaining Success

Cholera killed more than 20,000 people in England in the early 1830s.

In 1865, Frankland became London's water consultant, and a member of the Rivers' Pollution Commission in 1868. At the time, little was known about clean water (Robert Koch only identified the cholera bacillus in 1883).

While some experts thought that decaying matter directly caused disease or indirectly nurtured disease-causing microbes, others regarded faeces-rich water as no more than unacceptably disgusting. Terrified of cholera, people demanded sanitary water.

7.5.1.5 Discovering Helium

In 20 October 1868, Frankland co-discovered helium with English astronomer, Joseph Norman Lockyer.

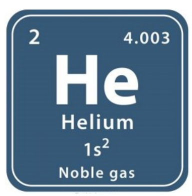


Figure 7.10: Helium's Entry on the Periodic Table

They observed a yellow line in the solar spectrum, which Lockyer named the D3 Fraunhofer line.

Frankland and Lockyer decided to name the element Helios, the Greek word for Sun.

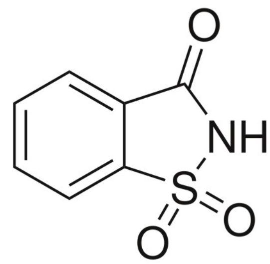
Although no one knew how cholera was spread, it was clear that there was a relationship between cholera and unsanitary water.

Frankland: "My motto, unlike that in criminal cases, has always been to assume water to be guilty until it is proven innocent."

He stressed that water's appearance should not be used as an indicator of its safety.

7.6 Saccharin

Saccharin is a low calorie sweetener. It is 300 times sweeter than sugar.



Anhydroorthosulphaminebenzoic Acid

Figure 7.11: Structural Formula for Saccharin

Saccharin has been used as a non-nutritive sweetening agent since 1907.

Saccharin quickly rose to popularity as the first calorie-free sweetener, when it became known as the "poor man's sugar" during World War II when real sugar was in short supply and thus more expensive.

Unfortunately saccharin had a bitter aftertaste, so there was an increasing demand for a new improved sweet substance.

In 1937, 59 years after saccharin had been discovered, Michael Sveda, a graduate student at the University of Illinois, discovered cyclamate, another sweetener.

7.6.1 Saccharin Story 1

Professor Ira Remsen of Johns Hopkins University was lecturing to his class using samples of newly-prepared chemicals before him. During the lecture, "he unconsciously poked his pencil into several samples".

Later, in his office, Professor Remsen happened to be troubled over a tough problem. While contemplating over it, he unconsciously touched the tip of the pencil to his lips and was amazed by the incredible sweetness.

He rushed back to his lecture hall and systematically tasted all the chemicals until he found the one prepared by Fahlberg.

7.6.2 Saccharin Story 2

Constantine Falhlberg discovered saccharin while working in Ira Remsen's laboratory at Johns Hopkins University. He spilled a chemical on his hand when he was researching new and interesting uses of coal tar derivatives.

Later on in the day when he was eating dinner, he noticed his bread rolls tasted sweeter than normal. However, when he mentioned this fact to his wife, she told him that they tasted the same as usual.

After realising he hadn't washed his hands, Falhberg traced the sweet taste to be coming from the chemicals.

7.6.3 Saccharin and Cyclamate

The FDA approved cyclamate in 1951. Cyclamate was blended with saccharin and sold as "Sweet 'n' Low", which quickly became popular in the United States. Cyclamate was also used to sweeten soft drinks.

in 1970, the Food and Drug Administration (FDA) banned cyclamate from all dietary foods in the United States, due to suspicion of inducing cancer in experimental animals.

A study by Wagner found an increased incidence of bladder carcinomas in rats. Cyclamate is converted to a very toxic metabolite, cyclohexylamine.

Studies in laboratory rats during the early 1970s linked saccharin with the development of bladder cancer, especially in male rats. It was banned in 1981.

Human epidemiology studies (studies of patterns, causes, and control of diseases in groups of people) have shown no consistent evidence that saccharin is associated with bladder cancer incidence.

In 2010, the U.S. Environmental Protection Agency removes saccharin from its list of hazardous substances.

7.7 Caffeine

Caffeine is a natural alkaloid found in coffee beans, tea leaves, cocoa beans, cola nuts and other plants.

It is probably the most frequently ingested pharmacologically active substance in the world, found in common beverages (coffee, tea, soft drinks), products containing cocoa or chocolate, and medications, including headache or pain remedies and over-the-counter stimulants

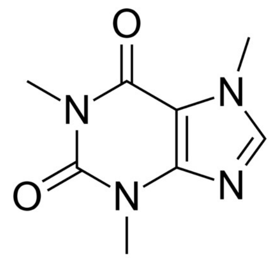


Figure 7.12: Structural Formula of Caffeine

In North America, coffee (60–75%) and tea (15–30%) are the major sources of caffeine in the adult diet, whereas caffeinated soft drinks and chocolate are the major sources of caffeine in the diet of children.

Coffee (Coffea Arabica and Coffea canephora) is one of the most widely consumed beverages in the world and is also a major source of caffeine for most populations.

The caffeine in coffee is a bioactive compound with stimulatory property on the central nervous system and a positive outcome on long-term memory.

7.7.1 Friedlieb Ferdinand Runge

German chemist Friedlieb Ferdinand Runge was born on 8 February 1794, the son of a pastor and the third of seven children.

While working as an apprentice in his uncle's pharmacy, he got a drop of henbane juice in his eye, and noticed that his pupil dilated.

Based on experiments on a cat's eye, he went on to write a dissertation on the toxic effects of atropine, a chemical found in plants like henbane and deadly nightshade.

Runge studied chemistry at the University of Jena, Germany, under Johan Döbereiner, an adviser to the writer Johann Wolfgang von Goethe. His fellow students called him "Dr Gift" – the German word for poison.

Döbereiner arranged for Runge to perform a demonstration of atropine's ability to make cats' pupils dilate for Goethe. Goethe was suitably impressed, and at the end of their meeting he presented Runge with a packet of coffee beans, suggesting that their chemical components might be worth investigating. Runge studied the beans, and later that year, he discovered caffeine.

7.7.1.1 Runge's Other Inventions

In 1819, while still a student, Runge made another remarkable discovery for which he is seldom credited, isolating quinine from cinchona bark. The discovery of quinine, the first effective antimalarial compound, is usually attributed to Pierre Joseph Pelletier and Joseph Bienaimé Caventou, who reported their work a year later.

He also invented paper chromatography, a method for separating chemicals.

Runge died on 25th March 1867, at the age of 73. He lived the last years of his life in poverty and obscurity.

7.8 MSG

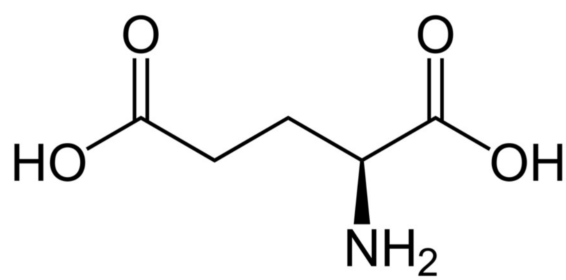


Figure 7.13: Structural Formula for MSG

One evening in 1907, Kikunae Ikeda, a chemist at the University of Tokyo, was feeling especially curious while he enjoyed a dinner of his wife's dashi and tofu soup.

Rather than simply enjoying his dinner like any other night, he stopped to ponder what made dashi not only so delicious on its own, but so complementary to other savoury foods. He suspected that the unique flavour of one of its primary ingredients, the seaweed kombu (giant kelp), might hold the secret to dashi's unique flavour-boosting ability.

Back at his lab at the University of Tokyo, Ikeda ran dashi through a series of evaporations and tests to isolate its individual chemicals as solids.

Eventually, he came across a brownish crystalline substance that had a mild but intriguing flavour, and the same flavour-boosting powers of dashi. The residue was mostly glutamic acid.

Ikeda became the first scientist to associate glutamic acid with savouriness in food. He called this taste umami – based on the Japanese root "umai," meaning "delicious," or simply "good."

7.8.1 Founding Ajinomoto

He refined and patented a way to produce pure glutamic acid, stabilising it with a salt ion to create what we now know as monosodium glutamate.

He called the company he founded to produce MSG Ajinomoto ("the essence of taste"), thus forever linking umami, the taste, with glutamic acid, the chemical. It remains one of the largest producers of MSG in the world today.

Ajinomoto began selling MSG in 1909 and in the next few years expanded across east Asia. In 1947, pure MSG was introduced for sale in America as the "flavour awakener" Ac'cent.

7.8.2 Chinese Restaurant Syndrome

Robert Ho Man Kwok, a Chinese-American doctor in Maryland, wrote a letter in the 4 April 1968 issue of the New England Journal of Medicine under the heading "Chinese Restaurant Syndrome":

> "For several years since I have been in this country, I have experienced a strange syndrome whenever I have eaten out in a Chinese restaurant."
>
> – Ho Man Kwok

The most prominent symptoms included "numbness at the back of the neck, gradually radiating to both arms and the back, and general weakness and palpitation."

7.9 Mauveine

Mauveine is the first synthetic organic dye.

Before the synthesis of mauveine from aniline by Perkin in 1856, the only materials available for the coloration of textiles were obtained from plants or animals (e.g., the insect cochineal).

Also known as aniline purple and Perkin's mauve, mauveine was soon used to dye silk and other textiles. In 1862, Queen Victoria popularized the colour by wearing a mauveine-dyed gown.

Mauveine consists of as many as 12 molecules.

William Henry Perkin grew up on London's East End. He dreamt of becoming an artist until he was showed some simple chemical experiments. From then, he began dreaming about an apprenticeship in an apothecary's shop.

In 1853, William enrolled in the Royal College of Chemistry (later, it becomes a part of Imperial College), where he studied with August Wilhelm Hoffman, a German chemist who had come to London at the personal invitation of Queen Victoria's German husband, Prince Albert.

7.9.1 August Wilhelm Hoffman

Prince Albert hoped Hofmann could teach Englishmen to use chemistry to solve important commercial problems concerning natural dyes, drugs and other essential commodities. Like many chemist of his day, Hofmann was analysing and testing compounds extracted from natural sources. In particular, he was investigating the chemicals in cold tar, an abundant waste by-product of coke production and coal gas lighting.

Hofmann speculated that he might be able to turn aniline in to quinine, and set William to investigate this. William had his own ideas on how this could be achieved, but his work for Hofmann left him little time to work on them.

Over Easter vacation in 1856, William decided to work on his ideas at home. Perkin began with a cold tar derivative with almost the same formula as quinine, but without as much oxygen. He chose different compounds to mix with, and with aniline, a black precipitate was produced.

Treating it with ethanol, he discovered that it made a ravishingly beautiful purple dye – a synthetic dye! Natural dyes were very expensive and coloured fabrics were still a luxury for most of the world's population. Growers of natural dyes were also hard-pressed to keep up with the accelerating demands of the cotton textile industry.

After experimenting with the solution on silk, Perkin realised that he had discovered a process for transforming the chemicals in coal tar into a colourfast purple dye. He mailed a sample to a Scottish dye time. After exposing the sample to sunlight, the owner replied:

> "If your discovery does not make the goods too expensive, it is decidedly one of the most valuable that has come out for a very long time. This colour is one which has been very much wanted in all classes of goods, and could not be obtained fast on silks, and only at great expense on cotton yarns."
>
> – Owner of a dye shop

Perkin and his brother prepared a few ounces of the dye – enough to apply for a patent, which they did no 26 August 1856. When he told Professor Hofmann that he was starting his own business, the professor was annoyed and discouraging.

Instead of buckling under, Perkin dropped out of college and plunged ahead with his purple dye. He promised himself that later in life, he would return to scientific research.

7.9.2 Imperial College's Speech

> "The purple in the hoods you and other Imperial graduates wear were chosen because of Perkin. The colour purple symbolises the spirit of endeavour and discovery, and the risk-taking nature that characterises those with an Imperial education and training.
>
> Like William Perkin you, our postgraduate students, are risk takers. When you enrolled, you knew you were taking on challenging advanced courses of study and research. [...] You have undertaken projects not knowing where they will lead."
>
> – Alice Petry Gast

7.10 Cocaine

Archaeological studies in South and Central America has established the antiquity of coca use. Analysis of mummified human remains from Northern Chile indicates the use of coca as early as 1000 B.C. These records establish that the use of coca has been ongoing for over 3,000 years among the native peoples of the Andes.

Under Incan rule, coca was used for numerous purposes, including mystical, religious, social, and medicinal uses. In 1532, a Spanish expedition conquered the Inca. The Spanish conquerors then attempted to eradicate the use of coca in the native cultures.

The Spanish failed, and decided to exploit coca growth instead.

Subsequently, coca use became more widespread throughout the former Incan empire, and the custom of giving agricultural workers a ration of coca leaves along with their daily wage began. Coca use continues to be a daily staple in the life of many Andean workers.

The Aymara people are an indigenous population of the Andes and Altiplano regions of South America. "Khoka" is an Aymara word that means "the tree."

This is the origin for our modern usage of "coca".

The coca shrub is indigenous to South America, Mexico, Indonesia, and the West Indies, with numerous alkaloid components.

After Paolo Mantegazza graduated as a medical doctor, he embarked upon a journey that ultimately brought him to Salta, Argentina. He practiced from 1855 to 1858 in Argentina and Paraguay where he came into contact with coca-chewing Indians.

Based on his experience with the locals in the Peruvian Andes, he became convinced of the widespread benefits of coca including reduction of fatigue, improvements to one's mood, and even the increase of sexual vigour.

7.10.1 From Coca to Cocaoine

When he returned to Italy in 1859, he published On the Hygenic and Medicinal Virtues of Coca, a monograph that combined physiological reporting with vivid descriptions of its effect on his mental state.

The leaf, he observed, aids digestion and has a central stimulant action on the nervous system. At low doses, this is barely noticeable, but at higher ones it impinges on consciousness to a marked degree. Muscular power is increased: “a new strength gradually drenches one’s organism in every sense, as a sponge soaks itself with water,” and “one feels stronger, more agile, and readier for any kind of work.”

By pushing his dose to the practical maximum, repeatedly chewing his way through an ounce of leaf at a time at top speed, Mantegazza was able to achieve “the delirium of coca intoxication.”

This was marked by a racing pulse, minor heart palpitations, a surge of “extraordinary happiness,” and, in the mind’s eye, “images that were more bizarre and splendid, in terms of colour, than could ever be imagined.”

Mantegazza’s work brought coca into the purview of German pharmacists, who had for the previous 30 years been working systematically through the alkaloid chemistry of medicinal plants.

7.10.1.1 Isolating Cocaine

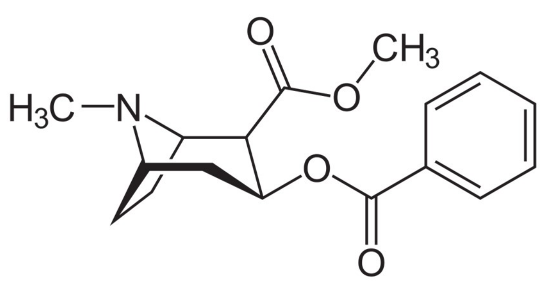


Figure 7.14: Structural Formula of Cocaine

In 1859, Friedrich Wohler of Gottingen University procured 25 kg of coca leaf from Lima, which he turned over to his young assistant Albert Niemann.

Niemann isolated from them a crystalline organic base that was named, according to the convention established by morphine, “cocaıne.”

Niemann reported that cocaine crystallized in “colorless transparent prisms” and had the bitter taste characteristic of an alkaloid; unsually, it left “a peculiar numbness, followed by a sense of cold when applied to the tongue.”

In 1863 an Italian chemist named Angelo Mariani brought onto the market a wine called Vin Mariani which had been treated with coca leaves. By the late 1880s, his product range would include Pate Mariani (cocaine lozenges for catarrh), The Mariani (a concentrated coca tea recommended for long walks), and Pastilles Mariani (for coughing fits).

Prior to the advent of local anaesthesia, operations on the eye were infrequent and the results most often unsatisfactory. General anaesthesia did not allow the patient to cooperate with the surgeon, e.g., by gazing in a particular direction.

7.10.2 Medical Uses of Coca

The Euro-American enthusiasm for coca quickly cooled in the early twentieth century with the increasing concerns of the addictive properties and poor side effect profiles witnessed with the use of cocaine.

1. **Relief of Gastrointestinal Upset**

   Coca leaf tea is taken to combat stomach pain, intestinal spasm, nausea, indigestion, and even constipation and diarrhoea. It is a comprehensive remedy that restores balance to the digestive system. It relieves painful oral sores and aids in the healing of oral lesions. It is used for toothaches as well.

2. **Environmental Stress Treatment**

   It is a remedy for dealing with the stresses of life at high altitude. help the user withstand hypoxia, cold, and hunger. Hand and foot temperatures were lowered in Andean people who used coca. Although the thermal difference between control and experimental subjects was not great, this small difference could be advantageous in decreasing the amount of heat loss in extreme environments.

3. **Hunger Treatment**

   Coca chewing is thought to decrease the feeling of hunger in Andean peoples. Chewing coca leaves has been found to elevate blood glucose above the fasting level, which lends scientific credibility to the native belief that coca staves off hunger pains.

4. **Altitude Illness Treatment**

   Coca chewers report less head pain and dizziness associated with working at high altitudes. The percentage of native peoples using coca increases with altitude. Physiological adaptations to cold may be enhanced by coca use.

   The belief in coca as an uplifting agent for those individuals working in a high altitude environment is not without its naysayers. Many have argued that it is merely a "spurious correlation" between coca chewing and high altitude.

7.10.3 Cocaine Abuse

Abuse refers to the use of any drug, primarily by self-administration, in a manner that deviates from the approved social or medical pattern within a given culture.

The term “drug abuse” thus conveys the notion of social disapproval.

The first epidemic of cocaine use in America occurred during the late 19th century.

Initially, there were no laws restricting the consumption or sale of cocaine. In fact, cocaine was freely available in drug stores, saloons, from mail-order vendors, and even in grocery stores.

Soon enough, the ill effects of cocaine became apparent, and by the 1920s cocaine was the most feared of all illicit drugs.

Most states began enacting laws against cocaine use.

7.11 DDT (i.e., Dichlorodiphenyltrichloroethane)

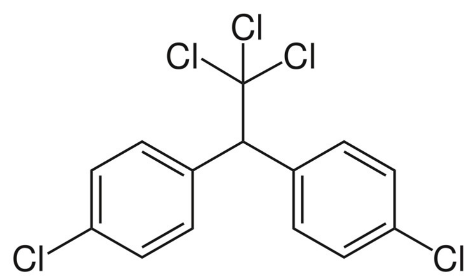


Figure 7.15: Structural Formula of DDT

The full name for DDT is 1-chloro-4-[2,2,2-trichloro-1-(4-chlorophenyl)ethyl]benzene.

DDT enters an insect by dissolving the thin layer of fatty substances that repel water from the creature’s waxy outer skin. Penetrating the layer, DDT reaches the insect’s nerve endings and gradually paralyses vital nerve centres. After a short period of extraordinary excitement, insects sprayed with DDT become progressively paralysed, fall on their backs, and die.

As Othmar Zeidler had already synthesised DDT (and also described its properties and developed the methods to manufacture it) in 1874, when Geigy took out a Swiss patent in March 1940, it was for DDT’s use as an insecticide.

7.11.1 Paul Hermann Müller

Paul was born on 12 January 1899, just outside Basel. He was an average student, and in his formative years, he witnessed two dangerous crises caused by a lack of effective insecticide.

During World War I, Switzerland suffered from serious food shortages. As Switzerland is mountainous, and most of its arable land is pasturage. Switzerland needed to protect its crops from insects, but could not.

While Müller was a student at the University of Basel, the greatest typhus epidemic in history erupted. An estimated 25 – 30 million Russians contracted typhus, and almost three million died.

After he graduate, Müller started work at the J.R. Geigy Corporation (today known as Novartis). Geigy was moving into a new field of research – insecticides. Company chemists discovered a compound that permanently protected woollens from clothes moths and their larvae.

Geigy's moth proofing agent was a stomach poison for moths and other keratin-eating insects. It had a strong affinity for woollens, was harmless to warm-blooded animals and people, and had no offensive odour. As a chlorinated hydrocarbon, it was extremely persistent despite exposure to light and moisture.

7.11.1.1 Early Insecticides

After mothproofing wool, the next logical step for Geigy was to invent an insecticide that killed more kinds of pests. Natural insecticides made from plants, including pyrethrum, rotinone and nicotine were expensive, not persistent, and were easily destroyed by light and heat.

The most popular insecticide at the time was lead arsenate, and combination of two dangerous poisons. The US used more than ten million pounds of lead arsenate yearly, and residues on West Coast apples had poisoned customers as far away as Great Britain.

To Müller, just starting out on his search for an effective insecticide, the situation looked desperate indeed. He realised that "only a particularly cheap or remarkably effective insecticide had any prospects of being used in agriculture.

Geigy's research director was interested in gastric poisons that insects of their larvae had to swallow along with their food. Müller realised that not all insects eat in the same way. Many serious diseases are spread by insects that suck human blood for food. Only a contact poison would affect them.

7.11.2 Searching for an Ideal Insecticide

Müller outlined the desirable characteristics of an ideal insecticide:

It should be toxic to insects but harmless to mammals, fish and plants - it should also:

1. Act rapidly
2. Have no irritating odour
3. Inexpensive
4. It should affect as many insects as possible
5. It should be chemical stable for a long time

Müller had several clues to guide his search. First, he knew from Henri Martin's mothproofing work that a chlorinated hydrocarbon worked as a gastric moth poison. Second, he early experiments showed him that compounds with the group CH2Cl has some insecticidal effect. Third a 1934 article in the Journal of the Chemical Society of London described the preparation of diphenyltrichloroethane, which Müller found to be somewhat poisonous to the flies in the glass box.

Taken together, these hints convinced him that a compound containing chlorine should make a good insecticide.

By the autumn of 1939, Müller had tested 349 compounds. For his 350th compound, Müller combined sophorific chloral with cholorobenzene and a catalyst, sulphuric acid. His product was dichlorodiphenyltrichloroethane (DDT).

Spraying DDT on the flies in his glass cage, Müller was amazed to see them fall helplessly onto their back in ten minutes. In every test he tried, the insects died, although it sometimes took them several hours or days. He was even more astounded when he cage remained poisonous for weeks and killed any fly that touched its walls.

7.11.3 Tests on DDT

1. **Test #1**

   DDT's first big field test occurred in Naples (where 90% of the population had lice) on 1 October 1943. Naples had been typhus-free for 30 years – largely due to soap, washable clothing, and public baths – so its inhabitants had no immunity. Within a month a typhus epidemic was underway with a death rate approaching 25%.

   1.3 million people were hand-sprayed, one at a time, with DDT. This kept a person louse-free for several weeks with few to no known side effects. A winter outbreak of typhus had been stopped for the first time in history.

7.12 Ammonia

Haber was born on 9 December 1868 in Breslau, Prussia (now, Wrocław, Poland). His mother died within days of his birth, and his father, a civic leader and successful trader of dyes and chemicals, rejected him and left his upbringing to various relatives.

As a young man, Fritz wanted to become a chemist, but his father insisted that he join the family business. To prepare to enter his father's business, he studied chemical technology in an alcohol distillery in Hungary, a Solvay soda factory in

Within six months of joining his father's firm, Fritz invested and lost a large amount of the company's money. At long last, his father acknowledged that his son might be more suited for scientific research than for commerce.

To succeed in a university, Haber would have to overcome two obstacles: (1) his spotty chemistry education; and (2) anti-Semitism. German universities rarely promoted Jews to professorships. Since Haber's family rarely attended synagogue, he pragmatically converted to Christianity in 1892.

Fritz was attracted to a new field, physical chemistry, and enrolled into the Karlsruhe Institute of Technology.

In 1901, Haber married Clara Immerwahr.

A month into their marriage, Clara became pregnant. Three months after the Habers' son Hermann was born, Haber left for a five-month trip to the United States. (Haber wasn't a great husband.)

In 1906, at the age of 38, he became a professor. The leading scientific and social problem of the day: How to turn atmospheric nitrogen into desperately needed ammonia for fertilizer.

On a mountain hike one hot summer day, Haber would be begin, he stuck his head into a well for a drink of water without noticing that an ox was doing the same thing. Simultaneously lifting their heads, they discovered, to their mutual shock, that they had exchanged heads. That is why Haber would chortle he had the head of a stubborn ox.

7.12.1 Some Background

Europe's population had tripled over the past 200 years as public relief expanded, the severity of epidemics declined, and food crops were diversified. Because of this, Europe feared that it would run out of food.

Hydroelectric power plants and local coal gas and coke factories produced small amounts of ammonia that could be used to make fertilizer for crops, but the quantities did not come close to meeting farmers' needs. Indeed, without North American and Ukrainian grain shipments and without fertilizer shipments from Peruvian guano, Europe in the early 1900s might have experienced another famine like the Irish disaster of the 1840s.

Europe looked to chemists to feed its growing populations. William Crookes stated, "It is the chemist who must come to the rescue of the threatened communities. It is through the laboratory that starvation may be ultimately turned to plenty."

Chemists knew they had to turn the nitrogen in air into ammonia, but they did not have a solution. The two nitrogen atoms that make up the a molecule of nitrogen are held together by one of the strongest known chemical bonds, and no one could break the nitrogen molecule apart long enough to make ammonia.

7.12.2 Incentives

7.12.2.1 Economic

The fact that Germany depended on imported fertilizer more than any other country gave it a special stake in the problem. The industrialization of Germany's sugar beet and potato farms was intimately linked to its use of natural fertilizer, especially nitrogen compounds from the marine bird manure imported from Peru, Chile, and Bolivia. Yet experts predicted that Europe would exhaust South America's guano in 30 years.

7.12.2.2 Military

Nitrogen compounds are also used in explosives. In 1900, when the Boer war broke out between German and English immigrants in South Africa, Anglo-German relations soured. In the event of a European war, Britain's navy would block the import of guano Germany needed to make nitrates for explosives.

Ostwald and Walther Nernst, the world's two leading physical chemists worked on nitrogen fixation, but got nowhere.

7.12.3 Conditions Required for Ammonia Production

Haber had knowledge of industrial chemistry, and was able to blend the talents of skilled technicians, industrialists and scientists from different disciplines.

Robert Le Rossignol developed the seals needed to maintain high pressures in an experimental chamber. Friedrich Kirchenbauer built precision equipment needed for the reaction.

In his Nobel Prize speech, he thanked them, and shared his prize money with both men.

Haber and Rossignol discovered that hydrogen and nitrogen would stay combined only under extraordinarily harsh conditions: temperatures of 200°C and atmospheric pressure 200 times stronger than normal.

Such conditions were unheard of at the time, yet even they produced ammonia extremely slowly. To speed up the process, Haber and Rossignol used osmium and uranium as catalysts.

Later, it was found that a mixture of iron and metal oxides worked best. Haber patented his process.

7.12.4 Haber at the Kaiser Wilhelm Institute

In 1910, Haber was offered a job in Berlin at the Kaiser Wilhelm Institute of Physical Chemistry and Electrochemistry. Leopold Koppel offered to finance the Institute with two conditions: (1) the Kaiser must thank him publicly; and (2) Fritz Haber must be the institute's director. Haber three other conditions: (1) he must be a tenured stated official with power to run the institute; (2) earn 15,000 marks yearly; and (3) live free in an institute villa.

BASF opened its factory in 1913. The Haber-Bosch process remains the cheapest and most efficient method of turning atmospheric nitrogen into compounds that plants can use.

Haber's 1913 contract with BASF gave him 1.5 pfennigs for every kilogram of ammonia produced. By the mid-1920s, BASF had paid him enough to start rumours that the Habers dined on gold plates.

He became close friends with Albert Einstein. During Einstein's divorce from his first wife, Mileva, Haber drew up Einstein's financial arrangement with her, promised her the Nobel Prize money that Einstein was expected to win, and mediated between Mileva and Einstein.

Haber's own family life suffered as he became more famous.

7.12.5 Chemical Weapons

Clara rejected their newfound wealth, and preferred a semi-socialistic lifestyle.

World War I broke out, and the military asked Haber to find a chemical substitute for traditional munitions. France was contemplating the use of tear gas, which is not fatal.

The Hague Peace Conference of 1899 and 1907 banned the use of unusual, new weapons that might cause unnecessary suffering.

Haber believed that poison gas would be more humane than high explosives, and no worse than flying shrapnel.

Haber agreed to find a chemical weapon, and invented poison gas. He personally directed the burial of 6,000 cylinders of liquid chlorine along a 1½ mile line near Ypres, Belgium.

On 22 April 1915, the Germans opened all the canisters simultaneously, releasing 150 tons of chlorine within ten minutes.

Vomiting and coughing in violent spams, the soldiers retreated in panic. Chlorine corrodes the eyes, nose, mouth, throat, and lungs, and can asphyxiate its victims.

Seven thousand people at Ypres were poisoned, and 350 died. The Emperor promoted, by imperial decree, Haber to the rank of captain.

Clara pleaded with Haber to stop his poison gas work. She was horrified by the experiments conducted on animals. Early in the war, an experiment in the lab exploded after Haber left the room. A young physicist, Otto Sackur, one of Clara's classmates, was killed. Haber later found a job at the institute for Sackur's daughter.

7.12.5.1 Boycotting Poisonous Gas

The Nobel prize unleashed an international storm of protest.

Except for one Englishman, the non-German winners boycotted the ceremonies, primarily because of Haber. Press reaction to the prizes was extraordinarily hostile. Many of the German winners had signed the manifesto supporting the invasion of Belgium.

Allied countries singled out Haber because his ammonia process had lengthened the war by four years. The 1925 Geneva Protocol prohibited chemical and biological weapons.

7.12.6 Haber's Nobel Prize

Sackur's death disturbed Clara profoundly. The week after the poison gas attack at Ypres, Clara gave her husband the ultimatum – stop working with poison gas or she would commit suicide.

On 1 May 1915, he threw a dinner party to celebrate his success. At dawn (2 May 1915), Clara shot herself in the heart. 2.5 years later, Haber married Charlotte Nathan.

When Germany surrendered, Haber plunged into a severe depression. A year after Germany's surrender, Haber won the 1918 Nobel prize for turning nitrogen into ammonia for fertilizer. Nothing was said about the use of ammonia in explosives.

7.12.7 Searching for Gold in Seawater

Haber was deeply disheartened by Germany's defeat. The Versailles Treaty had levied a 132-million-mark indemnity. Haber searched the seas for gold.

Accepting contemporary estimates that seawater naturally contained six milligrams of gold per metric ton, he figured that the oceans must contain eight million tons of gold, and extraction would be economically feasible.

Haber and Johannes Jaenicke started sampling seawater, and five years later, he found that contemporary estimates of seawater's gold content were a thousand times too high. Haber gave up the idea.

When Hitler became chancellor in 1933, he issued an order that no Jews would be allowed in civil service.

Haber was exempt from this due to his civil service during World War I. However, his employees were not. 75% of them were Jewish, and would have to be dismissed. Haber took a stand and resigned on 30 April 1933.

> "My most important goals in life are that I not die as a German citizen and that I not bequeath to my children and grandchildren the civil rights of second-class citizenship, as German law now demands that they accept and endure on account of their Jewish grandparents and great-grandparents. The second thing that's important to me is to spend my last years in a scientific community of people, with honour but without heavy duties."
>
> – Sir William Pope

Haber accepted the invitation of Sir William Pope to join him at Cambridge University. The invitation was arranged by Haber's former foes – Harold Hartley and Frederick Donnan of the Imperial College.

7.12.8 Haber's Death

> "Haber's significance for science and its nurturing is not remotely exhausted by his own scientific works and with those of his school. He was not merely a man of science and technology; he was also highly competent in matters of organisation and financial management ... Haber was a Jew, as were the overwhelming majority of his colleagues. This made conflict with the National Socialist state inevitable."
>
> – Speech on Haber in 28 June, 1934

On 29 January 1934, Haber collapsed with severe heart pains in a hotel room at Basel, Switzerland. Later that day, he suffered a heart attack, and died within a few hours.

He was buried in a Basel cemetery. At his request, the body of his first wife, Clara Immerwahr was buried next to his. On 29 January 1935, the Kaiser Wilhelm Society held a memorial service for Haber.

During World War II, the Nazis used the pesticide Zyklon B in concentration gas chambers.

7.12.8.1 Note on Zyklon B

Zyklon B was not invented by Fritz Haber. Walter Heerdt, Bruno Emil Tesch and Gerhard Peters invented it in 1922.

It was an insecticide used in Germany before and during World War II to disinfect ships, barracks, clothing, warehouses, factories, granaries, and more.

It was produced in crystal form, creating amethyst-blue pellets. Since these Zyklon B pellets turned into a highly poisonous gas (hydrocyanic acid, HCN) when exposed to air, they were stored and transported in hermetically-sealed, metal canisters.

7.13 Tetraethyl Lead (i.e., TEL)

Midgley was born on 18 May 1889. He majored in mechanical engineering in Cornell University. He worked for Charles Kettering, the inventor of the electrical self-starting ignition. Kettering assigned Midgley the problem of engine knock.

He improvised a high-speed camera to photograph the engine through a quartz window in a cylinder, and showed that part of the fuel inside the engine cylinder was exploding prematurely.

By chance, he found that iodine eliminated knock, but was too expensive, and it corroded and clogged the engine.

On 9 December 1921, tetraethyl lead, $Pb(C_2H_5)_4$, was found to eliminate knock. Tetraethyl lead (TEL) went on sale on 1 February 1923.

Many workers died in the process of manufacturing TEL, and General Motors paid the U.S. Bureau of Mines to conduct a study. The Bureau agreed to refer only to the trade name "Ethyl" without using the scientific term that included "lead".

Because of the deaths in the manufacture of TEL, it became an occupational, rather than a broader, environmental issue.

7.13.1 Pro-Lead versus Anti-Lead

The U.S. Surgeon General convened a hearing, and two camps formed.

The men engaged in industry, chemists, and engineers, take it as a matter of course that a little thing like industrial poisoning should not be allowed to stand in the way of industrial advance. On the other hand, the sanitary experts take as a matter of course that the first consideration is the health of the people.

The pro-lead camp – the petrochemical and automobile industries – represented the corporate backbone of the United States, and had the upper hand.

The Surgeon General's committee completed its study, and it was announced that TEL would add less lead to the atmosphere than house paint, production and distribution of TEL was resumed.

Standard Oil petrol stations put on the sign: "Ethyl is Back." The medical adviser of Standard Oil strongly urged corporate president Walter Teagle to abandon TEL, but his advice was unheeded.

Within two decades of the introduction of TEL, the octane rating of petrol rose from 55 to 75.

By 1928, Kettering was in charge of the General Motors research department, and Frigidaire was part of GM. Every refrigerant known at the time (e.g., sulphur dioxide and ammonia) was toxic, inflammable, or both.

7.13.2 Refridgeration

> "At least fifteen and perhaps more persons died in recent months in Chicago from gases used in artificial refrigeration. … Four persons have been victims of the gas [methyl chloride] in the last ten days in Chicago. Dr. Kegel [Health Commissioner] compiled a list of twelve persons who, he said, had been made ill by the gas, and a list of seven who had died from it in the last few weeks."
>
> – New York Times, 2 July, 1929

If refrigeration and air-conditioning were to become popular, a safe refrigerant would have to be found.

Methyl chloride, another refrigerant, proved lethal in some apartments in the 1920s when pipes connecting water-cooling equipment to refrigerators upstairs leaked.

7.13.2.1 CFCs

Midgley identified a new class of potential compounds: the chlorofluorocarbons, later nicknamed CFCs, and trademarked Freon by Du Pont. Dichlorodifluoromethane was found to be noninflammable and nontoxic. It was later called R-12 (for "Refrigerant-12").

At the American Chemical Society annual meeting in April 1930, Midgley demonstrated R-12 by lighting a candle, inhaling the R-12, holding it in his lungs for a moment, and the slowly exhaling, blowing candle flames out.

Air-conditioning and refrigeration took off!

Safe refrigeration revolutionised medicine by making vaccinations effective and by reducing food poisoning and diarrheal diseases. All vaccines must be refrigerated during shipment and storage.

Before refrigeration, the failure rate of vaccination was high as vaccines kept at room temperature were effective for less than a week.

Many types of bacteria thrive in unrefrigerated food, and in summer, milk kept more than 12 hours had to be boiled. Convenience was another advantage of refrigeration.

7.13.3 Refridgeration Impacts

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7.13.3.1 Impacts of CFCs

At the University of California, Irvine, Sherwood Rowland and Mario Molina discovered that CFCs could deplete Earth's atmospheric ozone layer, which blocks the sun's damaging ultraviolet rays. The scientists reported their findings in 1974. Rowland and Molina convinced sceptical industrialists, policymakers, and the public of the danger of CFCs.

The scientists' advocacy – and the discovery by other researchers that the ozone layer over the Antarctic was thinning – led to worldwide phase-out of CFCs and the development of safer alternatives. Rowland, Molina and Paul J. Crutzen shared the 1995 Nobel Prize in Chemistry.

7.13.4 Midgley's Death

In September 1940, Midgley contracted polio, paralysing him from the waist down. He wrote:

> "I have been spending my spare moments in bed figuring out the statistical probability of a 51-year-old male catching poliomyelis, as I have, and this comes out to be substantially equal to the chances of drawing a certain individual card from a stack of playing cards as high as the Empire State Building. It was my tough luck to draw it."
>
> – Midgley in writing

He could sit up for only for short periods of time, and found travel difficult.

On the morning of 2 November 1944, Carrie Midgley found Midgley dead. At 55, he had strangled on the overhead ropes and pulleys that he had designed for getting in and out of bed. His friends spread the story that he had become accidentally entangled, and the story stuck for 50 years.

Death and cemetery certificates, however, reveal what must have been obvious to his friends – a mechanical engineer of Midgley's prowess would not have accidentally strangled on his own invention. In despair, Midgley had carefully planned his death.

7.14 Phosphorus and Vitalism

Vitalism is a theory that an organic molecule cannot be produced from inorganic molecules, but instead can only be produced from a living organism or some part of a living organism.

Vitalists hold that living organisms are fundamentally different from non-living entities because they contain some non-physical element (a "vital force") or are governed by different principles than are inanimate things.

Vitalism suggested that an organic molecule such as urea cannot be synthesised solely from inorganic sources.

Phosphorus is an element that is essential for life.

Hennig Brand (c. 1630–c. 1710.) discovered phosphorus in 1669, in Hamburg, Germany, preparing it from urine. (Urine naturally contains considerable quantities of dissolved phosphates.) Brand called the substance he had discovered phosphorus ("light bearer") because it was luminous, glowing in the dark.

Although Brand kept his process a secret, phosphorus was discovered independently in 1680 by Robert Boyle.

8 Story of Physics

Physics is the study of natural forces in the universe. By studying these forces, we can understand why and how things work the way they do. When we understand matter, energy and the interactions between them, we can then use that knowledge to discover and create new ideas and technologies.

The fundamental ideas of physics underlie all science – astronomy, biology, chemistry and geology – and physics is essential to applied science and engineering.

Experimental physicists design and run careful investigations on a broad range of phenomena in nature, often under conditions which are atypical of our everyday lives.

Theoretical physicists propose and develop models and theories to explain mathematically the results of experimental observations.

Experiment and theory have a broad overlap. Experimental physicists remain keenly aware of the current theoretical work in their fields, while theoretical physicists must know the experimenters' results and the context in which the results need be interpreted.

8.1 Joseph John (i.e., "JJ") Thomson

Thomson was born on December 18, 1856, in Cheetham Hill, located just north of Manchester.

In 1876, he studied at Trinity College, Cambridge, obtaining his BA in mathematics in 1880, and MA (with Adams Prize) in 1883. In 1884 he became Cavendish Professor of Physics, succeeding Lord Rayleigh.

> "I regard the atom as containing a large number of smaller bodies which I will call corpuscles; … In the normal atom, this assemblage of corpuscles forms a system which is electrically neutral. Though the individual corpuscles behave like negative ions, yet when they are assembled in a neutral atom the negative effect is balanced by something which causes the space through which the corpuscles are spread to act as if it had a charge of positive electricity equal in amount to the sum of the negative charges on the corpuscles."
>
> – JJ Thomson on the Plum Pudding Model (1899)

He discovered the electron in 1897. He was also a gifted teacher, and seven of his research assistants and his son won Nobel Prizes in physics.

8.1.1 Corpuscles and Thomson's Plum Pudding Model

Thomson posited something which behaves as if it had a positive charge.

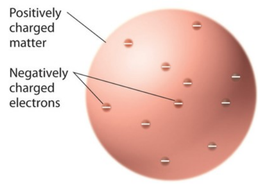

Figure 8.1: An Image of a Corpuscle

But he was certain about the overall system, namely the atom is a spatial domain filled with numerous negative corpuscles whose total charge is neutralised somehow by the spatial positive electrification.

Between 1904 and about 1910, Thomson's model of the atom was generally accepted as the best available atomic theory.

It became popularly known as the **plum-pudding atomic model**.

Figure 8.2: Traditional British Plum Pudding

Despite its name, this pudding contains raisins rather than plums. According to Thomson's theory of 1906, the electrons revolve on rings about the centre of the atom.

8.1.2 Electrons

The electron is the lightest stable subatomic particle known. It carries a negative charge which is considered the basic charge of electricity.

An electron is nearly massless. It has a rest mass of 9.1×10^{-28} gram, which is only 0.0005 the mass of a proton.

The electron was the first subatomic particle discovered. It was identified in 1897 by J.J. Thomson during investigations of cathode rays. His discovery of electrons, which he initially called corpuscles, played a pivotal role in revolutionizing knowledge of atomic structure.

8.2 Wilhelm Röntgen

Wilhelm Conrad Röntgen was born on 27 March 1845, at Lennep in the Lower Rhine Province of Germany. Röntgen, professor of physics at the University of Wurzburg, discovered X-rays while experimenting with high-voltage electricity.

Working in his darkened lab, he sent an electric current through a cathode ray vacuum tube. Out of the corner of his eye, he glimpsed a bright, greenish-yellow glow on a piece of paper on a nearby bench. He concluded that a new type of ray was being emitted from the tube.

Figure 8.3: An X-ray of Anna Bertha's Hand

Röntgen found that the new ray could pass through most substances casting shadows of solid objects. He also discovered that the ray could pass through the tissue of humans, but not bones and metal objects.

One of Röntgen's first experiments late in 1895 was a film of the hand of his wife, Anna Bertha. (Hands were a popular subject of early X-rays.)

Schuster recognised the medical value of X-rays.

The potential medical applications are why Röntgen decided not to patent X-rays.

Early X-rays were called:

1. Radiographs
2. Roentgenograms
3. Roentgenographs

X-rays quickly proved useful as a diagnostic and therapeutic tool as it allowed physicians their first look inside the body without surgery.

8.2.1 First Dental X-Ray

Fourteen days after Röntgen's first publication on X-ray (28 December 1895), Otto Walkhoff captured the first dental X-ray of his own teeth. He asked Fritz Giesel, a professor of physics to assist him – he experienced a 25-minute exposure.

> "I felt tremendously happy when I saw the results. It was when I weighed up the importance of Röntgen's discovery for future dentistry."
>
> – Fritz Giesel

Fritz Giesel eventually lost his hair. Today, the exposure to X-ray in in the order of milliseconds.

In the early days of X-ray, the exposure of 25 to 30 minutes. Patients suffered the after effects of the exposure in the following forms:

loss of hair, skin burn, skin blisters, fingernail growth stopped, bloodshot eyes, impaired vision, dermatitis, itching of the skin, basal cell carcinoma, metastatic carcinoma.

8.2.2 Émil Herman Grubbé

In 1896, barely a year after Röntgen had discovered his X-rays, a 21-year-old Chicago medical student, Emil Grubbé, had the inspired notion of using X-rays to treat cancer.

Grubbé had worked in a factory in Chicago that produced X-ray tubes, and he had built a crude version of a tube for his own experiments.

Having encountered X-ray, exposed factory workers with peeling skin and nails – his own hands had also become chapped and swollen from repeated exposures – Grubbé extended the logic of this cell death to tumours.

In 1896, in a tube factory in Chicago, Grubbé began to bombard Rose Lee, and elderly woman with breast cancer, with radiation, using an improvised X-ray tube.

Lee's cancer had relapsed after a mastectomy, and the tumour had exploded into a painful mass in her breast.

The tumour ulcerated, tightened, and shrank, producing the first response in the history of X-ray therapy. A few months after her initial treatment, the cancer metastasized to her spine, brain and liver.

X-rays could only be used to treat cancer locally, with little effect on tumours that had already metastasized.

A new branch of cancer medicine, radiation oncology, was born. Grubbé succumbed to the deadly effects of chronic radiation. By the mid-1940s, his fingers had been amputated one-by-one to remove necrotic and gangrenous bones, and his face was cut up in repeated operations to remove radiation-induced tumours and premalignant warts. In 1960, he died in Chicago, with multiple forms of cancer that had spread throughout his body.

8.3 Ernest Rutherford

Ernest Rutherford was born on August 30, 1871 at a small town called Bridgewater near Nelson in New Zealand's South Island.

he was able to win another scholarship to study from 1890 to 1894 and joined Canterbury College of the University of New Zealand in Christchurch.

He got his bachelors degree in 1892 and masters degree in 1893.

At this point Rutherford set his eyes on getting a scholarship of the Royal Commissioners for the Exhibition of 1851, which would enable him to study anywhere in the British-ruled countries.

This was not easy as only one scholarship was given every two years to a New Zealand student who had to be on the roll in the University at the time of applying for it.

Therefore Rutherford went back to Canterbury College in 1894 and completed BSc degree with geology, chemistry and some research work.

Rutherford decided to work with J.J. Thomson, who was then the Director of Cavendish Laboratory at Cambridge University.

Rutherford left New Zealand in 1895 and joined J.J. Thomson. He became the first non-Cambridge graduate to be admitted for PhD at Cambridge University.

Rutherford discovered alpha and beta rays in 1898.

Rutherford accepted an invitation to the Macdonald Chair of Physics (1898-1907) at McGill University in Montreal, Canada, and moved there without completing the PhD degree.

8.3.1 Discovering Half-Lives

Working with Frederick Soddy in 1902-03, Rutherford identified the phenomenon of radioactive half-life and formulated the still-accepted explanation of radioactivity: each decay of the atoms of radioactive materials signifies the transmutation of a parent element into a daughter, with each type of atom having its own transformation period.

A succession of such transformations forms a radioactive series.

8.3.2 Geiger-Marsden Experiments

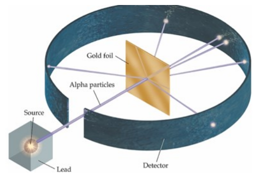

Figure 8.4: Setup of a Typical Geiger-Marsden Experiment

These experiments provided the first experimental evidence that led to the discovery of the nucleus of the atom as a small, dense, and positively charged atomic core. The discovery involved a series of experiments performed by Hans Geiger and Ernest Marsden under Ernest Rutherford.

With Geiger and Marsden's experimental evidence, Rutherford deduced a model of the atom, discovering the atomic nucleus. His "Rutherford Model" (or solar system model, or planetary model), outlining a tiny positively charged atomic centre surrounded by orbiting electrons, was a pivotal scientific discovery revealing the structure of the atoms that comprise all the matter in the universe.

8.3.3 Atom Interior

The experimental evidence involved the scattering of a particle beam after passing through a thin gold foil obstruction. The particles used for the experiment – alpha particles – are positive, dense, and can be emitted by a radioactive source.

Ernest Rutherford discovered the alpha particle as a positive radioactive emission in 1899. As these alpha particles have a significant positive charge, any significant potential interference would have to be caused by a large concentration of electrostatic force somewhere in the structure of the atom.

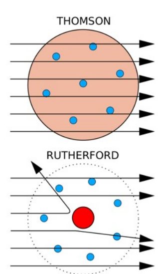

Figure 8.5: Electron Scattering

The scattering of an -particle beam should have been impossible according to the plum pudding model of the atom. This model held that atoms were comprised of a sphere of positive electric charge dotted by the presence of negatively charged electrons.

This model lacked the presence of any significant concentration of electromagnetic force that could tangibly affect any alpha particles passing through atoms. As such, -particles should show no signs of scattering when passing through thin matter.

8.3.3.1 Explanations

The alpha particles had run into huge concentrations of positive charge and were repelled. Rutherford explained that the atom composed almost entirely of empty space. It had no solid boundary and its outer limits were defined only by the movement of its outermost electrons, while at the centre lay the atomic nucleus.

> "…It was as if you fired a 15-inch naval shell at a piece of tissue paper and it came back and hit you. I realised that this scattering backwards must be the result of a single collision, and when I made calculations I saw that it was impossible to get anything of that order of magnitude unless you took a system in which the mass of the atom was concentrated in a minute nucleus"
>
> – Rutherford's Explanation

In relation to the atom, the nucleus was a mere speck in a cavernous void. The nucleus is so small that only 1 particle in 8000 would collide with it. It was like a fly in a cathedral.

8.3.4 In the Cavendish Laboratory

After the war, in 1919, Rutherford moved to Cambridge University, succeeding J.J. Thomson, as Cavendish Professor of Physics and the Director of the Cavendish Laboratory. Soon, he found that nuclei can be disintegrated artificially by bombarding with alpha particles, and thus cause transmutations. By this means he converted nitrogen nuclei into oxygen nuclei.

> "He (Rutherford) had … a volcanic energy, interest, enthusiasm and an immense capacity for work. He had the most astonishing insight into physical processes, and in a few remarks he would illuminate a whole subject. There is a stock phrase-'to throw light on a subject'. This is exactly what Rutherford did. To work with him was a continual joy and wonder. He seemed to know the answer before the experiment was made, and was ready to push on the irresistible urge to the next. (He was nicknamed 'crocodile', which cannot turn its head…must always go forward with all devouring jaws open.) He was indeed a pioneer – the word he often used – at his best exploring an unknown country, pointing out the really important

> features and leaving the rest for others to survey at leisure. He was, in my opinion, the greatest experimental physicist since Faraday.
>
> In appearance Rutherford was more like a successful businessman or Dominion farmer than a scholar ... he was of massive build, had a moustache and a ruddy complexion. He wore lose, rather baggy clothes, except on formal occasions. A little under six feet in height, he was noticeable but by no means impressive. It seemed impossible for Rutherford to speak softly.
>
> His whisper could be heard all over the room, and in any company he dominated through the sheer volume and nature of his voice, which remained tinged with antipodean flavour despite his many years in Canada and England. His laughter was equally formidable. Rutherford would not hesitate making fun of the Nobel Committee decision to choose him for the Chemistry Prize instead of the Physics Prize."
>
> – James Chadwick on Ernest Rutherford

He won the 1908 Nobel Prize in Chemistry for his "investigations into the disintegration of the elements, and the chemistry of radioactive substances."

8.3.5 Rutherford's Death

Rutherford died on 19 October 1937 in Cambridge. His ashes were buried in Westminster Abbey close to the tombs of Sir Isaac Newton and Lord Kelvin.

8.4 The Curies

> "Sometimes, I had to spend a whole day mixing a boiling mass with a heavy iron rod nearly as large as myself. I would be broken with fatigue at the day's end. Other days, on the contrary, the work would be a most minute and delicate fractional crystallization, in the effort to concentrate the radium.
>
> Our precious products ... were arranged on tables and boards; from all sides we could see their slightly luminous silhouettes, and these gleamings, which seemed suspended in the darkness, stirred us with ever new emotion and enchantment."
>
> – Marie Curie in her autobiography

Awarded a combined total of six Nobel Prizes, the celebrated Curie family's collective work and momentous achievements alone make their lives fascinating. But the lesser-known side of their story includes the controversy, the drama, the scandal, and the tragedy that surrounds them.

Now, the first full-scale biography of the Curies provides a well-rounded, honest look at both the private and professional lives of the world's most gifted scientific family.

8.4.1 Pierre Curie

Pierre was born in Paris on 15 May 1859. He was the second son of Eugène Curie and Sophie Claire Depouilly (his elder brother was Jacques).

His grandfather, Paul François Curie, had been a surgeon in the Military Hospital of Paris. Disenchanted with conventional medicine, he pioneered a new system of healing, called homeopathy, writing a book about it, entitled, Practice of Homeopathy.

His father, Eugène Curie was a doctor. His mother, Sophie Claire Depouilly was the daughter of a once wealthy cloth manufacturer in Puteaux.

Pierre's parents, and later, his brother, taught him at home. Throughout the elementary and high school years, they gave him a grounding in biology, chemistry, physics and geometry. He made up for his lack of schooling in literature and history by reading many of the books in his father's large library. Pierre could only learn a subject thoroughly by intense concentration, which he found impossible in a disturbing environment.

When Pierre was fourteen, his father realised that he was exceptional at math, especially spatial geometry, and hired Professor Albert Bazille to teach him advanced mathematics.

Bazille inspired him to such intense effort that despite his early casual home schooling, he matriculated at the prestigious Sorbonne at 16. There, in just two years, he got a degree in physics. Then at 18, because his financial help was needed at home, instead of pursuing a doctorate, he began to work as a physics lab assistant at the Sorbonne. Jacques was already employed as an assistant in the mineralogy department.

As a pacifist, having seen the horrors of war, Pierre avoided military service by agreeing to spend ten years working in public education – something he had already started to do as a lab assistant. He liked reading novels. Pierre and Jacques already knew that crystals heated in a fire attracted ash and wood to their surfaces like magnets.

Kelvin had also discovered that when certain crystals were heated, they generated electricity – this was known as pyroelectricity. The two brothers proved that pressure on some crystals had the same effect.

8.4.2 Discovering the Piezoelectric Effect

Jacques and Pierre Curie announced their discovery of the piezoelectric (from the Greek piezine, 'to press') effect to the French Academy of Science on 2 August 1880. Today, piezoelectric devices are ubiquitous. E.g., all quartz watches and clocks are based on piezoelectricity.

> "Their experiment led the two young physicists to a great success: the discovery of the hitherto unknown piezoelectricity, [...]. This was by no means a chance discovery. It was the result of much reflection on the symmetry of crystalline matter which enabled the brothers to foresee the possibility of such polarization. [...] With experimentation rare for their age, the young men succeeded in making a complete study of the new phenomenon, established the conditions of symmetry necessary to its production in crystals, and state its remarkably simple quantitative laws, as well as its absolute magnitude for certain crystals."
>
> – Marie Curie

The use of the phenomenon outside the laboratory began 35 years after its discovery during the first world war, in a search for a device to detect German submarines. The sonar, the product of this research, was put into use only after the war had ended.

8.4.3 Marie Salomea Sklodowska

Marie was born in Warsaw on 7 November 1867. Her parents, Vladislav and Bronislava, already had three daughters (Sophie, Bronia and Hela) and a son (Joseph). They grew up in a police state under the autocratic Russian Czar Alexander II. He was determined to enslave the intellectual and middle-class Poles who had opposed his rule, and to eradicate their language, culture, and history. Russian became the official language, Russian officials and teachers replaced the Poles, and Poland disappeared from maps to reappear as Vistula Land or Vistula Country. She danced joyfully in the classroom after hearing that Czar Alexander II had been killed by an assassin on 13 March 1881.

Marie's father was a professor and assistant principal of a boy's school, taught physics and mathematics, which he loved. Her mother was a headmistress and director of a prestigious girls' boarding school.

He established a boys' boarding school in the family home, taking in two or three boarders at first, then five, eight, ten. He gave lodging, food, and private instruction to these young boys, chosen from among his pupils. The house was transformed into a noisy barracks and intimacy vanished from family life.

When Marie was nine, one of the boarders caught typhus and 14-year-old Sophie was infected with the disease, which killed her. Marie was stunned by the death of her brilliant and high-spirited sister.

At ten, Marie left home to attend a private boarding school. Her teacher Mlle Antonina Tupalska, who doted on her, taught Polish history in Polish – a practice forbidden by the Russian authorities. Although Marie was two years younger than most of her 24 classmates, she beat them all in history, literature, German, and French.

8.4.4 Marie as a Governess

After a year, Marie decided to leave home to be a governess in a lawyer's family. It was a bad experience for her as she did not get along well with the wife.

Bronia wanted to study medicine in Paris, and raised enough money for the journey and tuition. But when she reached Paris, she hadn't enough money to survive on even in the inexpensive Latin Quarter. Marie, too, wanted to study in Paris, and so they made an agreement. Marie would accept another job, also as a governess. From her salary, she promised to subsidize Bronia until she graduated and got a job as a doctor. Then the roles would be reversed.

> "Today we had another scene because she did not want to get up at the usual hour. In the end, I was obliged to take her calmly by the hand and pull her out of bed. I was boiling inside. You can't imagine what such little things do to me: such a piece of nonsense can make me ill for several hours. Bur I had to get the better of her."
>
> – Marie Curie

Her experience in the Zorawski house was much better. Most evenings were devoted to her own studies – literature and sociology – but eventually, she decided that if she ever got to Paris she would focus on mathematics and physics.

8.4.5 Casimir Zorawski

Marie fell in love with Casimir Zorawski, the eldest son of her employers. He asked her to marry him, and she expected his family to be pleased. But when Casimir asked for his parents' approval to marry Marie, his parents disapproved. The idea of their son marrying a poor working woman was intolerable. In one instant, the social barriers went up, insurmountable.

The fact that Marie was of good family, that she was cultivated, brilliant, and of irreproachable reputation, the fact that her father was honourably known in Warsaw – none of that counted. One does not marry a governess!

> "If men don't want to marry poor young girls, then let them go to the devil!"
>
> – Marie to Joseph in writing

Subjected to his parents' disapproval, Casimir did not fight for the woman he loved. Heartbroken and humiliated, Marie wanted to leave immediately, but she remembered the pact she made with her sister – to send almost half her salary to support Bronia's studies in Paris. So she continued on as the family's governess, trying hard to hide her anger and bitter disappointment.

> “Everybody says I have changed a great deal, physically and spiritually, during my stay in Szczuki. This is not surprising. I was barely eighteen when I came here and what have I not been through! There have been moments which I shall certainly count among the most cruel of my life. I feel everything very violently, with a physical violence, and then I give myself a shaking, the vigor of my nature conquers, and it seems to me that I am coming out of a nightmare [...] First principle: never to let one’s self be beaten down by persons or events. I count the hours and days that separate me from the holidays and my departure to my own people. There is also the need of new impressions, of change, or movement and life, which seizes me sometimes with such force that I want to fling myself into the greatest follies, if only to keep my life from being eternally the same. Fortunately, I have so much work to do that these attacks seize me pretty rarely.”
>
> – Marie to Henrietta in writing

8.4.6 Improving Finances

On the home front, there were developments. Her father took on a job as director of a reform school near Warsaw. It paid well, and he was able to help Bronia and Marie.

Bronia told their father that she could live on 32 rubles a month and to save eight of the forty he usually sent her, and give to Marie instead, which he did. For the first time, Marie was able to save toward her future life in France.

In July 1890, Marie left the Zorawskys, and began planning for her own future. Her next job was with the Fuchs family.

> “I dreamed of Paris as of redemption, but the hope of going there left me a long time ago. And now that the possibility is offered to me, I do not know what to do ... I am afraid to speak of it to Father. I believe our plan of living together next year is close to his heart, and he clings to it; I want to give him a little happiness in his old age. And on the other hand my heart breaks when I think of ruining my abilities, which must have been worth something.”
>
> – Marie in writing

Marie had worked for less than a year when Bronia informed her that they would soon graduate as doctors, after which they intended to marry. If Marie could save a few hundred rubles to pay for her fees at the Sorbonne, she could then live with them for free, meals included.

8.4.7 Marie's Third Job as a Governess

> "Marie has a secret about her future, of which she is to speak to me at length … To tell you the truth, I can well imagine what it has to do with, and I don't myself know whether I should be glad or sorry. If my foresight is accurate, the same disappointments, coming from the same person who have already caused them to her, are awaiting her. And yet if it is a question of building a life according to her own feeling, and of making two people happy, that is worth the trouble of facing them perhaps. Your invitation to Paris, which fell upon her in such unexpected fashion, has given her a fever and added to her disorder … If she does not come back to me completely cured, I should oppose her departure, because of the hard conditions she would find herself in during the winter in Paris … without ever mentioning the fact that it would be very painful for me to separate from her, but this consideration is obviously secondary. I learned with great joy that Casimir (Bronia's husband) is doing well . How funny it would be if each of you had a Casimir."
>
> – Letter from father to Bronia.

During their walks in the mountains, Casimir merely repeated that he could not overcome his snobbish parents' opposition. And Marie made the final break with her parting shot, telling him that if he couldn't resolve the problem, it was not for her to teach him how to do it.

> "It would restore me spiritually after the cruel trials I have been through this summer which will have an influence on my whole life … I am so nervous at the prospect of my departure that I cant speak of anything else until I get your answer … I promise that I shall not be a bore or create disorder. I implore you to answer me, but very frankly."
>
> – Marie Curie

As Casimir was a lost cause, Marie wrote to Bronia (now married and pregnant) telling her that she would join her in Paris if her sister could feed her without depriving herself.

8.4.8 Inadequate Academic Grounding

Bronia and her husband were at Gare du Nord to receive Marie when she arrived in Paris. She began her studies at the Sorbonne's Faculty of Sciences on 3 November 1891, one of only 23 women among 1,825 students. Men outnumbered women almost a hundred to one.

To her dismay, her French failed her when a professor spoke quickly, and she could not grasp entire sentences. In addition, the physics and mathematics she had studied alone or in correspondence with her father was not up to the standard of her classmates education in French schools.

Marie took her physics exam in July 1893, and got the highest score.

Never before in the history of the Sorbonne, had a woman, and a foreigner, top the physics class. Marie was eager to return to the Sorbonne to get a master's degree in math. But her savings were exhausted, her father had already sacrificed too much, and Bronia, with a young child, couldn't be expected to extend their help for another year.

The Alexandrovitch Scholarship Fund came to the rescue with 600 rubles, enough to support her in Paris until she got a math degree.

8.4.9 Meeting Pierre

> "Marie was hired by the Society for the Encouragement of National Industries to test the magnetic properties of various steels. But the Sorbonne's crowded physics lab hadn't room for the equipment she needed for the tests. A friend, Professor Kowalski, who had known her since her days as a governess in Poland invited her to meet someone he thought could help her."
>
> -– Pierre Curie.

After meeting at Joseph Kowalski's apartment, they met again at the French Society of Physics, and at his lab.

Pierre completed his doctoral thesis in March 1895, titled "Magnetic Properties of Bodies at Diverse Temperatures". After this, he persuaded Marie to marry him.

The were married on 26 July 1895 at Sceaux's town hall. On 12 September 1897, Dr. Eugene Curie delivered Irène Curie. Late in 1897, Marie decided not to seek a teaching job right away, but to study for a doctorate. If successful, she would be the first woman in France, and possible the whole of Europe, with a Ph.D. in physics.

8.4.10 PhD Topics

The Curies agreed that a fundamental study of the nature of uranium would be an engrossing subject for Marie's PhD thesis. Professor Gabriel Lippman delivered her first paper on her research at the weekly meeting of the French Academy of Sciences, on 12 April 1898, titled, "Rays Emitted by Compounds of Uranium and of Thorium".

Marie was intrigued by the erratic results from testing pitchblende. She found that its radioactivity was four times more intense that justified by its uranium content. She repeated her experiment 20 times, but got the same results.

She suspected that she had found a new element.

> “The radiation from pitchblende that I couldn’t explain comes from a new chemical element. The element is there and I’ve got to find it. We are sure!”
>
> – Marie in writing to Bronia

At last, she found an element 150 more active that uranium. She called it polonium, after Poland. Henri Becquerel presented their report to the Academy, “On a New Radioactive Substance Contained in Pitchblende.”

Impressed by Marie’s research, the Academy of Sciences awarded her the Gegner Prize, but because its member were male chauvinists, did not tell her.

Instead, Pierre was asked to inform her that she had won the prize and with it, three thousand eight hundred francs. From barium, they isolated an element which was 900 more radioactive than uranium. They named this project radium. To isolate radium, they had to work with several tons of pitchblende from a mine in Jachomov (Czech Republic).

Pitchblende is one of the most complex minerals, containing up to 30 different elements, combined in a great variety of ways. In addition, the Curies were not trained chemists – yet they were not discouraged.

8.4.11 Finding Actinium

While working on pitchblende in 1899, André-Louis Debierne discovered actinium, a rare, highly radioactive silvery-white metal that also glowed blue in the dark.

Scientists began to notice the effects of radioactive material. They gave a glass tube of radioactive barium to Becquerel, who kept it in his waistcoat for about six hours. This caused a burn on his skin the shape of the glass tube. Yet he felt no burning sensation.

When young chemist Bertrand Goldschmidt arrived for an interview in June 1933, she told him in a strong Polish accent, ‘for a year or two, you will be my slave in chemistry and do everything for me’.

He was in awe of this ‘rather small old lady with big hairs on her chin, who looked much older than her sixty-five years’.

He was fascinated by the stories still circulating of a once-active love-life. There were ‘many rumours’, including that Eve Curie, born in 1904, and with her blue eyes and dark hair so different from her older, fairer sister, was not Pierre Curie’s daughter, ‘but André Debierne’s’.

8.4.12 Dangers of Radioactivity

> "If one leaves a small glass ampulla with several centigrams of radium salt in one's pocket for a few hours, one will feel absolutely nothing. But in 15 days afterwards redness will appear on the epidermis, and then a sore, which will be very difficult to heal. A more prolonged action could lead to paralysis and death."
>
> – Pierre Curie in his Nobel Prize Lecture

Pierre personally confirmed the possibly dangerous effect by intentionally inducing a burn on his own arm with radioactive barium. It took fifty-two days to heal, leaving a gray spot he believed indicated a deeper injury. Both he and Marie had already noticed that handling containers of radioactive material caused their fingertips to become hard and painful for as long as two months. It was clear that radium was a health hazard.

Doctors started to experiment with radium. It reduced their patients' tumours, lesions, and some kinds of cancer. This radium treatment became known as Curie-therapy.

8.4.13 The Spirit World

Pierre and Jacques had already been interested in the paranormal. This interest was fuelled by their friendship with William Crookes, an independently wealthy British chemist.

In 1905, Pierre renewed his interest in the supernatural. He once told Marie that he thought that some aspects of spiritualistic phenomena "touch closely on physics." On 24 July, he persuaded Marie to attend a demonstration by Italian medium, Eusapia Palladino, an "ignorant, invalid woman of thirty who apparently is capable of defying natural laws. She floated in the air as if flying on a couch, then slowly descended to the floor.

On 17 April 2010, Palladino was exposed as a fraud during a séance in New York – at that séance, two men in black tights crawled under the chairs in the darkness and caught her trying to lift a table with her foot.

She angrily told the investigators that it was up to them to stop her from cheating, her usual response after being caught in the act.

The dean of the University of Geneva attempted Pierre with an offer of an idyllic life in the Swiss mountains, his own laboratory equipped with anything he wanted, two full-time assistants, a generous salary of ten thousand francs, and an allowance for his residence. Marie was also promised an undefined position in the university.

They visited the university and were impressed. Their current income, augmented by grants and prize money, were not even enough to meet their frugal lifestyle. This offer would solve their financial problems.

8.4.13.1 A Counteroffer from France

Henri Poincare pulled strings, and Pierre was offered a minor teaching position at the School of Physics, Chemistry and Natural Science. Marie was offered a part-time teaching position at the Sevres, a teachers college for women in a Paris suburb.

They then rejected the Swiss offer, deciding that it would disrupt and delay their work on radium. Instead, they accepted the teaching positions, although that too, would delay their research (but not as badly).

Marie's early classes were a disaster! The students ridiculed her Polish accent.

8.4.14 Radiation

> '...radioactivity "seemed to violate the first law of thermodynamics, i.e., energy can be converted from one form to another but cannot be created of destroyed." '
>
> – the Curies

In 1900, the Curies produced a detailed report on radioactive substances for the International Congress of Physics, held in Paris.

> "One may also imagine that in criminal hands radium may become very dangerous, and here we may ask ourselves if humanity has anything to gain by learning the secrets of nature, if it is ripe enough to profit by them, or if this knowledge is not harmful. One example of Nobel's discoveries is characteristic: power explosives have permitted men to perform admirable work. They are also a terrible means of destruction in the hands of the great criminals who lead the peoples towards war. I am among those who think, with Nobel, that humanity will obtain more good than evil from the new discoveries."
>
> – Pierre Curie

In 1901, they wrote a joint paper with Debierne, "On Induced Radioactivity and the Gas Activated by Radium".

They mentioned "the deplorable situation in the lab, where everything has become radioactive. This does not seem to us to be explained by the direct radiation of radioactive dust spread about the lab. It is probably due ... to the continual formation of radioactive gas."

Pierre was able to show that this gas was largely responsible for radium's intense radiation.

8.4.14.1 Competition in Research

> "I have to publish my present work as rapidly as possible in order to keep in the race. The best sprinters in this road of investigation are Becquerel and the Curies in Paris, who have done a great deal of very important work in the subject of radioactive bodies during the last few years."
>
> – Ernest Rutherford

On 28 March 1902, they produced enough pure radium, and brought it to Eugene Demarcay, asking him to weigh it. The atomic weight was found to be 225.93, remarkably close to today's value of 226. This was the evidence that was needed.

> "Their discovery of radium opened the doors to twentieth-century physics. Scientists now had a powerful source of radiation. Its study would enable them to witness for the first time the manifestation of atomic energy. Radium was the key to unlock the mystery of the composition of the universe, for it would help them explore and understand the structure of the atom, the base of all matter on earth."
>
> – Pflaum

> "It may have an importance for the future of civilization comparable to that which allowed man to discover the power of fire."
>
> – Paul Langevin

It had taken them four exhausting years to produce, a process they had expected to take a few weeks!

Marie's father congratulated her, but expressed his disappointment that the work seemed to have no practical value!

The Curies could have become rich by patenting the process of producing radium. Factories were already preparing to exploit it, but they decided to give it to the world. They had discussed how the prospective money could provide for Irene's future, making their life easier, and allow them to build the laboratory of Pierre's dreams. But they decided that taking financial advantage of their discovery was against the scientific spirit, especially as radium might be used to fight disease. Consequently, one Sunday morning, Pierre wrote to the American engineers who had asked for details about radium production and gave them all the answers.

Thirty-six year old Marie, three months pregnant with her second child, defended her dissertation on radium at the Sorbonne. Bronia, Pierre and his father were there. Close friends like Kean Perrin and Paul Langevin was also there. Gabriel Lippmann, Henri Moissan, Edmond Bouty.

8.4.14.1.1 Marie's Miscarriage

> "Write to me, I beg of you, if you think I should blame this on general fatigue – for I must admit that I have not spared my strength ... and I regret this bitterly, as I have paid dearly for it. The child – a little girl – was in good condition and was living. And I had wanted it so badly."
>
> – Marie in writing

In early August 1903, during the fifth month of her pregnancy and while vacationing at Saint-Trojan, Marie miscarried and was devastated. She wrote to Bronia: I had grown so accustomed to the idea of the child that I am absolutely desperate and cannot be consoled.

8.4.15 Nomination for Nobel Prize

Pierre and Marie had been nominated by the French pathologist Charles Bouchard for the physics prize the first year it was awarded, 1901. That year, it was awarded to Röntgen.

The following year, they were nominated again, but it went to Dutch physicists, Hendrik Lorenz and Peter Zeeman.

In 1903, they were told they were on the shortlist for the Nobel Prize.

There was an attempt to prevent Marie from getting the Nobel Prize. In researching the early history of the Nobel Institution, Elisabeth Crawford found that Gabriel Lippman, Jean-Gaston Darboux, Eleuthere Mascart and Henri Poincare, all members of the French Academy of Sciences, had signed a joint letter to the Nobel Prize selection committee.

In it, they credited Pierre Curie alone with isolating polonium and radium and described Pierre and Becquerel as competing with foreign rivals for the radium supply and obtaining the "precious material" with great difficulty.

They had concluded that because Pierre and Becquerel had studied together it was impossible "for us to separate the names of two physicists and therefore we do not hesitate to propose that the Nobel Prize be shared between Mr. Becquerel and Mr. Curie.

Lippmann and Poincare knew that Marie and Pierre had isolated polonium and radium as a team, with her, in the lead.

Magnus Mittag-Leffler, Swedish mathematician and a member of the Nobel Prize nominating committee came to her rescue when he learnt of the plot against her.

The Nobel committee agreed to split the 1903 prize three ways, between Becquerel and both Curies. The plot to exclude Marie was foiled. They were informed on 14 November 1903.

But radioactivity research involved both physics and chemistry. For which category should the award be given? The committee finally decided on physics, leaving open the possibility of a future Nobel Prize in chemistry in connection with radioactivity. This is how Marie Curie became the only woman scientist ever to win two Nobel Prizes, and for almost the same work!

As Marie was too ill, and Pierre had teaching commitments, the did not attend the ceremony in Stockholm on December 10. The King of Sweden handed the medal to their representative, French minister Jean-Baptiste Marchand. The president of the Swedish Academy of Sciences summarised the work of Becquerel and the Curies.

The response of Le Figaro was to admonish the French people for not knowing who their great scientists were, and for leaving it to foreigners to discover them.

The Nobel prize money arrived on 2 January 1904, and allowed Pierre to follow a less rigorous schedule. Though Marie continued to teach at Sevres, which she enjoyed, she insisted that Pierre quit his onerous teaching chose at the School of Physics and Chemistry. He was replaced by his friend and former student, Paul Langevin.

Marie lent 20,000 francs to Bronia to sustain their tuberculosis sanatorium. She paid for Mme Mozlovka's visit to her birthplace, Dieppe. Mme Mozlovka was Marie's childhood teacher. Who had long dreamed of revisiting her birthplace.

8.4.15.1 Second Nobel Prize

Sick, worn, and worried, Marie Curie made the exhausting forty-eight-hour journey to Sweden, comforted by the presence of her sister Bronia and daughter, Irene. On 11 December 1911, Marie delivered her Nobel lecture titled, "Radium and the New Concepts in Chemistry".

Far from being defeated, Marie was acclaimed and revered throughout the rest of the world as a unique two-time Nobel Prize winner. She continued to lecture at the Sorbonne and to work in her laboratory. And all her friends, including Langevin, stuck with her.

8.4.16 International Fame

A day after the ceremonies, a desperate Marie write to her brother that they had been overwhelmed by hordes of photographers and journalists, and "would like to dig into the ground somewhere to find a little space."

In addition to journalists, eccentrics, inventors, beggars, autograph-hunters, and "snobs, worldly people and sometimes scientists have come to see us in the magnificent setting of rue Lhomond."

"With all this there is not a moment of tranquillity in the laboratory and a voluminous correspondence to be sent off every night. On this regime I can feel myself being overwhelmed by brute stupidity."

8.4.17 Marie's Working Conditions

> "At my earnest request, I was shown the laboratory where radium had been discovered shortly before .... It was a cross between a stable and a potato shed, and if I had not seen the worktable and items of chemical apparatus, I would have thought that I was been played a practical joke."
>
> – Friedrich Wilhelm Ostwald

With the press publicising the Curies' miserable working conditions in their cold, leaky, and ramshackle shed, the French government was shamed into creating a new professorship in physics for Pierre at the Sorbonne, with Marie as its laboratory chief and giving them two assistants.

In fact, there was no laboratory until eight years after Pierre's death – just a room shared with medical students and other researchers. Marie said, "One of the best French scientists never had a suitable laboratory at his disposition although his genius had been revealed from the age of twenty."

8.4.18 Loie Fuller

The Curies were friends with Loie Fuller, who was a dancer. Fuller admired the Curies, but also needed their expert advice. She had read that radium was luminous and planned to dance as a butterfly with the wings painted with radium.

When she asked the Curies about it, they warned her that it was dangerous, Undaunted, she experimented with phosphorescent salts, until an explosion blew off her eyebrows and eyelashes. Only then did Fuller give up the idea. Through Fuller, the Curies met Auguste Rodin.

8.4.19 Pierre's Death and Marie's Future

> "We kissed your cold face for the last time. Then a few periwinkles from the garden on the coffin and the little picture of me that you called "the good little student" that you loved.... Your coffin was closed and I could see you no more.... They came to get you, a sad company; I looked at them, and did not speak to them. We took you back to Sceaux, and we saw you go down into the big deep hole.
>
> Then the dreadful procession of people. They wanted to take us away. Jacques and I resisted. We wanted to see everything to the end. They filled the grave and put sheaves of flowers on it. Everything is over. Pierre is sleeping his last sleep beneath the earth; it is the end of everything, everything, everything."
>
> – Marie Curie in Writing

After working in the laboratory all morning, he braved the heavy rain, umbrella in hand, and travelled across Paris to his luncheon meeting. There he spoke forcefully on a number of issues that concerned him, including widening career options for junior faculty and drafting legal codes to help prevent laboratory accidents.

After the meeting was over he headed out toward his publisher in the rain, only to find that the doors were locked because of a strike. Hurrying to cross the street, he was run over by a horse-drawn wagon with a load of military uniforms, weighing some six tons. He was killed instantly.

Marie's indifference towards money did not apply to funding for scientific research. She welcomed the support of Andrew Carnegie, who met her briefly in Paris and donated fifty thousand dollars to help build and staff a laboratory for radioactivity research.

It was also to honour Pierre'smemory and to be known as the Curies Foundation, created by Andrew Carnegie, for which Marie should be in full control. With this new source of funding, Marie recruited a group of young scientists, especially women, to work for her.

In December 1910, Marie competed for membership in the French Academy of Sciences. This attracted press coverage as this would mean that they would have to break the tradition and allow a woman to join.

Most of the members voted to allow a woman to be a candidate and to challenge the two other aspirants – Edouard Branly and Marcel Brillouin. The votes were: Branly, 29, Curie, 28; Brillouin, 1.

Another vote was taken to decide whether a woman should ever be admitted. They voted 90 to 52 to bar them for eternity.

8.4.20 World War I

Determined to play an active role in the war, Marie offered her services to the president of the National Aid Charity, Paul Appell.

There was a critical shortage of X-ray equipment in Paris hospitals. Marie got permission from the War Minister, Alexandre Millerand, to try to solve the problem.

In an exhaustive tour of Paris, she collected unused X-ray equipment from various sources: university laboratories, offices of doctors, patriotic manufacturers of scientific instruments, and delivered them to the city's hospitals.

On September 2, expecting the city to fall within two days, the French government left for Bordeaux. German troops were within 30 miles of the city when the French government realised Marie's radium was a national asset, and instructed her to take it to Bordeaux for safety.

She left the radium at the University of Bordeaux's Faculty of Sciences, and returned to Paris on a military train the next day.

When Marie had taken X-ray equipment to Paris hospitals, she had learned that many wounded soldiers who might have survived were dying because it took too long to get them medical help.

The entire French army had only one mobile X-ray station, and few emergency stations at the battlefront had the electricity needed for X-rays. She transformed ambulances into mobile X-ray stations complete with electric power. A fleet of sixteen X-ray equipped ambulances was formed. To be more self-reliant, Marie learnt to repair as well as to drive the ambulance.

There was an appeal for gold and silver to pay for the war effort, and Marie offered her medals, including the Nobel Prize medal. Her offer was declined.

Then, after discussing it with Irene, she used most of her Nobel Prize money – Irene's future inheritance – to buy war bonds, knowing that at war's end they'd probably be worth much less.

Since the spring of 1919, the U.S. Army had been paying Marie $75 a week to teach American army officers waiting to be shipped home how to use X-ray equipment.

Irene's participation was an appeal for the soldiers, who, according to Marie, "studied with much zeal the practical exercises directed by my daughter." Despite a lack of makeup, a long-sleeved black smock down to her ankles, and a curt manner, 21-year-old Irene could not conceal her attractive green eyes and obvious intelligence.

8.5 Radium Girls

One application of radium is in radioluminescent paint, invented by William Hammer. Hammer discovered that by mixing the radium with glue and zinc sulfide, he could make glow-in-the-dark paint.

Radioluminescent paint first came into industrial use in 1917 when the Radium Luminous Material Corporation – later known as the United States Radium Corporation – developed a paint known as Undark, which used zinc sulfide crystals and radium salt and was the first radioluminescent paint.

In 1917, the Radium Luminous Material Corporation began producing luminous watch faces and clock dials using Undark in Essex County, New Jersey.

Factory workers wore no protective gear, and were instructed to lick the tip of their paintbrushes to create a fine point (a practice known as "tipping"). While they were assured that the paint was non-toxic, this claim proved to be tragically wrong.

Figure 8.6: Radium Girls in Action

Quick workers could make good money since the pay was determined by the number of dials painted. The best dial could paint about 250 watches a day, making nearly $25 a week.

The paint glowed in the dark because it was laced with a tiny amount of radium.

8.5.1 Amelia Maggia

She and two of her sisters worked as dial painters beginning in late 1917, painting 250 watches a day, and making nearly $25 a week.

The United States had entered World War I in April 1917, and many of the watches painted were destined for the wrists of soldiers on the front lines. Soldiers found wrist watches much more practical than picket watches. Dial painting paid well, and was patriotic!

Amelia developed a toothache, and a tooth extraction did not help. Amelia's health also began to deteriorate, and she was forced to quit her job in 1922.

Others soon began to complain of jaw pain, fatigue, and skin and tooth problems. In the late 1920s, medical investigations revealed that the bones in their jaws had necrosed, their tongues had been scarred by irradiation, and many had become chronically anaemic (a sign of severe bone marrow damage). Some women, tested with radioactivity counters, were found to be glowing with radioactivity.

8.5.2 Harrison Stanford Martland

The link between radium and the health problems of the dial painters was established in 1925, when Harrison Martland published his research linking radium to the deaths of some of the dial painters:

Martland, H.S., Conlon, P., Knef, J.P. (1925). Some unrecognized dangers in the use and handling of radioactive substances. Journal of the American Medical Association, 85(23), 1669–1776.

U.S. Radium refused to pay for the medical bills of the workers, and the only alternative was to sue the company.

8.5.3 Aftermath

In 1926, the factory workers brought a class-action lawsuit against the U.S. Radium, and in 1927 their main factory in New Jersey was forced to close under the burden of legal costs. The predominantly female factory workers became known as the "Radium Girls".

Amelia Maggia's body was exhumed in October 1927. The autopsy showed that her body was highly radioactive, and that there was no sign of syphilis. She had died from radium poisoning.

U.S. Radium used delaying tactics claiming that some of their witnesses were holidaying in Europe.

Walter Lippmann wrote that the delays were a "damnable travesty of justice … There is no possible excuse for such a delay. The women are dying. If ever a case called for prompt adjudication, it is the case of five crippled women who are fighting for a few miserable dollars to ease their last days on earth."

A year later, the case was settled out of court with a compensation of $15,000 to each of the girls, and $600 per year to cover living and medical expenses. the "compensation" was not widely collected. Many of the Radium girls, too weak even to raise their hands to take an oath in court, died of leukaemia and other cancers soon after their case was settled.

8.6 Radithor

The promoters of radium continued to do a roaring and deadly trade, particularly William J.A. Bailey, a Harvard drop-out who claimed to hold a doctorate from the University of Vienna. Bailey had been involved in a number of fraudulent business schemes prior to his foray into radium, but he finally hit jackpot with his patented radium-laced drink called Radithor.

Bailey bought radium from the U.S. Radium Corporation and mixed it with distilled water. He was able to sell more than 400,000 bottles of Radithor between 1925 and 1930, promoting it primarily as an aphrodisiac.

Radithor contained two radium isotopes, radium-226 (half-life of 1600 years) and radium-228, also called mesothorium (half-life of 6.7 years – highly active).

Radium is chemically similar to calcium, and a significant fraction is absorbed into the bloodstream and deposited mainly in the skeleton. The amount that remains in the body is called the "body burden," and is effectively an internal radiation source.

The diagnosis of radium poisoning on the basis of the detection of radon produced by the decay of radium.

8.6.1 Eben Byers

Eben Byers was the chairman of the board of the A.M. Byers Steel Company of Pittsburgh, and served on the board of several other Pittsburgh-based companies.

He was also an avid sportsman who in 1906 won the national amateur golf championship. In addition, he owned race horses and was a skilled trap shooter.

In 1927, Byers injured his arm on a train ride home, falling out of an upper sleeping car berth. The injury bothered him, and also affected his sex life.

Physiotherapist Charles C. Moyar, suggested that he might find relief by using Radithor. Byers began to drink several bottles every day, and initially, it seemed to help. He even became a Radithor endorser.

After two years, his jaw began to bother him, and he started to suffer from severe headaches. Later, he suffered from sinusitis and his teeth began to abscess.

A radiologist who examined his X-ray noticed there were similarities between Byer's jaw problems and those of the Radium Girls. Dr. Frederick B, Flinn, a Columbia University physiologist who worked on the Radium Girls case confirmed that Byers was dying of radium poisoning.

> "A more gruesome experience in a more gorgeous setting would be hard to imagine. We went up to South Hampton where Byers had a magnificent home. There we discovered him in a condition which beggars description. Young in years and mentally alert, he could hardly speak. His head was swathed in bandages.
>
> He had undergone two successive operations in which his whole upper jaw, excepting two front teeth, and most of his lower jaw had been removed. All the remaining bone tissue of his body was slowly disintegrating, and holes were actually forming in his skull."
>
> – Robert Hiner Winn

The once powerful, athletic man was a 93-pound skeleton. Most of his upper and lower jaw and part of his skull was removed in the hope of preventing the splintering and breaking of his bones.

The Federal Trade Commission began investigating some of the questionable claims made in Radithor advertisements. Byers was too ill to testify.

Byers died on March 30, 1932. He was 51 years old. An autopsy, as reported by Time Magazine, "revealed that he had only six teeth left. Both jaws were rotted. His brain was abscessed. Distributed through his bones ... were 36 micrograms of radium. Ten micrograms is a fatal quantity."

A 12 May 1932 headline from the New York Times noted a meeting of prominent doctors from around the world whose sole purpose was to ban radium water. Regulations were quickly adopted that killed off this dangerous industry.

Moyar and Bailey both questioned the diagnosis of radium poisoning. Both drank Radithor regularly and surprisingly never suffered any ill-effects.

Moyar lived to about age 62, and Bailey died at the age of 64 from bladder cancer. By 1930s standards, both of these men were relatively old when they died. When Bailey's body was exhumed 20 years after his death, it was found to be highly radioactive. Neither Moyar nor Bailey was ever prosecuted for their part in the demise of Eben Byers.

8.6.2 Revigator

The Revigator was intended to add radioactivity (radon) to drinking water.

Water without radioactivity was "devoid of its life element". Water without radioactivity was like air without oxygen.

8.7 Marie and Education

As the daughter of dedicated teachers, Marie had strong views on education. She believed that French schoolchildren were overworked and trapped for too many boring hours in badly ventilated classrooms. Instead of subjecting her daughter to that endurance test, she asked Dr. Curie and a succession of governesses to give both girls an hour of stimulating schoolwork in the morning and let them spend the rest of the day in the fresh air, gardening, walking, or exercising on the crossbar, trapeze, flying rings, and climbing rope that she had installed in the garden.

Marie solved the problem of education by persuading several Sorbonne professor friends to join in a unique experiment. To avoid sending their offspring to an uninspiring, underfunded, state-run school, they agreed to teach them in their own homes or laboratories.

Consequently, some ten boys and girls spent one day at a chemist's laboratory, the next in a mathematician's study, the third in the home of a historian, and so on – learning the subject from brilliant young men and women at the peak of their professions. At times, instead of going to classes, the children went to museums or art galleries.

Marie Mattingly Meloney, the editor of the Delineator, a popular women's magazine, was introduced to Marie, who expressed her frustration.

Marie and Irene were frustrated by the lack of modern equipment and a limited amount of radium. The one gram they had was in constant demand from doctors and medical researchers.

The United States had almost cornered the radium market, possessing some 50 grams with millions of dollars. And she knew where much of it was: 4 g in Baltimore, 6 g in Denver; 7 g in New York. Yet in the whole of France, there was only one gram of radium – and that was in her safe.

Marie's greatest wish was for another gram of radium to continue her researchers, but she couldn't buy it because it was too expensive. Meloney now has a story: Marie Curie has contributed to the progress of science and the relief of human suffering, and yet, in the prime of her life she is without tools which would enable her to make further contribution to her genius.

Within days of her return home, Meloney organised an advisory committee of scientists. As the appeal would be from women to women, she also formed another all-female committee to run the campaign under her direction.

Meloney also asked for one- or five-dollar donations from her readers. College women responded by taking up campus collections, and children who heard of the campaign from their mothers mailed in their nickels and dimes.

When Maloney told Marie that the $100,000 had been collected, Marie was expecting to stay in the US for two weeks, but Maloney urged her to emulate recent visitors, the kind and queen of Belgium, and to make it six, encouraging her to bring her daughters along.

8.7.1 Marie in America

Marie boarded White Star Line's Olympic at Cherbourg on 4 May 1921. She was escorted to the bridal suite she was to share with her daughters. The Olympic docked at New York City on 11 May, her first trans-Atlantic trip.

Excited fans waving American, French and Polish flags greeted her. The brass bands played three national anthems. Hundreds of women from the Polish American Society carrying red and white roses mobbed her along with a large contingent of Girl Scouts, members of scientific committees, and masses of other admirers.

Marie escaped into one of two limousines sent by Andrew Carnegie's widow, which took her and her entourage to Maloney's Greenwich Village home.

While discussing the several colleges that intended to award Marie honorary degrees, it was discovered that Marie did not have an academic gown. A nearby tailor took care of the problem.

She received honorary degrees from Smith College, Wellesley, Simmons, Radcliffe, and Bryn Mawr. Her schedule in the US was punishing.

The highlight of Marie's trip took place on the afternoon of 20 May, when she was received in the East Room of the White House in the presence of more than 100 eminent scientists and diplomats from Poland and France.

President Warren G. Harding presented her with a deed inscribed on a scroll tied with red, white, and blue ribbons and gave her a small, elaborate golden key to open the polished, lead-lined, ribbon-draped, steel box within a mahogany box containing the gram of radium, in 10 small tubes, weighing a total of 125 pounds.

The American tour had been an overwhelming success. The one disappointment was that the Manhattan eye specialist Meloney had recommended had not helped Marie, and because of her worsening cataracts she feared that she was going blind.

As she said good-bye to Maloney, she said "Let me look at you one more time, my dear, dear, friend. This may be the last time I will ever see you." And as they embraced, they wept. Entering her cabin on the new French liner, Paris, Marie found it was full of telegrams and flowers.

8.7.1.1 Marie's Second Trip to America

Meloney encouraged Marie to make a second trip to the US to raise money for the Polish Institute, which had no radium of its own, stressing that her presence was vital to its success and that she would be protected from an intrusive press.

Meloney accepted Marie's proviso that she would do none of the following – give autographs or interviews, sit for portraits, shake hands (with some exceptions), or attend large formal dinners or receptions – except for a banquet honouring Thomas Edison.

She was willing to make only four public appearances during her stay.

8.7.2 Marie Curie's Death

Arrangements were made for Eve to accompany Marie to the sanatorium and stay with her for several weeks. Marie's brother and sisters from Poland were willing to keep her company through July, when Irene would take over and spend August with her. By then, she was expected to be fit enough to return to Paris.

Eve and a nurse accompanied Marie on her journey south to Sancellemoz, near Annecy. On arriving at Saint-Gervais, she fainted in the arms of Eve and the nurse.

Professor Roch arrived from Geneva to examine her, and reported an extremely high temperature above 104 degrees, assured her that she would not have to face a gallstone operation, and diagnosed extreme pernicious anemia.

Then, in confidence, he told Eve that Marie's condition was hopeless. Determined at all cost to protect her mother from the fear that she was dying, she chose not to call the family to the bedside, and, to save her from additional suffering, vetoed any treatment that would only prolong the pain.

Marie Curie died on 4 July 1934.

As Marie would have had wished, there were no officials, priests, prayers, or politicians at her funeral; just her family, friends, and loving coworkers – among them Langevin, Regaud, the Perrin, and the Borels. She was buried at the cemetery in Sceaux above Pierre's coffin.

As her sister Bronia and brother, Joseph, threw earth from Poland into the open grave, they were watched at a distance by uninvited reporters who had climbed over a wall to watch the burial and refused Joliot's request for them to move away.

The ashes of Marie Curie were enshrined in the Pantheon in Paris on 20 April 1995, making her the first woman honoured at the memorial dedicated to the "great men" of France.

President Francois Mitterrand, who had ordered that the ashes of Marie Curie and her husband, Pierre Curie, be transferred from the Sceaux Cemetery to the majestic domed monument that also holds the remains of Frenchmen like Voltaire, Jean-Jacques Rousseau, Victor Hugo and Emile Zola. President Lech Walesa of Poland and 91-year-old Eve Curie, the couple's lone surviving daughter joined Mr. Mitterrand at the ceremony today.

8.7.3 About the Pantheon

The king had intended that it be a church, but, when it was completed in 1791 after the French Revolution, Genevieve's body was removed from it and burned. And the new French Parliament turned it into a secular necropolis, installing the body of Mirabeau as its first permanent resident.

During the rule of Napoleon Bonaparte and Napoleon III, the Pantheon was returned to service as a church. But since the transfer of Victor Hugo's body there in 1885, it has remained a mausoleum.

8.8 James Chadwick

He became fascinated with physics after attending Ernst Rutherford's lectures, and graduated with a first-class honours degree in 1911.

In 1913, he received his master of science degree, and was awarded an Exhibition of 1851 Senior Research Studentship. A condition of the award was that Chadwick work in another laboratory, and he chose to go to the Physikalisch-Technische Reichsanstalt near Berlin, to continue his studies of radioactivity with Hans Geiger.

Not long after he arrived, WWI broke out and Chadwick ended up spending the next four years as a prisoner!

This did not entirely stop his scientific studies. To keep from being bored, he and some fellow prisoners formed a science club, lectured to each other, and managed to convince the guards to let them set up a small lab.

Though many chemicals were hard to get hold of, Chadwick even found a type of radioactive toothpaste (containing thorium oxide) that was on the market in Germany at the time, and managed to persuade the guards to supply him with it. Using some tin foil and wood he built an electroscope and did some simple experiments. Very bad living conditions and poor nutrition left him with permanent digestion problems.

From 1919 to 1935, Chadwick worked at the Cavendish Laboratory of Cambridge University. Chadwick's most important scientific discovery was his identification of the neutron in 1932.

The neutron, which joined the electron and the proton as an elementary particle, has a mass almost equal to that of the proton, but has no charge. Its existence was predicted by Rutherford (as a combination of an electron and proton) in a 1920 lecture, and Chadwick soon came to share Rutherford's belief in it.

8.8.1 Discovering the Neutron

In 1930, Walther Bothe and Herbert Becker bombarded light elements with alpha particles from polonium, recording the results with a Geiger counter, and in certain cases, the counter registered the presence of very powerful rays.

Chadwick showed that the beryllium emission could not consist of gamma rays or any other electromagnetic waves. He proved that the experimental facts were consistent with the view that the emission was a beam of neutral particles. Later, he showed the neutron was an elemental particle rather than a combination of proton and electron.

Chadwick's discovery of the neutron not only explained the hitherto unresolved problem of just what particles composed the nuclei of atoms but also gave a powerful tool to explore the nature of these nuclei.

Starting in the mid-1930's, Enrico Fermi and his group in Rome used neutrons as projectiles, since they are not repelled by the electrical charge on nuclei, to bombard many elements toward the high end of the periodic table.

For his discovery, Chadwick was awarded the 1932 Hughes Medal of the Royal Society and the 1935 Nobel Prize for Physics.

In 1935, Chadwick accepted the Lyon Jones Chair of Physics at the University of Liverpool, where he had the opportunity to create his own laboratory and especially to realize his plan to build a cyclotron.

He was convinced that such a machine, which accelerates particles to great energies and then directs the beam upon a target, was necessary to be at the forefront of nuclear physics.

After World War II began, Chadwick was closely involved in nuclear research for military purposes and was influential in furthering the atom bomb projects of both the British government and the American government.

When the two allies joined their efforts, Chadwick became head of the British Mission in Washington, D.C., a critical administrative position. His remarkable friendship with the combined project's military commander, General Leslie Groves, an able but tactless man whom most scientists disliked, went far toward minimising the inevitable policy differences any two nations would have.

8.8.2 Discovering Neptunium

In 1940, Edwin McMillan and Philip Abelson demonstrated that when uranium-238 was bombarded with neutrons, a new element neptunium was produced (neptunium-239). These experiments were performed at the Berkeley Radiation Laboratory of the University of California.

8.8.3 Discovering Plutonium

In 1941, Glenn Seaborg, Joseph Kennedy, Arthur Wahl, and Emilio Segrè, building on the earlier work, isolated the daughter of neptunium-239, an element, also of mass 239. They then demonstrated that the isotope had the properties predicted by Turner – it underwent fission with slow neutrons with a greater cross-section than uranium-235, making it a potentially favourable material for an explosive chain reaction. The new element was named plutonium by its discoverers in 1942.

An article explaining the discovery was prepared by the team and sent to the Physical Review to be published in March 1941.

The paper was withdrawn after the subsequent discovery that an isotope of the new element, plutonium-239, could undergo fission and be used as fuel for an atomic bomb.

In 1946, it was published with a footnote: "This letter was received for publication on the date indicated but was voluntarily withheld for publication until the end of the war."