INSTITUTE OF CHEMISTRY CEYLON

CHEMISTRY in Sri Lanka

Volume 39 No. 02 October 2022

Themed Collection

ROLE OF BASIC SCIENCES FOR SUSTAINABLE DEVELOPMENT

IYBSSD2022
International Year of Basic Sciences for Sustainable Development

Neglected Treasure for a Better Future

Student Corner

The Tri Annual Publication of the Institute of Chemistry Ceylon

Chemistry in Sri Lanka ISSN 1012 - 8999

The Tri-Annual Publication of the Institute of Chemistry Ceylon

Founded in 1971, Incorporated by Act of Parliament No. 15 of 1972

Successor to the Chemical Society of Ceylon, founded on 25th January 1941

Vol. 39 No. 2 **October 2022**

Theme for the year -

Role of Chemist in Achieving Sustainable Development Goals

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Outline of our Institute

The Institute of Chemistry Ceylon is a professional body and a learned society founded in 1971 and incorporated by act of Parliament No. 15 of 1972. It is the successor to the Chemical Society of Ceylon which was founded in 1941. Over 50 years of existence in Sri Lanka makes it the oldest scientific body in the country.

The Institute has been established for the general advancement of the science and practice of Chemistry and for the enhancement of the status of the profession of Chemistry in Sri Lanka. The Institute represents all branches of the profession and its membership is accepted by the government of Sri Lanka (by establishment circular 234 of 9-3-77) for purposes of recruitment and promotion of chemists.

Corporate Membership
Full membership is referred to as corporate membership and consists of two grades: **Fellow (F.I.Chem.C.)** and **Member (M.I.Chem.C.)**

Application for non-corporate membership is entertained for four grades: Associate (former Graduate) (A.I.Chem.C.), Licenciate (L.I.Chem.C.), Technician (Tech.I.Chem.C.) and Affiliate Member.

Revision of Membership Regulation
All Special Degree Chemists can now apply directly to obtain Associate (Graduate) Membership. Three year B. Sc. Graduates (with an acceptable standard of Chemistry) can
(i) directly become Licentiate
(ii) obtain corporate membership in a lesser number of years.

Tech.I.Chem.C.
Those who have passed the DLTC examination or LTCC examination or have obtained equivalent qualification and are engaged in the practice of Chemistry (or chemical sciences) acceptable to the Council are entitled to the designation Tech.I.Chem.C.
Members/Fellows with Membership for Life are entitled to the designation of **Chartered Chemist (C.Chem.)** on establishment of a high level of competence and professionalism in the practice of chemistry and showing their commitment to maintain their expertise.

All corporate members (Members / Fellows) are entitled to vote and become Council/ Committee members whether Chartered Chemists or not.

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Any application for admission to the appropriate class of membership or for transfer should be made on the prescribed form available from the Institute Office.

Current Subscription Rates
Fees should be payed on 1st of July every year and will be in respect of the year commencing from 1st July to 30th June

Fellow	Rs. 2000
Member	Rs. 2000
Associate	Rs. 1500
Licenciate	Rs. 1200
Technician	Rs. 750
Affiliate	Rs. 1200
Membership for Life	Rs. 15000

Entrance Fee

All the grades	Rs. 1000
Processing Fees*	Rs. 500
Processing Fee for	
Chartered Chemist designation	Rs. 5000
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*per application for admission/transfer to any grade

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(PTO)

Committees 2022/2023 (contd.)

Cover Page

October issue of Chemistry in Sri Lanka of year 2022 is dedicated to the theme, Role of Basic Sciences for Sustainable Development in parallel with the declaration of United Nation (UN), the year 2022 to be the International Year of Basic Sciences for Sustainable Development. It illustrates the logo of UN for the International Year for Basic Sciences for the Sustainable Development and the Seventeen Sustainable Developmental Goals to be achieved.

CHEMISTRY IN SRI LANKA

Chemistry in Sri Lanka is a tri-annual publication of the Institute of Chemistry Ceylon and is published in January, May and September of each year. It is circulated among the members of the Institute of Chemistry and students of the Graduateship/DLTC course and libraries. The publication has a wide circulation and more than 500 copies are published. Award winning lectures, abstracts of communications to be presented at the annual sessions, review papers, activities of the institute, membership news are some of the items included in the magazine.

The editor invites from the membership the following items for publication in the next issue of the Chemistry in Sri Lanka which is due to be released in January 2023.

- *Personal news of the members*
- *Brief articles of topical interests*
- *Forthcoming conferences, seminars and workshops*
- *Latest text books and monographs of interest to chemists*

All publications will be subjected to approval of the 'Editorial and Publicity Committee' and the Council of the Institute of Chemistry Ceylon.

Further, prospective career opportunities for chemists, could be advertised in Chemistry in Sri Lanka at a nominal payment. The editor in chagrge welcomes suggestions from the members for improvement of the publication.

Editorial

Science Education in Sri Lanka: Past and the Future

Ayanthi N. Navaratne

Senior Professor in Chemistry, Department of Chemistry, University of Peradeniya

The education in Sri Lanka has a history of over 2,300 years. Astonishing irrigation system built in the ancient time is the best evidence for how basic sciences and applied sciences were utilized in the country in the past. During the colonial era, Christian Missionary education system was introduced to Sri Lanka. British administration was very instrumental in establishing education in English medium. However, it was confined to rich people who spoke English representing the inequality of education. After the independence was gained, Dr. C.W.W. Kannangara introduced education reforms and established Central Colleges (Madya Maha Vidyala) by bringing fairness, equity and impartiality of education. The University system was established in Sri Lanka under the University Act No 16 of 1978 and the University administration was centralized by the University Grant Commission (UGC).

The Central colleges had facilities for basic science subjects as well as for other subjects. This reforms finally established the free education by emphasizing the importance of "Girls" education also. With the establishment of the Central Colleges, science education was strengthened by introducing basic sciences; Chemistry, Physics, Mathematics and Biology together with other non–science subjects.

Further education reforms were introduced to the Sri Lankan education system in 1972, 1998 and 2007. In 1972, the government introduced free textbooks, mid-day meals and limited curriculum reforms. The educational reforms introduced in 1972 further expanded the facilities and the quality of free education with the introduction of English, Mathematics and science education to all schools.

After the reforms introduced in 1972, there was a drastic change from grade six to include ten subjects in the curriculum. Subsequently, the "National Certificate of Education (NCG) Examination" was conducted in grade nine; not in grade ten as in the old system. Introduction of Pragurthiya I and Pragurthiya II for this curriculum was a drastic change that introduced students to various types of vocational training. Then, qualified students were proceeded to the "Higher National Certificates Examination" which was equivalent to GCE (A/L) in the old system. In this curriculum, in addition to the four main–stream subjects, four additional subjects were introduced (8-subject curriculum). However, these changes did not exist more than a year due to the government change, and the new system was converted back to the old system (GCE A/L). If it were continued, it could have been one of the best educational reforms for sustainable development of Sri Lanka.

In late 2000 and onward, Project Work was introduced to the advanced level syllabi including science subjects. Nevertheless, it has never been successful due to various reasons such as students' and teachers' negative attitudes, dishonesty (downloading projects from the internet for submission), no contribution to A/L results and university entrance, and lack of a monitoring programme by authorities. Therefore, the main aim of students, teachers as well as parents in the current science-stream is to make professionals, mainly doctors and engineers. However, the importance of basic sciences for the development of the country was never emphasized. Findings of basic sciences are of utmost importance to establish applied sciences which has a direct impact on the development of the country. While other countries were moving forward with this direction, our country was lagging behind.

When we look back the continuation of the science education system over the past years, it has created very unhealthy competition for the limited resources of the

Sri Lankan Universities for producing above-mentioned professional degrees. With realization of this competition to get into the state universities, students were motivated to enter science-based faculties in the state universities. Consequently, applied research based on basic sciences was established which could contribute to economic developments. During this period, private universities came to the picture, but their emphasis was also on professional degrees and split programmes with overseas universities, and some are only steppingstones to link foreign universities for Sri Lankan students.

In order to support the research activities of state universities mainly science stream, funding was provided by HETC (Higher Education for Twenty First Century) and AHEAD (Accelerating Higher Education Expansion and Development) grant schemes. These are World Bank - funded Sri Lankan government-operation to support the higher education in Sri Lanka. These grants were awarded within the period 2013 – 2017 for researchers before the economic turmoil in Sri Lanka.

In the recent past, new science subjects were evolved, such as Data Science and Biomedical Sciences. The latter one is inherently interdisciplinary in nature. Biomedical Science provides the basic sciences necessary for medicine and allied sciences. Until recently, these basic sciences were never appreciated, but not anymore.

Although Sri Lanka performs high in internal efficiency of the current education system, the external efficiency is low due to heavy academic and examination-oriented education system. This examination structure has created very unhealthy, inefficient school system and education as witnessed today. What dominates today is out of school, tuition-based education which never addresses student's skills. For example, even grade 10 students do not regularly attend schools, and the attendance of advanced level students is out of the question. Ultimate result of this system is that it has neglected development skills of students, a mandatory aspect for development of a country.

In 20th century, many developed countries, including USA, Finland and Canada, adapted the skills-based education system and succeeded the development of their countries. Now, being in the 21st century, different socio-economic conditions are prevailed and hence education reforms must be made accordingly. The learning framework of the 21st century demands generic skills as a learning outcome. This means that the subject contents including science subjects should involve IT and media skills, critical thinking skills, collaborative and communication skills, and creativity. Furthermore, teacher-centered classroom-based teaching should be replaced with student-centered out of classroom-based leaning. However, how much of these objectives can be achieved within Sri Lankan education system?? especially in the science education sector?

There are many things to be considered: Regardless of the 21st century outcome-based teaching and learning process, students must face highly competitive GCE (A/L) examination in the science stream to secure a place in state universities. This would not be a problem if there are enough universities as in developed nations where students can enroll by paying relevant tuition fees. Nevertheless, in the Sri Lankan context, majority of students who are successful in GCE(A/L) examination would not be able to afford to do this. Furthermore, Public schools must be granted enough money to do student- centered leaning at least in the advanced level (Science stream). These issues must be addressed for achieving 21st century education reforms in par with developed nations.

However, at present, we need to have a country where law and order prevail, and corruption-free good governors to run the country. It will then be possible to come out of this economic turmoil and think about the education reforms which would fit the best for our country.

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3. Sedere M Upali (October 16, 2016); Educational Reforms Beyond Kannangara for the 21st Century, National Institute of Education Maharagama, Sri Lanka

Professor Ayanthi N. Navaratne *is currently serving as a Senior Professor in Chemistry at the University of Peradeniya. She obtained a B.Sc.(Honours) degree in Chemistry from the University of Peradeniya. She obtained her MS degree in Inorganic Chemistry (Bioinorganic Chemistry) and PhD in Analytical Chemistry (Bioelectroanalytical Chemistry) in 1989 and 1992 respectively from the University of Hawaii at Manoa, USA.*

Message from the President

N. M. S. Hettigedara

Grad.Chem., MSC (Food Science and Nutrition), D.Pharm., B.Pharm. (Hons), Ph.D. (Reading), CChem, F.I.Chem.C.(SL), FRSH (UK), R. Nutri., RD, RPh, RDN FDIASL,

President, Institute of Chemistry, Ceylon

Aims and Objectives of the Institute of Chemistry Ceylon: Further Steps in the Year 2022 and beyond.

It is indeed a great pleasure to issue this message to the Web site of the Institute of Chemistry Ceylon at a time when we have commenced several programs for the benefit of the professional chemists and chemical industry and to contribute to the achievement of Sustainable Development Goals (SDGs) of the United Nations. During the past, it has been possible to do much work towards most of the aims and objectives of the Institute of Chemistry Ceylon as laid down in its Act of Incorporation. However, some of them are yet to be achieved or they are in different stages of progress. I wish to address a few more of them during this year onwards with the cooperation of the State sector and the private sector as well as the relevant national and international organizations.

Initiative for enhancing status of the profession of Chemist

On the important requirement of enhancing the status of the profession of Chemistry in Sri Lanka, we have not yet been able to take necessary steps to make the registration of Chemists and the Accreditation of Chemical laboratories mandatory, although several activities in this direction were in progress during the past. We are aware that, Malaysia is one of the countries in which such legislation has been already enacted. It is necessary to increase awareness on this matter amongst the policy makers so that, we can make a distinct and positive contribution to enhance the professional status of our Chemists and the profession of Chemistry in Sri Lanka. As a novel approach toward this objective, I have taken action in June 2022, to establish a National Secretariat under the Institute of Chemistry Ceylon. The Secretariat thus formed will be responsible for the Professional Practice of Chemistry which covers the performance of a service related to public interest, public safety, and legal or regulatory matters.

As a further step towards enhancing the status of profession of Chemistry in Sri Lanka, relationship with the industrial sector will be developed through effective communication systems with the industry, assisting to solve their subject related problems and encouraging the industry for research and development with the involvement of the College of Chemical Sciences (CCS) and the Institute while organizing a suitable platform to discuss industrial issues and find solutions.

Advancements in the Educational Arm

In addition to the already existing globally recognized and most demanded professional Graduateship in Chemistry (GIC) program of the Institute, and with a view to promoting education in Chemistry at all levels and to promote encourage and foster original research in Chemistry, the BSc (Hons) Degree program in Chemical Science was introduced in 2020. This BSc (Hons.) program is accredited by the University Grants Commission (UGC), and the Institute now operates its second year. The program has shown a growing demand already, having 37 students in the initial year of 2020, and more than 200 in the subsequent year (2021).

In regard to the objective of academic and professional development of the enrolling students, action will be taken for continuous follow-up on academic achievement/drawbacks, periodic review, strengthening student counseling, attending to student welfare issues, and improving academic/professional quality of CCS graduates. To ensure the maintenance of high standards in the professional activities and the general conduct of its members, action will be taken to provide internship and research opportunities for the graduate chemists who seek to become Chartered Chemists. In addition, a Master of Chemical Analysis and Measurement program has been developed for the practicing Chemists in the industry.

Improved Infrastructure

Under the program for infrastructure development, the Institute has already initiated action to expand its physical facilities by developing an Educational Complex at Malabe. In addition, the land donated by Clodagh Nethsinghe to the Institute which is 30 perches in extent, and located in Dehiwala will be used to establish a Chemical Laboratory and Training Center. The major functions of the proposed laboratory would be providing Analytical Services to cater to the needs of the Chemical Industry, providing consultancy services on all disciplines in chemistry and chemical industry (*e.g.* paint sector, agriculture sector, food sector, green chemistry, *etc.*), training/internship for newly passed out Graduates/GIC /DLTC students to obtain hands-on experience, innovations in Chemical Sciences, chemical analysis of imported or exported chemicals and issuing of Certificates and conducting CPD programs.

Aligning with the Sustainable Development Goals (SDG)

The Institute will launch suitable programs towards achieving Sustainable Development Goals (SDGs) of the United Nations. Being a member of the International Union of Pure and Applied Chemistry (IUPAC), our Institute has a great responsibility to contribute to the Sustainable Development Goals (SDG) by 2030 and to launch our programs towards achieving sustainable development in the country.

Celebrating the International Year of Basic Sciences for Sustainable Development

The UN has declared the year 2022 as the International Year of Basic Sciences for Sustainable Development (IYBSSD 2022) at its 76th session of the General Assembly. The Institute has developed a number of programs to actively participate in the IYBSSD 2022 which include a grand Virtual IYBSSD 2022 Exhibition and Trade Fair, seminars and workshops, news releases and publication of articles and supplements, publication of IYBSSD 2022 special issue: 'Chemistry in Sri Lanka', public awareness programs, chemical magic shows, inter-university debates, cultural programs, webinars: seminars/discussions (University/Industry/IChemC), interschool chemistry quiz programs, 'Education for All'- highlighting Graduateship in Chemistry, BSc, and Diploma in Laboratory Technology course, *etc.*, strengthening the evaluation of the quality of programs to achieve SDGs, feeding information to the Website / YouTube/Facebook, publication of an IYBSSDC 2011 Souvenir with all the events included, and special programs to achieve 12 Sustainable Development Goals of Chemistry.

Interaction with Global Institutions

I hope to work closely with the UNESCO, WHO, OPCW, UN, and FAO and Government ministries, departments and statutory bodies, professional organizations, and the chemical industry, in order to achieve the above objectives. As students, academic and non-academic staff, and professional chemists, members of the Institute, let us work together and achieve the above objectives for the benefit of our Institute, the profession of chemistry, the chemical industry, and for the betterment of the whole country.

Mr. N M S Hettigedara *graduated from the Institute of Chemistry Ceylon. He is a Senior Nutritionist and Dietitian at the Sri Lanka Police Hospital, Colombo having the rank of Senior Superintendent of Police (SSP). He obtained a BPharm (Honours) degree, MSc in Food Science and Nutrition and currently reading for his PhD. He is a Chartered Chemist. He is a Fellow of Institute of Chemistry and a Fellow of Dietitian's Association of Sri Lanka. He is also a registered pharmacist and a member for life of Pharmaceutical Society of Sri Lanka and Nutritional Society. Member of the American Society of Nephrology.*

Themed Collection

Role of Chemistry in Sustainable Development

R. M. G. Rajapakse

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Chemist plays a pivotal role in sustainable development. American Chemical Society identified seven sustainable development goals and additional five of them that a chemist has direct contributions. In this feature article, chemistry and sustainable development are defined at the inception. The article then describes how a chemist is contributing to achieve seven sustainable development goals. Wherever possible, examples are taken from locally achieved developments. Let us work for national and global development through achieving the needs of the present generation without compromising the ability of future generations to meet their own needs.

INTRODUCTION

The Oxford dictionary defines chemistry as "the branch of science concerned with the substances of which matter is composed, the investigation of their properties and reactions, and the use of such reactions to form new substances" [1]. Indeed, this is the branch of science that deals with matter. In general, matter involves all physical substances that occupies space and possesses rest mass, especially as distinct from energy. However, chemistry also deals with energy transformations involved in chemical processes as exemplified in chemical thermodynamics and statistical mechanics. Matter that a chemist is dealing with may be from atoms, molecules and ions to planets, stars, galaxies. Nonetheless, a chemist should be conversant in analyzing matters of all size scales from picometers to lightyears. Chemist discovers complicated structures of matter, their stereochemistry, chemical and physical properties, and chemical reactions, and uses this knowledge to design and develop new substances that are beneficial to the humankind, other animals, ecosystem, and so forth. The substance, material, device, and product that a chemist develops should meet the criteria of sustainable development or else the invention is detrimental. The Brundtland Report, published in October 1987, by the United Nations, through the Oxford University Press, defines sustainable development as the "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" [2–4]. That is the development preserving environment and ecosystem without exhaustion of raw materials. This means that the sustainable development should correlate with the organizing principle for meeting human development goals without undermining the integrity and stability of the natural system. The Rio Process initiated at the 1992 Earth Summit in Rio de Janeiro first institutionalized the sustainable development. The United Nations General Assembly, in 2015, adopted seventeen sustainable development goals (SDGs) addressing the global challenges, including poverty, inequality, climate change, environmental degradation, peace, and justice [4]. Chemistry plays an essential and mandatory role in helping society achieve the SDGs. The American Chemical Society (ACS) identified seven priority SDGs and five additional SDGs that are foundational to the work of the chemistry community [5]. Chemistry is central in developing technologies for addressing key issues such as zero hunger, human health and well-being, clean water and sanitation, affordable and clean energy, industries, innovation & infrastructure, responsible consumption & production, and climate action.

CHEMISTRY IN SUSTAINABLE DEVELOPMENT GOALS

Sustainable Development Goal 2: Zero Hunger

Food is essential for living of humans and animals. The development of Harbor-Bosch process that converts nitrogen in air to ammonia, conversion of phosphate minerals to soluble phosphorus species, and extraction of potassium from minerals made it possible to develop synthetic fertilizers to produce sufficient food for ever increasing global population. Advances in chemical research will enable the development of better protection of plants and crops from pest infestations, improve food production and transportation channels, extend the shelf-life of postharvest products and food items through improved packaging, and maintain food quality and safety. Development of high-yield seeds and improved fertilization methods will undoubtedly increase the food production while reducing soil erosion. Fortification of foods to supply essential nutrients can combat malnutrition issues. Better utilization of fertilizers will enable the prevention of eutrophication due to excess N- and P- leached into water reservoirs. N-fertilizers such as urea and ammonium compounds are highly water soluble and a significant proportion leach into water bodies thus losing the fertilizers and creating adverse effects. Incorporation of these soluble fertilizers in suitable carriers for developing slow- and constant-release formulations over a period eliminates the problem of wastage and its consequent adverse effects. It is a task of chemist to develop such technologies to help farmers to better use fertilizers without wasting. On the contrary, phosphate fertilizers are not very water soluble and making them water soluble by developing charged nanoparticles of phosphates for allowing plants to readily absorb them is also a task of a chemist. This will eliminate washaway of phosphate fertilizers eventually causing eutrophication. Climate change caused by environmental pollution is a serious global problem that results in lengthy droughts and flooding. Long-lasting droughts create water shortages which can adversely affect vegetations. Therefore, developing technologies for water retention in plants will help retard this problem. The Cutler group at University of California, Riverside, developed quinabactin which is a compound that mimics the plant hormone abscisic acid (ABA) that helps to retain water in some plants [6–8]. However, they found that this compound does not work for some key crops such as wheat and tomato. Extensive structural studies performed to find out reasons for this effect revealed that ABA binds to ABA receptors present in plants through two positions but in some ABA receptors quinabactin binds to only one position. Having realized the problem, the research team developed a new compound called opabactin that binds to ABA receptors in two positions of all ABA receptors. Therefore, the latter compound works better than the former in helping to retain water in many crops [9]. Figure 1(a) shows the chemical structures of quinabactin and opabactin and 1(b) reproduced with permission shows the structure-guided optimization and thermodynamic profiling of abscisic acid receptor agonists that led to the discovery of opabactin.

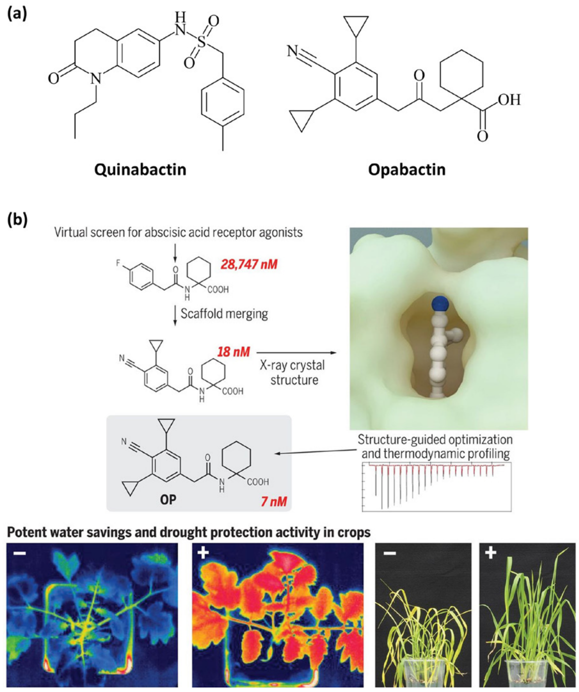

Figure 1: (a) Chemical structures of quinabactin and opabactin. (b) Structure-guided optimization and thermodynamic profiling of optabactin as a potent water saving compound for drought protection of crops (Reproduced with permission from [9]).

Phosphate recovery from sludges such as sewage is yet another important area for manufacturing P-fertilizers. While there are several methods available to do so, microbial fuel cell-based bio-electrochemical wet phosphate recovery from iron phosphate sewage sludge presents a low-cost and scalable process as reported by Blatter et al [10]. The process flow diagram reproduced with permission is given in Figure 2. Here, they used iron salts to competitively precipitate phosphate in a microbial fuel cell. We have also used various nanomaterials to recover phosphate present in wastewaters, their adsorption isotherms, kinetics of adsorption, revealed [11,12]. There are many other reports for the recovery of phosphate from various waterbodies [13–18].

Managing pests and diseases without having to use toxic chemical pesticides is also an area where chemist can contribute. The sustainable crop protection involves several methods. Out of these, the use of natural pesticides to combat pest and disease issues is an interesting area where less harmful natural materials are used instead of synthetic pesticides. Spraying mild soap or oil can be used to destroy sap-sucker insects. Urine diluted with water kills some pests. Boiled tobacco leaves also used to protect crops from pest attacks [19]. Pyrethrins are natural pesticides extracted from flowers of some plants. In general, pyrathrins have lower toxicity to humans and mammals. Pyrethrin insecticides extracted from Tanacetum cinerariifolium provide a human-safe and ecologically friendly alternative to widely used synthetic insecticides. However, care should be taken to ensure not to expose to high doses since even the natural pesticides at high doses are toxic.

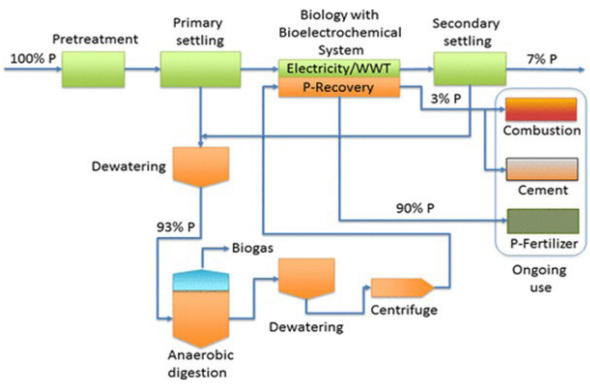

Figure 2: The process flow diagram for phosphate recovery from sewage. Reproduced with permission from [20])

Food protection and spoilage detection are another important aspect in combatting hunger. Ma et al. developed a highly sensitive, printable nanostructured conductive polymer wireless sensor for food spoilage detection [21]. They developed a nanostructured conductive polymer-based gas sensor with high sensitivity of $\Delta R/R0$ = 225% toward 5 ppm ammonia NH3 and unprecedented sensitivities of 46% and 17% toward 5 ppm putrescine and cadaverine, respectively, with the near-field communication (NFC) labeling technology using smartphones with non-line-of-sight sensing functions to improve the environment, human health, and quality of life. Increasing shelf-life of food products is done through active packaging. This involves modified atmosphere packaging (MAP) where manipulated compositions of carbon dioxide, oxygen and nitrogen are used to preserve appearance, texture, taste, freshness, and hygiene while extending the shelf-life and quality of the food [22]. Since the MAP has a higher level of CO_2 and lower levels of O_2 than those present in the outside air, the respiration, biomass loss and microbial spoilage are reduced. Additionally, SO_2, CO and ethanol are used in limited quantities. For foods that are packaged for use in a relatively long term, the passive modified atmosphere packaging can be used. Here, the properties of the food product and the permeability of the packaging material are used to achieve and maintain the desired atmosphere. The respiration of fresh food produces CO_2 to maintain a high level of concentration. In the active MAP, a vacuum is created first and then required quantities of desired gases are introduced. Use of desiccants to remove excess water vapour, hygroscopic pads or sheets to remove moisture, deliquescent salts, such as calcium chloride and magnesium chloride packed in sachets are also used in dry food packaging. Also, silica gel, modified starch, natural clay, calcium oxide, and calcium chloride are some moisture absorbers used. Oxygen scavengers are used to control oxidation of food products, rancidity of fats and oils, ripening and senescence of fresh produce, staling of bakery products, and controlling aerobic bacteria that would damage food products. Ethylene absorbers are used to remove phytohormones to delay ripening of fruits and some vegetables. The oxygen scavengers such as potassium permanganate, activated carbon and finely dispersed mesoporous silica are used in the form of film and sachets.

Sustainable Development Goal 3: Good Health & Well-Being

Advances in chemistry enabled understanding how human health is implicated by diseases and hazardous chemicals present in environmental segments such as air and water and discovering new medicines to combat diseases and removing environmental pollutants. Chemistry is central in developing tools for disease diagnosis and control. Green chemistry approaches should be used in all these chemical processes such as manufacturing of pharmaceuticals, development of disease diagnosis methods, and so on. The old practice of using harmful solvents should be minimized and biomimetic routes or harmless solvents such as supercritical carbon dioxide are encouraged. The American Chemical Society (ACS) has a Green Chemistry Institute (GCI) and its Green Chemistry Roundtable is dedicated to the implementation of green chemistry in pharmaceutical and other industries. In collaboration with relevant industries, the ACS-GCI developed a variety of high-quality tools and metrics to help scientists and engineers to make better decisions about chemical selection and route and process design incorporating green chemistry approaches [23] . They found that the chemical selection (*i.e.*, solvents, reagents, etc.) has a decisive role in determining synthetic process cost and environmental, safety and health impacts across the life cycle. The use of high-pressure liquid chromatography (HPLC), ultra-high pressure liquid chromatography (UHPLC), and advancing supercritical fluid chromatography (SCFC) to UHP-SCFC enabled faster and more efficient separations. They have also developed an Analytical Method Greenness Score (AMGS) Calculator to provide a straightforward metric to enable the comparison of separation methods used in drug development. The AMGS metric includes the solvent health, safety and environmental impact, cumulative energy demand, instrument energy usage, and method solvent waste to benchmark and compare one method to another. The ACS-GCI member companies are also provided with biocatalysts guide to replace synthetic catalysts with enzymes. The green chemistry and also enables the reduction of waste in the industrial processes. To this effect, we developed a low-cost, low-temperature route to breaking ilmenite structure and separating titanium and iron components for the synthesis of phase-specific titanium dioxide, iron oxide and zero-valent iron nanomaterials. The waste contains only sodium chloride that can also be recovered in a saltern ultimately discharging clean water to the environment [24–28]. We have also improved industrial wastewater treatment technologies by introducing precipitation of heavy metals and zinc as their sulphides at the beginning and introducing Fenton and photo-Fenton processes for oxidative degradation of organic contaminants and finally both aerobic and anaerobic bacteria based microbial treatment plants to remove soap molecules and ions. The microbial plant sludge generated was analyzed for its zinc, aluminium and heavy metal contents and methods were developed to remove them well below the maximum allowable levels stipulated by the Central Environmental Authority of Sri Lanka. The nutrient value of the toxic substance removed bacterial sludge was determined and C:N ratio, NPK and micronutrient contents were analyzed. Table 1 shows the data obtained. The high N content was reduced by diluting the sludge with other raw materials and organic fertilizer formulations were produced.

Table 1: Selected tolerance limits for the discharge of industrial wastewater to different categories under the act of Central Environmental Authority (1534/18). Reproduced from AAS Mendis, Ph.D. Thesis, University of Peradeniya, 2021.

Characteristics	**Value**	**Requirement (SLS 1236:2003) guidelines**	**Method of test**
pH	6.5 – 7.5	6.5 – 8.5	ISO 10390
Organic carbon, % by mass	37.20	20	2.2.1.2 Method
Nitrogen content, % by mass	6.20	1.0	2.2.1.1 Method
Phosphorous content, as P_2O_5 % by mass	3.5	0.5	SLS 645: Part 5
Potassium content, as K_2O % by mass	0.1	1.0	SLS 645: Part 4
Magnesium content, as MgO % by mass	0.08	0.5	SLS 645: Part 6 Section 1
Calcium content, as CaO % by mass	7.1	0.7	SLS 645: Part 6
C/N ratio	6/1	20/1	

The organic fertilizer thus produced were analyzed for its nutrient value and impurities and having confirmed that they are in accordance with the recommended values, the fertilizer was applied to vegetable and fruit plantations. The soil, plant parts, fruits and vegetables were analyzed as a function of repeated application for heavy metals, zinc and aluminium and made sure that they are within the maximum allowable limits [29]. We are currently working on developing bacteria and fungi-based potassium releasing system from feldspar.

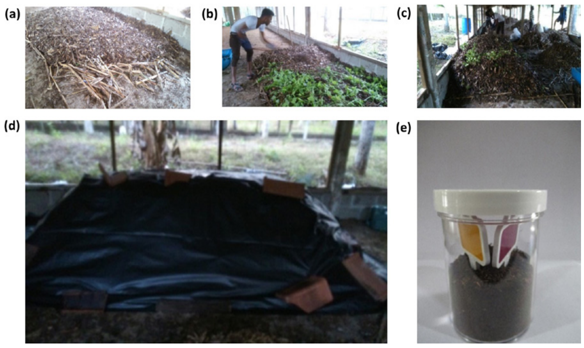

Figure 3: Stages of organic fertilizer production (a to d) and maturity testing (e). Reproduced from AAS Mendis, Ph.D. Thesis, University of Peradeniya, 2021.

Sustainable Development Goal 6: Clean Water & Sanitation

Access to clean drinking water is a fundamental right of a human and chemist plays an important role in providing clean drinking water. Chemist helps to develop clean water resources by removing water pollutants and also desalination processes. Current research also involves the development of low-energy, high-efficiency separation methods for removal of metal ions and micropollutants. Also, chemist develops strategies for reduced water usage in industries and reduced wastewater production. As explained earlier, it is the responsibility of the chemist to develop technologies for industrial wastewater treatment plants and to make sure the water that is finally discharged to the environment is safe and pollutant free. There are two aspects that needs consideration here: solar assisted desalination and heavy metal removal. The solar assisted desalination is a way of producing clean water in a greener manner by using electricity produced from solar energy. The Elemental Water Source™ is a plug & play is the first of such industry that utilizes 100% solar energy produced from off-grid solar panels for desalination process making it economical and environmentally friendly.

Metal-organic frameworks can be used to remove heavy metals, such as Pb^{2+} and Hg^{2+}, selectively and rapidly from water [30]. Also, we developed several nanomaterials that can remove heavy metals [31–34].

Sustainable Development Goal 7: Affordable & Clean Energy

Chemist plays a major role in developing Earth-abundant, non-toxic materials for use in solar cells, fuel cells, supercapacitors and batteries, thermal energy collection and in wind energy conversion. Also, new catalysts are developed to improve efficiency of chemical industrial processes, and to optimize process design. Additionally, chemist works on replacing expensive Nobel metal catalysts by low-cost materials such as clay-polymer nanocomposites as oxygen reduction cathodes in fuel cells to replace platinum [34-36], graphite, expanded graphite and graphene products as counter electrodes in solar cells [37-40], and in converting quartz to solar grade silicon for solar cell production [41]. Figure 4 (a) shows large electrodes fabricated from Sri Lankan vein graphite in developing 10 kW h Zn/Br_2 flow battery and (b) shows a lab-scale version of the flow battery.

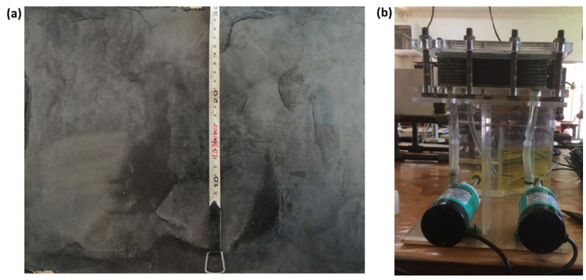

Figure 4: (a) Graphite electrodes fabricated for developing 10 kW h Zn/Br_2 flow battery. (b) A lab-scale version of a Zn/Br_2 flow battery.

Nanowires for electrochemical energy storage by Zhou et al. reviews the state-of-the-art research progress on nanowires for electrochemical energy storage, from rational design and synthesis, in situ structural characterizations, to several important applications in energy storage including lithium-ion batteries, lithium-sulfur batteries, sodium-ion batteries, and supercapacitors [35]. The cleanest fuel is hydrogen because the combustion of hydrogen gas produces water as the only product that is environmentally benign. However, hydrogen as $H_2(g)$ does not exist as it can escape out atmosphere. It exists mainly as water and hydrocarbons. Currently, $H_2(g)$ is produced in the process of hydrocarbon cracking in the petroleum industry. However, there are two reasons as to why this process is not attractive: rapid depletion of fossil fuel deposits and environmentally unfriendly processes used. Other alternative is to split water to $H_2(g)$ and $O_2(g)$ electrochemically or photo-electrochemically through the efficiencies of these processes are significantly low and currently used technologies demand expensive platinum as the catalyst. Chemists have developed relatively inexpensive transition metal-based catalysts, such as oxides, sulfides, hydroxides of cobalt, nickel, iron etc. However, unlike platinum, most of these inexpensive catalysts can accelerate either hydrogen evolution reaction (HER) or oxygen evolution reaction (OER) but not both. To overcome this difficulty, chemists developed a novel heterostructured catalyst consisting of hollow cobalt sulfide (CoSx) and nickel-iron (NiFe) layered double hydroxide (LDH) nanosheets that simultaneously boosts both the half-reactions [36]. Figure 5 shows an AC Transit hydrogen fuel cell bus. Credit: Eric Fischer [37] .

Figure 5: An AC Transit hydrogen fuel cell bus. Credit: Eric Fischer [37]

Sustainable Development Goal 9: Industries, Innovation & Infrastructure

Chemist plays at least three major roles in this goal: (i) upgrading infrastructure and retrofit production facilities of chemical processing industries to become more sustainable, (ii) making the infrastructure more sustainable and resilient by the design, synthesize and manufacture of innovative advanced materials and coatings and (iii) encouraging chemistry research that enhances innovation for commercial applications. In this sense, we collaborate with ten Sri Lankan industries: namely, ATG Lank Ltd., Teejay Lanka Ltd., Bogla Graphite Pvt. Ltd., LTL Galvanizers Pvt. Ltd., Isabella and Sarasavi Industries, Sarasavi Exports Pvt. Ltd., Varna, and Sithra Industries, CODEGEN International Pvt. Ltd. where we develop highly value-added products. The sustainability in this goal involves assessing greenness of a reaction or product and developing greener analytical techniques, developing biobased chemicals, homogeneous and heterogeneous catalysts based on organic, organometallic, inorganic and biological materials, managing the extraction, use, reuse of depleting materials, developing tools and metrics to measure greenness, controlling process engineering, rational molecular design for reduced toxicity, environmentally friendly solvents and solvent-free synthesis methods, and converting waste to chemicals. It is noteworthy to mention here that waste is just the important materials in a wrong place at wrong times. There is nothing called waste and recycling waste to valuable materials is an important step forward in sustainable development. Figure (6) shows collaboration with industries (a) ATG Lanka Ltd., (b) Teejay Lanka Ltd., and (c) LTL Galvanizers Pvt. Ltd. The ATG produces latest technology NBR gloves, and its wastewater treatment plants are designed to discharge pollutant free water to the environment. The Teejay Lanka Ltd. manufactures smart and advanced textiles, fabrics and garments. The LTL liquid sludge has been converted to iron oxide based antimicrobial pigments and bricks.

Figure 6: Advanced gloves manufactured at the ATG Lanka Ltd. (b) Advanced and intelligent textiles, fabrics and garments manufactured at the Teejay Lanka Ltd. and (c) Antimicrobial pigments and bricks manufactured from the LTL Galvanizers liquid sludge.

The green coating market is developing, and zero volatile organic compound (VO) coatings are becoming attractive. Very common VOC materials include acetone, acetic acid, butanol, carbon disulphide, ethanol, isopropyl alcohol, formaldehyde, and methylene chloride. Day-to-day consumer products also contain these VOC materials. Developing materials, devices and products without VOCs is a prime need and responsibility of the chemist.

Sustainable Development Goal 12: Responsible Consumption & Production

Responsible consumption and production are key issues addressed by the chemist. These include improved quality and efficiency of production processes, improving water stewardship efforts and energy efficiency, better and safe food packaging, and additives to prevent food loses to innovations in waste management systems. The chemical processing industry helps to reduce the life cycle impacts of consumption. The circular economy considers the reduction, reuse, recycling, and redesign of the materials. Since food packaging causes concerns such as high production volume, short usage time, waste management and littering, circular economy as regard to food packaging materials has also become an important issue. However, there are problems associated with recycling of food packaging materials. These include the increased levels of hazardous materials, after migration of components from packaging materials to food items. Geuek et al. [38] reveals the "Food packaging in the circular economy: Overview of chemical safety aspects for commonly used materials" and is an important reference to workout consequences of circular economy as applied to food packaging materials. The graphical abstract of [38] that is reproduced here in Figure (7) with permission clearly show the problems associated with circular economy of food packaging materials (left) and how to overcome these problems (right).

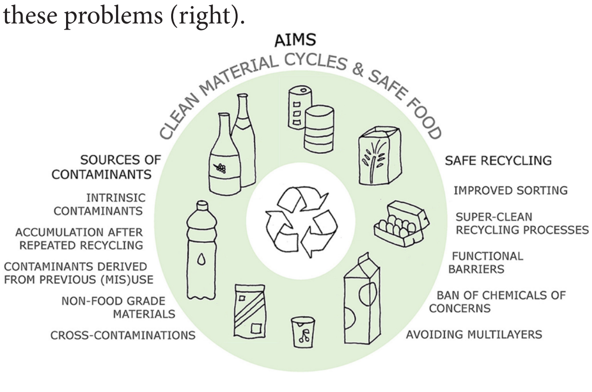

Figure 7: Problems associated with recycling of food packaging materials (left) and ways of overcoming these problems (right). Reproduced with permission from [39].

Sustainable Development Goal 13: Climate Action

The global climate change has become a serious issue potentially threatening the existence of biota including humans. Unexpected drought and flood conditions have arisen as consequences of global climate change. Atmospheric chemistry plays a major role in understanding causes of global climate change. Chemical research also enables mitigating and adapting to climate changes. The carbon footprint that is the amount of greenhouse gases released into the atmosphere as a result of the activities of a particular individual, organization, or community, plays an important role in global climate change. The carbon footprint is measured in tonnes of carbon dioxide ($CO_{2)}$ or carbon dioxide equivalents (CO_{2e}). According to the global data obtained in 2017, the major contributors of carbon footprint are as follows [38].

- **Energy** (the burning of fossil fuels) produced 36013.52 million tonnes of CO_{2e}.
- **Agriculture** produced 5795.51 million tonnes of CO_{2e}.
- **Land-use change, and forestry** (altering or converting land) produced 3217.07 million tonnes of CO_{2e}.
- **Industrial processes** produced 2771.08 million tonnes of CO_{2e}.
- **Waste** produced 1560.85 million tonnes of CO_{2e}.

As we see, there are only a few industries casing the major fraction of the carbon footprint. Therefore, taking remedial measures such as switching to green energy resources, safe and green agriculture, responsible land and forestry use, green industrial processes and responsible waste management are important in controlling the carbon footprint to preserve the planet for future generations to survive.

Finally, the ACS Green Chemistry Institute presents "Design Principles for Sustainable Green Chemistry & Engineering" [39]. It emphasizes the following green chemistry goals.

- Maximization of Resource Efficiency.
- Elimination and minimization of hazards and pollution.
- Holistic design systems and use of life cycle thinking.

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Management of Cancer Patients using Radiopharmaceutical Therapy

D. Rajapaksha, P. Rathnayake and S. R. D. Rosa

Sri Lanka Atomic Energy Board

Cancer is the major cause of morbidity and mortality around the globe. Cancer shows a significant annual increase, approximately 30,000 new cases were recorded in 2021. It has become one of the major health burdens in Sri Lanka. The death rate due to cancer has doubled over the last 25 years and this has become the second commonest cause of hospital mortality in Sri Lanka. Female breast cancer has surpassed oral cancer as the most commonly diagnosed cancer type. There were an estimated 29,604 new cases and 16,691 cancer deaths in Sri Lanka in 2020. This figure is expected to increase by 23% every year till 2030. For cancer treatments and patient managements, Radiopharmaceuticals are widely used in the PET-CT scanning. 18F-fluorodeoxyglucose (FDG) PET/CT is a major imaging modality for cancer imaging, assisting diagnosis, staging of patients with newly diagnosed malignancy, restaging following therapy and surveillance.

Radionuclides, and the radiopharmaceuticals derived from them, are an established tool for key investigations in numerous disciplines of the life sciences and for diagnosis and treatment of many life-threatening diseases. Radiopharmaceuticals are produced by specialized machine called Cyclotron. A key component of the successful operation of a PET(Positron Emission Tomography) center is the on-demand availability of radiotracers (radiopharmaceuticals) labelled with suitable positron emitting radioisotopes. Out of the hundreds of positrons emiting labelled radiotracers, 2-[18F]-fluoro-2-deoxy-D-glucose (FDG) is the most successful and widely used imaging agent in PET today. FDG is a glucose analog, and it tends to accumulate in the tissue with high glucose demand like tumors and inflammatory cells.

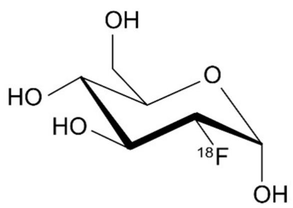


Figure 1: Molecule of 2-[18F]-fluoro-2-deoxy-D-glucose (FDG)

Whole body PET imaging with FDG measures glucose metabolism in all organ systems with a single examination, thus improving detection and staging of cancer, selection of therapy, and assessment of therapeutic response. Although it begins within a specific organ, cancer is a systemic disease, the most devastating consequences of which result from metastases. The FDG–PET method often allows for the early detection and quantification of metastasis; thus FDG–PET has found applications in the diagnosis, staging, and restaging of several clinical conditions including lung cancer, colorectal cancer, lymphoma, melanoma, head and neck cancer, and oesophageal cancer. Similarly, clinical applications in the fields of neurology, cardiology as well as inflammation/infection are on the rise. These radiopharmaceuticals have very short half-life radioisotopes, so they cannot be imported and stored in advance.

What is a Radiopharmaceutical?

Radiopharmaceutical is a radioactive compound for diagnosis and therapeutic treatment. They are injectable drugs. 95% of the radiopharmaceuticals are used for diagnostic purposes. Radiopharmaceutical is consisting with two Components a Radionuclide and a Pharmaceutical. PET is a nuclear medicine imaging technology that provides moderate-resolution, sensitive images of the biodistribution of a radiotracer in vivo. Hence, PET imaging with a suitable radiopharmaceutical can provide interpretation of a biological function. In addition to applications for diagnosis of diseases, PET imaging can provide important insights for both drug discovery and development and for potentially limiting side effects due to off-target binding. PET is based on the simultaneous detection of photons that are linearly traveling in opposite directions. Coincidence detection is used to determine the annihilation.

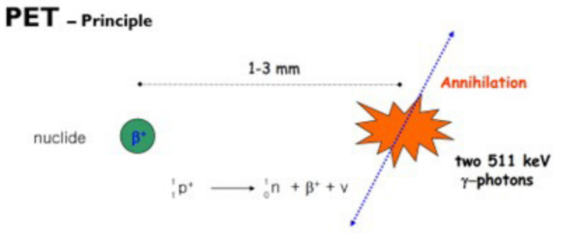


Figure 2: Principal of Positron emission tomography (PET) Scanning

Positron-emitting radiopharmaceuticals labeled with the short half-life positron emitting radionuclide fluorine-18 (t1/2=110min) are being increasingly used in clinical diagnosis. Fluorine-18 has relatively long half-life of 110 min compare with other radionuclides.

Table 1: Half Life of Radionuclides

radionuclide	half-life (min)	energy (keV)
C-11	20.4	511
N-13	10	511
O-15	2.07	511
F-18	110	511
Ga-68	68	511
Cu-64	12.7 h	511

^{18}F has the most ideal half-life for labeling of radiopharmaceuticals (small organic molecules, peptides, aptamers, and proteins) and has a unique and diverse chemistry for introduction into various molecules. In medicinal chemistry, fluorine is a favorable atom in drug development due to its physical properties including small van der Waals radius (1.47 Å), high electronegativity, and ability to form a strong bond with carbon (C–F energy bond of 112 kcal/mol), which in comparison to a carbon–hydrogen bond (C–H = 98 kcal/mol) is more thermally stable and oxidation resistant. Fluorine can act as a bioisostere with hydrogen (size and valence electrons) and oxygen (size and electronegativity). As a result of its significance in the pharmaceutical field, several selective fluorination reagents for nucleophilic (F^-) and electrophilic (F^+) incorporation have been developed and have become commercially available.

Cyclotron and F-18 Production

Medical Cyclotron technology started new era in Nuclear Medicine diagnosis. In the Cyclotron, particles such as protons, deuterons are accelerated and made to bombard to a suitable target material to produce positron-emitting radioisotopes. A charged particles can be accelerated during circular motion by combining magnetic and electric field. The positron emitters are produced using stable, non-radioactive isotopes by the (p, α), (p, n) or (d, n) reactions. The neutron activation of the surrounding medium draws the major attention in radiation safety. After irradiation, radioactive gases and liquids produced in the target is normally transferred out of the cyclotron vault into the hot laboratory through tubing.

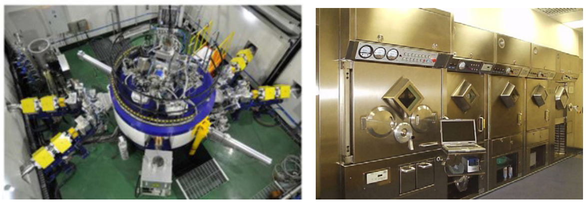


Figure 3: Cyclotron Facility and radiopharmaceutical synthesis in hot cells

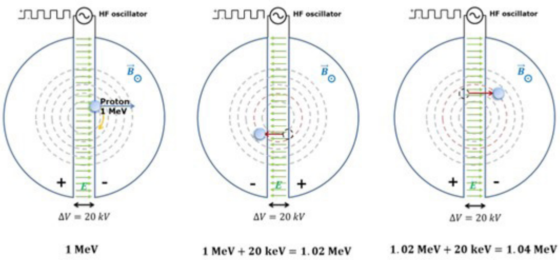


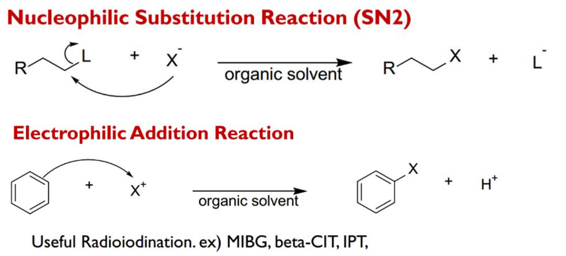
Figure 4: Electric field for accelerating (electric potential)

Cyclotron produced radioisotopes are incorporated or tagged with chemicals to produce radiopharmaceuticals. Chemical processing is carried out in specific units built for the purpose. A chemical synthesis module is use to prepare radiopharmaceutical from the positron emitting radioisotopes produced in a cyclotron. The cyclotron vault is the area with the highest amount of radioactivity, when the cyclotron beam is 'ON' for irradiation of the targets. After irradiation produced radioactive materials are transferred to the hot-cells. Fluorine-18 is produced primarily by proton (^{1}H) irradiation of ^{18}O, a stable naturally occurring isotope of oxygen. When the target is liquid $H_2{}^{18}O$, an aqueous solution of ^{18}F-fluoride ion is obtained.

$$^{18}_{8}O + ^{1}_{1}H \rightarrow ^{18}_{9}F + ^{1}_{0}n$$

Figure 5: The nuclear reaction for the production of ^{18}F.

The production method used is depend on the desired subsequent chemical reactions; ^{18}F-fluoride is produced for use as a nucleophile, while ^{18}F-fluorine is produced for use in electrophilic methods.



The specific activity (SA = radioactivity/mol) is the key differences between these two chemical forms synthesis ^{18}F isotope. Nucleophilic ^{18}F-fluoride is produced by the efficient nuclear reaction $^{18}O(p, n)^{18}F$ to give a high amount of radioactivity (>370 GBq/batch). Fluorine can replace hydrogen with minimal steric interference: maintaining favorable interaction with the target. Fluorine is also often used as a substituent in pharmaceuticals because it can increase the activity, potency, and stability of biologically active compounds.

How to Introduce Single Fluorine Atom into Aliphatic Organic Compound?

Although fluoride ion is a strong nucleophile, it is non-reactive for nucleophilic substitution in aqueous solution as it has bonds with the surrounding hydrogen in water molecules. To achieve nucleophilic fluorination, the ^{18}F-fluoride must be substantially dehydrated by evaporation of the water and subsequent displacement reactions conducted in polar aprotic organic solvents. The solubility and nucleophilicity of fluoride ion in organic solvents is enhanced by the addition of a phase transfer catalyst (PTC) (such that the cryptand Kryptofix 2.2.2 complexes potassium) or by the addition of bulky tetrabutylammonium cation.

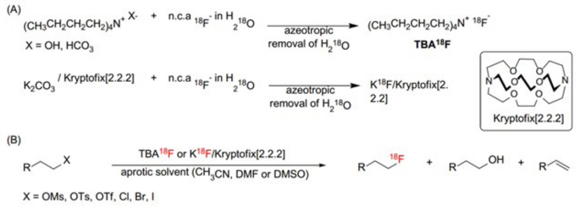


Figure 6: Synthetic routes of known radiotracers by 18F-aliphatic nucleophilic mechanism.

Common anionic leaving groups are halides such as Cl^-, Br^-, and I^-, and sulfonate esters tosylate (TsO-), mesylates(OMs), triflate(OTf).

Quality Control of Radiopharmaceuticals

With diagnostic radiopharmaceuticals, it is important to have a product with acceptable quality control (QC) parameters in order for the nuclear medicine study to be effective yet not to deliver unnecessary radiation exposure to the patient. However, with therapeutic radiopharmaceuticals it is mandatory to satisfy the guidelines for quality control because otherwise, the results could be life threatening to the patient. Radiochemical purity (RCP) of a radiopharmaceutical is defined as the percent of the total radioactivity present in the desired chemical form in a radioactive pharmaceutical. Without acceptable RCP in a diagnostic radiopharmaceutical, image interpretation can be compromised which can result in a delay of an accurate diagnosis and unnecessary radiation exposure since the nuclear medicine study must be repeated. Unlike the conventional pharmaceuticals, radiopharmaceuticals are often not heat sterilized prior to patient use. Application of aseptic processing is, therefore, of primary importance for microbiological purity of the radiopharmaceutical preparation. This is achieved through production in clean room environment where airborne particles are controlled to reduce the possibility of contaminant particles entering the product, and ultimately the patient.

Since synthetic methods are utilized in the preparation of these PET compounds, analysis of chemical purity is also necessary. To characterize and determine the quantity of potential chemical contaminants in the final product several methods maybe used, including Gas chromatography, HPLC, spectrophotometry, ion exchange and solvent extractions. Using the example of ^{18}F-FDG, a colorimetric test for the detection of Kryptofix 2.2.2 has been developed to streamline the clinical production of this product. With this test, one can interpret whether the level of Kryptofix 2.2.2 is within the acceptable regulatory limits in the USP monograph for ^{18}F-Fluorodeoxyglucose. Half-life determinations for routine identity testing of PET radiopharmaceuticals of fluorine F-18 fludeoxyglucose (18F-FDG) are commonly performed using a dose calibrator and linear regression analysis. In the example of ^{18}F, the allowable physical half-life is 109.7 minutes, and the acceptable range is 105 to 155 minutes.

Figure 7: Quality Control Laboratory in Radiopharmaceuticals production facility

Establishing Radiopharmaceuticals production facility in Sri Lanka

PET-CT referrals are currently low in Sri Lanka as clinicians have to consider patient's financial status and the limited resources available for such health care services due to lack of cyclotron facilities and the costly ^{18}F-FDG transport. FDG is currently imported from India since the Cyclotron facility has not been established in the country, since over 97% of it decays while being transporting from India due to short half-life. The objective of the establishing a facility is to produce radiopharmaceuticals including ^{18}F-FDG use in PET-CT Scanners needed to improve health care services in Sri Lanka. By establishing such a facility, the country can manufacture and supply ^{18}F-FDG for PET-CT scanners efficiently while saving foreign exchange spent on importation of radiopharmaceuticals and on obtaining the necessary health-care services from abroad. Since the Sri Lanka Atomic Energy Board (SLAEB) is mandated by its Act No 40 of 2014 to utilize peaceful applications of nuclear science and technology for the socio-economic development of Sri Lanka, one of SLAEB's key functions is to build and operate the facility for the production and distribution of radioisotopes. A project to establishment of a Cyclotron in Sri Lanka has started by SLAEB under the technical support of International Atomic Energy Agency (IAEA). The project is now at the awarding stage. Once the project is successfully completed, the life expectancy of cancer patients would be increased while reducing the cost per scan incurred in such patients' management by the government.

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Biology for Sustainable Development in Sri Lanka

G. A. U. Jayasekera

Retired Professor in Department of Agricultural Technology Faculty of Technology, University of Colombo

Conserving, and consuming all kinds of resources in a responsible manner leaving enough for the future generations is the core definition of sustainability. Sustainability in Sri Lanka is difficult to define; as a country rich in resources, it is easy to be driven to exploit them for money. There are many facets to this scenario, as there are some resources that we over exploit, and some that we don't use to its maximum potential. Biology as a basic science plays an important role behind the curtains of everything we see – and this includes sustainable development. It can help identify and rectify erroneous practices in the society that could lead to great damage due to their unsustainable nature.

Agriculture is a major field where sustainability comes into play in Sri Lanka. The first step to sustainable agriculture starts before the paddy field. It begins with choosing the right variety of rice for the soil and season. It has to be followed through by sharing the right knowledge to farmers, especially regarding the correct use of fertilizer. The simplest of biological reactions can be looked into to improve agriculture. Photosynthesis is such an example. Ongoing research in trying to convert C3 rice varieties into C4 varieties brings hope for this sector. Having such higher yield crops that can be grown continuously is a big part of sustainable agriculture.

Another area that is important to Sri Lanka would be energy. The current research interest in biofuels is a great path to the future. The current use of biofuels is extremely unsustainable, especially considering the economic situation in the country. An interesting approach is distilling isopropyl alcohol using Mana plant to be used as vehicle fuel. Biofuel also has the potential to replace fuel in industries.

Our national policies highlight the need for "creating awareness of biotechnology amongst people to enable informed decision making and position biotechnology in our society" and "enhancing local industries through biotechnology." This includes promoting food production in agriculture, improving health & wellbeing through improved healthcare, promotion of bio energy and sustainable use of biodiversity and promoting clean energy. These policies are well versed, which would be vastly beneficial if implemented properly with good governance. Not only in Sri Lanka, biotechnology should be used wisely globally to improve quality of life sustainably.

As an example of how we can improve the healthcare sector, more than a century ago, two young graduates from the University of California started an innovative entrepreneurial venture. Their small business was based on producing insulin in bacteria. By 1982, their insulin was approved by the FDA to treat type I diabetes. Their drug was even able to create the highest gain in stocks for this type of product. The same process continues to be used to produce vaccines as well. Sri Lanka has the potential to lead this kind of innovation. We definitely have skilled minds to come up with innovative ideas. But what is holding us back?

Extracting anti-cancer compounds from local plants and producing finished products is another example of biology (in combination with chemistry) in healthcare. However, to make this sustainable, we need to make sure we replace the natural resources that are exploited. Sri Lanka is rich in biodiversity, and there are many avenues for scientists to explore plants with bioactive compounds. Countries like Sudan are producing some of their own vaccines at this point; in this perspective, we are falling behind.

We need more national forums for our young minds to share their ideas. These should also be multi-disciplinary, and that is when true sustainability can be achieved, as a single subject cannot do it alone. More connections need to be made between investors and bright young minds. We see many students face a lack of resources, coming in from rural areas, or unable to access a good network to bring their innovative ideas to fruition. Focusing on balancing "brain drain" and "brain gain" is the key. As Sri Lankans, we all need to think about moving forward as a country, and work together to build the future we wish to see. This requires individuals to work hard to follow their passions- make new roads to reach beyond the obstacles presented to us. We need to make better networks with global scientists so that we can carry out better research, and expose ourselves to new technology.

Having large scale physical buildings for the sake of establishing scientific institutes is proving to be redundant, and exhausts more of the limited resources we have. What we need is to exemplify working hard, in a minimalist environment. Focusing on the work rather than the facilities available is what we need. This is sustainable; otherwise, we unknowingly spend our money, time, electricity, etc into a small amount of work that does not produce good results.

Incorporating modern biology in school syllabi and university courses going beyond the old basics would be a great way to encourage the young generation towards this field. It is important to focus on it, especially in A/L syllabi, clearly stating why we need to focus on using biology in new ways. Including practical courses in syllabi is also important, rather than moving towards a memory-based education system. We keep losing our talent because our industries fail to cater to our graduates. We have to go beyond the traditional paths beyond school, and explore what our sciences have to offer.

As a country, we should also promote extra reading among students. The world is full of knowledge, and many areas remain untouched. If we push our young minds beyond the customary boundaries, our country will surely reap the results. Improving English literacy among our youngsters is also a must. It is impossible to penetrate the market today without good language skills. Encouraging science-based entrepreneurship to go beyond just publishing papers is important. That is how we have to move forwards as a country. Slowly, we can reduce losing our knowledge pool to foreign countries. We can retain our graduates if we expand our horizons, not only in using biology for sustainability, but for advancement of our country as a whole.

Interviewed and drafted by Yohara Ranasinghe, CCS Media Circle

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Integration of STEAM into Science Education for Sustainable Development

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Introduction

As a response to a growing concern about human society's impact on the natural environment, the concept of sustainable development emerged. The concept was defined in 1987 by the Brundtland Commission (formally the World Commission on Environment and Development) as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987). This definition acknowledges that sustainable development should happen without a negative impact on the capacity of the natural environment in order to meet the present and future needs of human beings, while development processes may be necessary to meet human needs and enhance the quality of life are being made. This indicates that sustainable development seeks human well-being without stretching ecological limits. Furthermore, 17 sustainable development goals (SDGs) aiming to set attainable targets that can be achieved as a 2030 agenda for sustainable development were adopted in 2015, at the General Assembly of the United Nations (UN). These SDGs are further decomposed into 169 targets, and there are currently about 230 indicators that have been proposed for realizing these targets. According to the sustainable report 2027 (Jeffrey D. Sachs & Christian Kroll, 2021) achieving the SDGs requires success in realizing six major transactions: Quality education (SDG 4); access to good quality and affordable health care (SDG 3); renewable energy and circular economy (SDGs 7,12, and 13) sustainable land and marine management (SDGs 2,14, and 15); sustainable urban infrastructure (SDGs 6,9, and 11); and universal access to digital services (SDG 9). In short, the Agenda is a universal call to action to eradicate some factors and they are poverty, protect planet Earth, and ensure that all people live in peace and prosperity. Considering these factors, it is clear that education has to play a key role in inculcating a comprehensive positive understanding, especially among the young generation in achieving sustainable development Goals. This was already emphasised at the UN World Summit in Johannesburg in 2002, where the reorientation of current education systems was outlined as key to sustainable development. Education for sustainable development (ESD) promotes the development of the knowledge, skills, understanding, values, and actions required to create a sustainable world, which ensures environmental protection and conservation, promotes social equity, and encourages economic sustainability. The aim of this article is to explore how science education with the integration of STEAM approach could support sustainable development. STEAM is simply defined as an interdisciplinary approach to learning, which can deliver academic concepts coupled with real-world lessons as students apply science, technology, engineering, mathematics, and arts. Therefore, this article first discusses science education, then STEAM education, and finally it describes how science education with the integration of the STEM approach supports the process of sustainable development.

Science Education

The term science has been defined from many perspectives but in common, they all address similar characteristic features. Setiawaty et al (2018) define science as knowledge, which is initially acquired and developed based on experiments. That means science is not just the acquisition of knowledge but also a process of discovery. In parallel to that Kalantzis (2005) views science as highlighting several key elements: science has a basis in lived experience and also has an empirical foundation, Science builds theories that model the world and develops frames of reasoning and explanation, Strong science also analyses the world, Science is application-oriented and at its best, science is inventive and innovative. The Cambridge Advanced Learner Dictionary (2012) defines science as the "*knowledge obtained from the systematic study of the structure and behavior of the physical world, especially by observing, measuring and experimenting, and the development of theories to describe the results of these* *activities*." Further, science deeply influences every aspect of human life. The expert given in the Microsoft Encyclopaedia Encarta (2003) describes that science helps to understand objects and systems that are related to our everyday life and therefore learning science is very important.

"*From its early beginnings, science has developed into one of the greatest and most influential fields of human endeavor. Today different branches of science investigate almost everything that can be observed or detected and science as a whole shapes the way we understand the universe, our planet, ourselves, and other living things* (p.82)."

As a result, science has been able to acquire a permanent place in the school curriculum in all countries throughout the world. Further, the literature provides evidence to show that to have a meaningful experience in science, it should not happen only inside the classroom and may be outside | (Reiss 2007) depending on the appropriate pedagogical actions and decisions. For instance, to provide opportunities to have fruitful science learning, it should extend to the places where the students can learn science authentically in real contexts. Moreover, science education essentially aims to systematically develop and sustain learners' curiosity about the world while enhancing scientific thinking and understanding of how natural phenomena in the world can be explained (Das and Amrit, 2014; Harlen et al, 2015). Further, the processes and content of science are of great importance to everybody in their day-to-day life, which has been defined from different angles by scholars as the aims of science education. In line with that, Trna and Trnova (2016) present three concepts of science education;

(A) Awareness of science in current, social, globally relevant, and occupational contexts in both educational and out-of-school settings, enhancing emotional personality development and basic skills

(B) Intellectual education in interdisciplinary contexts refers to an engagement with science, its terminology, methods, basic concepts, interdisciplinary relations, findings and their perspectives, which enhance individual intellectual personality development

(C) General science-related education and facilitation of interest in the contexts of nature, everyday life, and living environmental issues which take up and promote students' interests, enhancing general personality development and education.

Moreover, according to Halen (1999), preparing students for a career in science (pre-professional training) (ICUS, 2011; Chief Science Advisor-NZ, 2011), preparing the young generation for their adult roles as citizens, employees, managers, parents, volunteers, and entrepreneurs (Trna and Trnova,2016), building students' capacity for innovation and creativity (Chief Science Advisor-NZ,2011) and developing Science Process Skills (SPS) are among the major goals to be achieved in science education. Altogether, the aims of science education can be summed as, scientific literacy, individual benefit, democracy, social justice or socio-political action, and criticality (Reiss, 2007). In addition, Holbrook (2010) raises the fact that "school science education needs to respond to a changed social context and to help prepare young people to contribute as citizens to shaping the world in which they will live". Moreover, scientific literacy through science education is required by each and every individual in modern society since it influences every moment of life. ASPIRES (2013) also ensures that the population has a good level of scientific literacy (understanding of science) is also very important not only because it is good for the economy, but also because it can benefit individuals and communities economically and socially, helping to promote active citizenship and enabling people to participate in, and shape, scientific and technological developments in society. The promotion of scientific literacy has been recognized as a major goal of school science education in the world (Turiman et al., 2012, Holbrook,2010) and it is nurtured by quality science education (ICUS, 2011).

Most researchers and science educators agree that students must not only know a body of information about science, but also they must be able to do a range of scientific tasks and processes. Elaborating on this further, (Newton, 1988) claims that science education consists of two components: the content and the processes. The content of science includes laws, facts, and theories, and the processes of science consist of observing, measuring, recording,

processing data, hypothesizing, communicating and discussing, investigating, trying things out, handling things, watching, and monitoring (Wellington, 2004). Considering the teaching of science, in order to support students' scientific understanding, two interrelated areas, namely understanding of content and processes should be developed (Braund, 2008).

Science process skills can be interpreted as adaptations of skills used to study a problem, a concept, or a phenomenon in a systematic manner to compile knowledge, find answers and make conclusions. Students are directed to observe, classify, measure, use numbers, guess, conclude, and communicate the object being studied during science lessons. In addition to that, students are also guided to identify variables, form hypotheses, define variables into operational forms, experiment, interpret data, and draw conclusions. Hence, Science process skills are defined as tools that acquire information about the world (Gultepe,2016) and on the other hand is also defined as problem identifiers, formulation of the hypothesis about the problem, making a valid prediction, identifying and defining of variables, designing and experiment to test the hypothesis (Kamba et al,2018). It is well recognized that the pedagogical approaches used by teachers have to play a major role in providing opportunities for students to obtain knowledge and skills in science learning. The recent research literature provides evidence that the support of the STEAM approach for teachers in creating such a meaningful and safe learning environment.

STEAM

SMET Education which evolved out of the American government policy in the early 1990s, within the National Science Foundation [NSF] (Deghaidy et al, 2016) was later redefined as 'STEM' (Koonce, Zhou, & Anderson, 2011, Deghaidy et al, 2016). Historically, the Morrill Act of 1862, World War II, and the launch of the Soviet Union's Sputnik triggered the initiation of STEM Education in the USA, aiming to provide all students with critical thinking skills that would make them creative problem solvers and ultimately more marketable in the workforce (White, 2014). Today, all nations require a knowledgeable, skilled, and innovative workforce to be competitive in the ever-changing knowledge-based economy of the 21st century. Hence, there is a strong consensus among stakeholders in every field, especially in education and economics on the importance and development of STEM education. The acronym STEM stands for the four primary discipline families of Science, Technology, Engineering and Mathematics (Koonce, Zhou, & Anderson, 2014) and it is commonly used to describe education or professional practices in those areas (McDonald, 2016). As White (2014) states STEM can have different meanings to different people and basically, definitions for STEM fall into one of two domains: education or occupation (Koonce, Zhou, & Anderson, 2014). Accordingly, from the educational point of view STEM education includes the knowledge, skills, and beliefs that are collaboratively constructed at the integration of science, technology, engineering, & mathematic content subject of its epitome of interdisciplinary education (Lapek, 2018) or it may sometimes be referred in the literature and government reports encompassing the teaching of individual curriculum areas of science, digital and design technology, mathematics (Honey, Pearson and Schweingruber,2014).

According to the literature it has proved that STEM education can be applied in all educational stages including the Montessori (preschool) stage. As emphasized by Granovskiy, (2018), typically STEM education includes educational activities across all grade levels from preschool to post-doctorate in both formal (classrooms) and informal (after-school programs) settings. Authentic STEM education is expected to build students' conceptual knowledge of the interrelated nature of science and mathematics, in order to allow students to develop their understanding of engineering and technology (Hernandez et al., 2014). In other words, students acquire the knowledge and skills learned in two or more STEM disciplines that are applied to real-world problems and/or used to deepen understanding and find the most suitable solution.

The importance of STEM educational implementations is emphasized by scholars in several studies. They energize the learning environment, revitalizing the curriculum with real-world relevance and establishing connections to everyday life experiences while fostering creativity, problem-solving, and critical and higher-order thinking. Moreover, such a learning experience empowers the student to cope with multifaceted and complex real-world problems in the future as they essentially require multidisciplinary understanding. As well it has identified and proven that knowledge and competencies gained studying science, mathematics, engineering and technology is essentially useful to build up individuals to meet the challenges of the 21st century globally. As well they are proficient enough to meet the demands of 21st-century workplaces.

According to Feng-Day (2017) STEM education only concerns the project itself (what and how to do), While ignoring the concern for the person itself and the background (who does and why), so STEM in the breadth and depth of interdisciplinary knowledge there are still some limitations. All these resulted in the transformation STEM into STEAM, where A stands for arts.

At present, there is a growing emphasis on STEAM, which engages students in the subjects of science, technology, engineering, arts, and mathematics. As Dell' Erba, (2019) defined, it is an approach to teaching, in which students demonstrate critical thinking and creative problem-solving at the intersection of science, technology, engineering, arts, and mathematics. According to Yakman (2008), the founder of STEAM education, STEAM is a developing educational model of how the traditional academic subjects (silos) can be structured into a framework removing the boundaries between each by which to plan integrative curricula.

On the other hand, STEAM education directs students to collaborative problem-solving (Herro et al, 2017) through interdisciplinary thinking (Jia, Zhou, and Zheng, 2021) and collaborative learning. Collectively all these processes develop students '21st-century skills, referring to the knowledge, skills, and character traits that are deemed necessary to effectively function as citizens, workers, and leaders in the 21st-century workplace (Bryan et al., 2015).

Science education with the integration of STEAM, toward sustainable development

As discussed above it would be worthwhile to think about how the integration of STEAM into science education would open more avenues to obtain meaningful learning experiences that support sustainable development by promoting the development of the knowledge, skills, understanding, values, and actions required to create a sustainable world, which ensures environmental protection and conservation, promotes social equity and encourages economic sustainability.

Science education while integrating STEAM appropriately can be offered to enhance the quality of education. For instance, while integrating STEAM students are offered more avenues to learn science in an overall view while interrelating to other disciplines in the real context as an actively engaging collaborative activity that provides meaningful learning. Furthermore, the integration of STEAM allows teachers more space get pedagogical decisions and actions to provide learning experiences in students centered approach (Kurshan and McManus,2017). This approach develops students' communication skills, decision-making skills, team working skills, reasoning ability development of ideas and solutions which are essential components in 21st-century skill and competency development. Moreover, by integrating STEAM, a science teacher can provide more opportunities for students to learn science while empowering them to be curious learners who seek creative solutions to take thoughtful risks, engage in meaningful learning activities, become resilient problem solvers, embrace and appreciate collaboration and work through the creative proces .

As mentioned above science is a subject that can be taught while incurring curiosity among students. The integration of STEAM opens more opportunities to the teacher to get pedagogical actions in creating learning activities while incurring students' curiosity about the world while enhancing scientific thinking and understanding of how natural phenomena in the world can be explained (Das and Amrit, 2014; Harlen et al, 2015). Not only that by integrating STEAM, as the teacher provides opportunities for students to acquire the knowledge and skills connecting to two or more STEM disciplines that are applied to real-world problems helps to deepen understanding and find the most suitable solution for the given problem. This experience will contribute to a positive impact on sustainable development.

The integration of STEAM energizes the learning environment of the science classroom, revitalizing the curriculum with real-world relevance and establishing connections to everyday life experiences while fostering creativity, problem-solving, and critical and higher-order thinking definitely contribute the sustainable development.

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Themed Collection

Sustainable Development Goals and the Role of Chemists and Chemical Sciences

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Background

One of the most important and remarkable events in the 70-year history of the United Nations (UN) was the declaration of 17 Sustainable Development Goals (SDGs) on 25 September 2015. Through this declaration, 193 member states of the United Nations which includes Sri Lanka also, agreed on a collective global mission to transform the planet to achieve a sustainable future by with a target year of 2030. Progress towards the SDGs will be measured against 169 specific indicators. While the Millennium Development Goals declared by the UN in 2000 focused on specific problems of the world's poor and shaped the development aid policies of the richest countries, the new SDGs envisage a global vision of development for all, based on the principle of sustainability. The responsibility is shared by all the countries. At its heart are the 17 Sustainable Development Goals (SDGs), for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and induce economic growth while tackling climate change and working to preserve our oceans and forests.

Generally, awareness of the SDGs, and their central importance is inadequate among the majority of practicing chemists or their professional bodies. The probable reason is that, the chemists too often busy themselves with short-term problems and research interests and do not see the broad picture. The International Organization for Chemical Sciences in Development (IOCD) with a deep concern for the future of both the planet and the chemical sciences, have issued a call to all their chemists to adopt the SDGs, as done by their governments and use this platform to reposition chemistry in a broader context and to ensure that chemistry plays its specific role as the central science.

Importance of Chemistry in achieving sustainable development goals

The knowledge and products contributed by chemistry such as providing sources of energy; a host of materials including polymers, plastics, semiconductors and solid-state display devices, agents for crop protection and plant growth, pharmaceuticals and many more have been a major factor in the advances in human wealth, health and well-being over the past two centuries and justify chemistry's claim to be the 'quality of-life' science than any other discipline. It is the source of innovative new products and processes, including smart materials for better lifestyles, catalytic processes for light harvesting towards hydrogen production and carbon dioxide fixation, new vaccines and drugs for currently incurable diseases, and sensors for disease diagnosis *etc*.

We are also aware that, agriculture, irrigation/drinking water, food, medicines, textiles, surgical equipment, soap, toiletries, detergents, washing powder, building materials and equipment used in detecting diseases are all based on chemicals and chemistry itself is the Central Science. It plays an important role in day-to-day life as well as in high technology products crossing all the sectors. If we just look into our food and nutrition aspects, we need to develop agriculture to produce food and to achieve this we should provide organic/chemical fertilizer. Especially, we should provide NPK and micronutrients in the form of chemicals or organic material. The plants absorb what they need. If that is so, we should produce standard fertilizer and ensure the quality. Similarly, we should introduce environmentally friendly weedicides. Inadequate human resources and advanced technology, tractors, machines, suitable seed and fertilizer etc are the constraints affecting agriculture.

By the year 2050, food should be provided to a population of an estimated 9.4 billion. Therefore, action should be taken not only for increasing food production but prevention of wastage of foods to 100% and ensure food security. Chemicals that are not harmful will be required for this purpose. With a view to maintain the quality standards, the services of professional chemists are required.

We know that there is no good attitude towards CHEMICALS in our country as well as in the world. Chemistry must also accept responsibility as one of the sources of many processes and products that have inadvertently contributed to a range of emerging global problems. The changes to earth's air, land and sea environment due to human activity have accelerated in the past 200 years resulting in global warming, damage to the protective ozone layer and depletion of natural resources. Increasing energy consumption, industrial activity, population growth and urbanization add pressure to the planetary system and it is clear that major changes are now needed if multiple crises (relating to food, water, climate and energy) are to be avoided and humanity is to move to a path of sustainability.

We use fossil fuel but they are running out and causing global climate change. Precious elements which are in short supply, in a linear use-and-discard economy, causes resource depletion. The only way out is using renewable resources. We must use them in a circular economy in which everything is used for longer, reused, repaired and eventually fully recycled. Then only the generations could enjoy the diverse and beautiful world which will be good to inhabit. This important transformation, which is now urgent, will have new chemistry and chemical engineering processes at the forefront which must be implemented quickly. Application of circular economy concept, could be started even from the home set up. Achieving almost all of this requires major inputs from chemists and chemical engineers. We should do whatever possible to contribute towards achieving these goals.

It is very convenient to combine **green chemistry** and 12 principles of sustainable chemistry and green food analysis principles to achieve 17 **Sustainable Development Goals**. Similarly, in the chemical analysis of food it could be done according the **concept of green food analysis**.

17 Sustainable Development Goals (SDGs)

1. No Poverty: End poverty in all its forms everywhere.
2. Zero Hunger: End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3. Good Health and well-being: Ensure healthy lives and promote wellbeing for all at all ages.
4. Quality education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
5. Gender equality: Achieve gender equality and empower all women and girls.
6. Clean water and sanitation: Ensure availability and sustainable management of water and sanitation

for all.

7. Affordable and Clean energy: Ensure access to affordable, reliable sustainable and modern energy for all.
8. Decent work and economic growth: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
9. Industry, innovation and infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
10. Reduced inequalities: Reduce inequality within and among countries.
11. Sustainable cities and communities: Make cities and human settlements inclusive, safe, resilient and sustainable.
12. Responsible consumption and production.: Ensure sustainable consumption and production patterns.
13. Climate action: Take urgent action to combat climatic change and its impacts.
14. Life below water: Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
15. Life on land: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.
16. Peace, justice and Strong Institutions: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and effective, accountable and inclusive institutions at all levels.
17. Partnership for the Goals: Strengthen the means of implementation and revitalize the Global Partnership for sustainable development

The Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges faced by the people, including those related to poverty, inequality, climate change, environmental degradation, peace and justice. The 17 Goals are all interconnected, and in order to leave no one behind, it is important that we achieve them all by 2030. (https://www.un.org/sustainabledevelopment/sustainable-development-goals;).

Role of Chemistry in achieving SDGs

The importance and relationship of Chemistry as a Central Science and SDGs are reviewed below based on a literature review carried by us. The relevant SDG's are taken together to facilitate discussion.

Zero Hunger: End hunger, achieve food security and improved nutrition and promote sustainable agriculture (SDG2)

It has been observed that Agrochemicals (fertilizers, weed-killers and pesticides) can enhance crop production by up to 50 %. Since we produce approximately the amount of food needed to feed the world's population, although some people have too little and others too much, it follows that around 2–3 billion extra people are able to be fed because of the positive effect of agrochemicals. Agrochemicals must be highly active (only small amounts used), highly specific (only having the required effect and only in the desired place) and non-toxic (if they enter the food chain, they must be benign). Many chemicals with all these properties are available, but some are threatened with a ban without a full risk–benefit analysis being carried out and on the assumption that they are affecting the health or environment. The recent attempts to ban the use of glyphosate in some countries including Sri Lanka falls into this category.

Promotion of preserving agricultural products for the use during lean periods, food technology, chemical technology and traditional methods to prevent post harvest losses and longer storage, proper supply chain management, reduction of waste during transport, getting maximum price by maintaining good quality are important in achieving this goal. Use of traditional foods such as kos, del, manihot etc as substitutes for rice, should be promoted. Use of products such as coconut water and coconut scrapings after obtaining its milk should be promoted.

Good Health and welfare: Ensure healthy lives and promote wellbeing for all at all ages (SDG3)

Tackling antibiotic-resistant organisms, ameliorating (make something better) diseases of ageing (dementia, Parkinson's disease, many cancers) and lifestyle diseases (obesity, diabetes, drug and alcohol abuse) will require many new kinds of medicines. These will be made by chemists and commercialized by chemical engineers. Economically prepared balanced diets will provide essential macronutrients, carbohydrates and fats along with vitamins, minerals and water.

Polyphenols, flavones, anti-oxidants are naturally available chemicals. Consumption of them in correct portions at correct age will prevent NCDs while protecting health. During certain seasons there will be food shortage and therefore, chemists should identify proper chemicals and technology to preserve the foods for future (*e.g.* dehydration of food) the quality which will be same as their natural products. When foods such as "Yahaposha" are provided, people will not be satisfied to take them as a main meal. When fresh fruits are not available dehydrated fruits can be consumed. Availability of adequate food of good quality will certainly lead to a healthy population. This will enable to build up immunity of the population. Necessary action should be taken for awareness building. At the same time measures for consumer protection can play an important role.

Quality Education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all (SDG 4)

Chemical education throughout the world is generally of very high quality at school and secondary and tertiary levels. The skills of a chemistry graduate are in high demand not only for employment in chemistry but in many sectors in which analytical thinking is required. However, one area which accords little attention in chemical education is ethics. The European Chemical Society (EuChemS), through Jan Mehlich, has developed the online course Good chemistry—methodological, ethical, and social dimensions consisting videos with quizzes, case studies, assignments and assessments. Such a course should be a prerequisite for working in any chemical or other scientific environment. It is also important to start capacity development even during the childhood and up to adults level. Application of Green chemistry, synthesis as well as technology and analysis are important in achieving the SDGs. Communication materials should be developed and workshops, seminars, exhibitions and teacher education should be conducted.

SDG 5. Gender equality: Achieve gender equality and empower all women and girls (SDG5)

Surveys in many countries show that although almost equal numbers of men and women take chemistry undergraduate programmes, only about 30% of the workforce in the chemical industry are women. In academia, the situation is worse with only 9%of chemistry professors being women. There is even poorer involvement of women in chemical engineering. We are losing a huge talent pool and therefore, we must change the culture, the working hours, childcare and the handling of maternity leave so as to make our wonderful subject attractive and accessible to all.

Committee on Women Chemists has been established by the American Chemical Society (ACS) in 1927 as the Women's Service Committee to encourage women chemists to take an active interest in Society activities. The Committee serves as a forum for women in chemistry and related professions; develop recommendations regarding issues of interest to women chemists; provide a means of increasing and improving participation of women in the chemical sciences and the Society; promote the recognition of women chemists; and inform the Council and other appropriate Society bodies of the Committee's activities. The Institute of Chemistry Ceylon as the professional body of Chemists in Sri Lanka has established a Women Chemists Committee.

Clean water and sanitation: Ensure availability and sustainable management of water and sanitation for all (SDG6)

It has been estimated that about 2,000 babies and children under the age of 5 die each day because they do not have access to clean water. In many countries, having ready access to cheap chlorine allows for safe purification of water. The dual use of chemicals is a serious problem so the development of new water purification processes that can be carried out in remote places is essential. Sophisticated processes such as using photoexcitation of TiO_2 with sunlight to generate hydroxide radicals that destroy pollutants will have their place, but many other possibilities urgently await attention of chemists. On the other hand, the process of reusing water has to be started from household level. Using and reusing of water in industry and labs without wasting it is of utmost importance.

Affordable and Clean Energy and Climate Action (SDG 7& 13)

The provision of clean energy and climate action are closely associated with each other. Sun light is the only source of energy coming into the earth which must be harnessed more effectively than we do at present.

Biomass, wind, wave, hydro are all methods of converting solar energy to electricity, and more recently we have introduced photovoltaics. These must all be expanded and the conversion made more efficient by the chemists and chemical engineers who should lead the process.

Hydrogen could be an ideal fuel. It burns only to make water and it can be produced from water by electrolysis or perhaps direct photolysis using sunlight. Direct photolysis has been rather inefficient, but a system based on earth-abundant elements has achieved 4.7% conversion efficiency but more work is required before its commercialization. Handling and storing of hydrogen would be another challenge, whether it be stored through physical adsorption or reversible chemical complexation. Therefore, further progress is required in this area. "Town gas" had been in use in stoves for heating and cooking which is still used in some countries. Town gas contains 50% hydrogen and it was stored in gasometers and distributed through pipes. Despite its explosive nature, its distribution and safe use is well known.

Governments should promote setting up of smaller solar panels at household level as well as in other small establishments. Production of bio gas using wastes from agriculture and animal husbandry and use of solar power will save much needed foreign exchange. Some people in urban areas as well as in rural areas started using burned coconut shells in specially prepared hearths for cooking of their food during the shortage of fuel and LP gas in Sri Lanka recently.

To ensure that global warming can be controlled, it is probably not sufficient just to stop using fossil fuels, especially with the disparity in per capita energy use. It is necessary to extract CO_2 from the air and use or store it safely. This will be a major undertaking with CO_2 present at only 400 ppm; too much for the climate but very dilute for extraction. Although the overall atmospheric concentration is low, the amount of CO_2 that will have to be removed is huge. Still, we do not really know about any methods that should be adopted. Therefore, more creative thinking is now necessary. However, clearing forests in large scale as seen in many countries without replanting schemes and devastation of large extents of forest areas due to fire will quickly make the problem even more urgent.

Methane is emitted from variety of anthropogenic and natural resources. It is more efficient at trapping heat than other gases. Methane has more than 80 times the warming power of CO_2 over the first 20 years after it reaches the atmosphere while it is responsible for around 30% of the current rise in global temperature. Australia has recently signed a global pledge to cut methane emissions by 30% by 2030 thus becoming the 122th country that had already adopted the non binding pledge. Farming and food production should be more environmentally friendly. Animals should be fed with more nutritious feed.

The chemical sciences help to understand, mitigate, and adapt to climate change. A detailed understanding of pollutants and their chemistry in important in interpreting health effects, regulating emissions and developing pollution reducing technologies. Chemists can also be part of the effort to understand and address new problems such as potential effects of different chemicals that the people are exposed to.

Industrial Innovation and Infrastructure, Sustainable Cities and Communities and Responsible Consumption and Production (SDG 9, 11 and 12)

Our attitude towards the way we make and use consumer items need to change. At present we make an item for consumer use and build in redundancy so that when one part breaks, for example the door of an oven, we think of buying a new machine and the old one is discarded or kept on the road side for the garbage truck to remove it. This is an example of the linear economy which consumes raw materials sometimes at an unsustainable rate and also it produces considerable amounts of waste.

Therefore, we will have to move very quickly towards the circular economy where we manufacture objects to last, we use them for longer, we replace or repair parts that breakdown, we reuse them in whole or in part. When the object has come to the end of its useful life, we recycle as many of the elements in it as possible thus the waste becomes a raw material and we move away from both element depletion and waste accumulation.

In the present economy some manufacturers are reluctant to produce long lasting equipment and machinery with a view to reducing the cost and meet the requirement of the ordinary people who have lesser purchasing power. Such items with a short span of life will be disposed without repairing and reusing. Certain equipment cannot be repaired due to high cost of spare parts. Manufacturers should be encouraged to produce durable items and contribute to circular economy.

The European Chemical Society (EuChemS) released a new version of the periodic table as a part of celebrating the International Year of Periodic Table (2019) which highlights element availability and vulnerability towards dispersion. It also highlights which elements can come from conflict minerals and 31 elements that are in smartphones. It is important to note that all the elements that can come from conflict minerals are in smartphones and six of the elements in smartphones are expected to be depleted within 100 years if we carry on as we are. Smartphones are the archetypal use and-discard technology, often being replaced every 2–3 years. It has been estimated that about 10 million smartphones are exchanged in Europe every month. Many of these phones are not traded in but kept in drawers or cupboards. The elements in these phones are beyond reach for recycling. In a recent survey the Royal Society of Chemistry (RSC) found that 51% of all homes in the UK have at least one unused piece of electronic equipment and 42% have more than five. For those phones that are handed in, there are not enough ethical recycling facilities available. Sri Lanka, with a population of 21.6 million use 38.9 million phones according to statistics.

Life below water: Conserve and sustainably use the oceans, seas and marine resources for sustainable development. (SDG 14) and Life on land: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. (SDG 15)

Fisheries development is an important source of food production and hence action should be taken to protect our territorial sea water from exploitation by other countries. Every measure should be taken for sustainable fish production which needs a common approach by the countries. Marine environment pollution should be minimized. Bilateral agreements, awareness creation and implementation of rules and regulations play a greater role. Life forms which are diverse depend on a clean and vibrant ecosystem. Our waste cannot be continued to dump into the land and the sea.

We grow plants, which we eat either directly or through animals that have eaten them. All the nutrients then end up in human bodies and mostly in human excrement which, after treatment, is flushed into water areas and ultimately into the sea. We then have to replenish the land using fertilizers—another example of the linear economy. There are considerable opportunities in recovering elements such as phosphorus from human excrement.

All around us we use plastics which is a very popular material due to their unique properties. Polyethylene gas pipes and Perspex windows are just two examples. As people abuse the use of plastics through thoughtless, reckless linear economy the land and the seas become heavily polluted. Single-use plastics can be stopped, but there is a need to have good ways of dealing with end-of-use plastics. All plastic objects should be reusable and recyclable.

Some plastics are biodegradable, but they can do considerable damage to the environment during the period of biodegradation. Hence, they should not be allowed into the wider biosphere. Some of the plastics used can be replaced by paper, wood, plant material, clothe and other bioderived materials, but still there is a considerable opportunity to design new polymers for specific tasks.

Partnership for the Goals: Strengthen the means of implementation and revitalize the Global Partnership for sustainable development (SDG 17)

Chemists and chemical engineers should play a key role for future sustainable world, but they must work with experts from other disciplines such as agriculture as well as sociology, psychology and politics and all the other branches of science and engineering. They should not limit risk assessment of everything that they plan to do in the lab but it is necessary to take a much wider view about the long term consequences of what they propose. They should discuss with other partners on their plans and get necessary advice on minimizing possible risks.

No Poverty, Decent work and economic growth, Reduced inequalities, Peace, justice and Strong Institutions: (SDG 1, 8,10 and 16)

The objectives of these goals are to end poverty in all its forms everywhere, promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all reduce inequality within and among countries and promote peaceful and inclusive societies for sustainable development, provide access to justice for all and effective, accountable and inclusive institutions at all levels.

The challenges mentioned above and their successful completion will provide considerable benefits to those who have been involved in the discoveries and their implementation will help in achieving the four goals of “no poverty”, “decent work and economic growth”, “reduced inequalities” and “peace and justice. The chemists and chemical engineers will play an indirect but important role in achieving these goals.

Establishment of a National Secretariat for the Professional Practice of Chemistry (NSPPC)

The Institute has taken steps to establish a National Secretariat for the Professional Practice of Chemistry (NSPPC) since June this year (2022), which covers the performance of services related to public interest, public safety, and legal or regulatory matters. The National Secretariat will be responsible for identifying special fields of importance for the practice of Chemistry, maintaining a Register of Chemists for each field, continuing professional development, implementation of the Code of Ethics for Chemists and overall administration. The National Secretariat will undertake programs for the implementation of Sustainable Development Goals (SDGs) and the International Year of Basic Science for Sustainable Development (IYBSSD 2022) in view of their relevance to the objectives of Institute of Chemistry Ceylon. The activities lined up for the Year are as follows:

1. Communication with UNESCO, IUPAC, OPCW and other relevant agencies regarding raising of funds.
2. Virtual official inauguration of IYBSSD 2022: Professional organizations, Institutes of Biology, Physics, Mathematics will be contacted for participation
3. Virtual IYBSSD 2022 exhibition and trade fair.
4. Seminars and workshops
   a. CPD : Professional Chemists
   b. SDG: 1. Individual, 2. Industry, 3. Policy makers, 4. Universities and schools
5. News releases and publication of articles and supplements
6. Publication of IYBSSD 2022 special issue: ‘Chemistry in Sri Lanka’
7. Public Awareness programs / chemical magic shows/Inter university debates/cultural programs
8. Webinars: Seminars/Discussions (University/ Industry/IChemC) Identify Webinar topics.
9. Chemistry day in schools
10. Establishment of mobile laboratory units
11. Interschool chemistry quiz programs
12. ‘Education for All’- BSc, Diploma in Laboratory Technology course and Chemistry Graduateship program etc: Strengthen the evaluation of quality of programs to achieve SDGs

13. Feeding of information to the Website /U tube/ Facebook
14. Publication of an IYBSSDC 2011 souvenir by the end of the year.
15. Launching of programs to achieve 12 Sustainable Development goals of Chemistry

Institutes and others to be involved

Based on the experience gained by the Institute of Chemistry Ceylon in the capacity of National Adhering Organization for International Year of Chemistry (IYC 2011), action has been already initiated to involve institutions such as UN, UNESCO, IUPAC, IUPAP, RSC, all the government ministries, relevant government statutory bodies, government academic institutes, chemists, scientists, academics, university students, school children, and private sector industries in the programmes that have been planned by the Institute. The industries will include the following.

1. Production of Chemicals (Raw)
2. Food Industry
3. Packaging Industry
4. Pharmaceuticals/Medical drugs Industry
5. Medical Diagnostics products industry
6. Cosmetic Industry
7. Plastics Industry
8. Rubber Industry
9. Cement & cement products Industry
10. Agrochemicals Industry
11. Petroleum industry
12. Paint Industry
13. Paints Industry
14. Textiles & Apparels industry
15. Herbal products Industry
16. Ayurvedic products
17. Medical devises Industry
18. Veterinary products / foods / pharmaceuticals industry
19. Ceramics Industry
20. Steel Industry
21. Mineral Industry
22. Printing industry
23. Water technology
24. Environmental products industry
25. Pulp & paper industry
26. Printing industry
27. Computer industry

Summary

The theme of the Institute of Chemistry for the Year 2022/2023 is "Role of Chemists in Achieving Sustainable Development Goals". Chemistry can help to meet all of the SDGs to varying degrees. In particular, the chemical sciences are central to (i) the development of clean and sustainable forms of energy, for example, through efficient capture of solar energy, clean fuel cells and carbon capture, storage and reuse; (ii) the application of green chemistry principles and processes to manufacturing and for material substitution; (iii) ensuring the efficient and affordable recycling of resources in short supply including 'endangered elements' and natural products; and (iv) developing new analytical techniques needed for more effective monitoring of the environment. Orientation of chemistry and chemical research towards sustainable topics is the main gateway to attain SDGs in the society. Careful interaction with chemistry and chemical compounds leads to sustainable life. As the leading professional body of chemists in Sri Lanka, the Institute will take action to contribute to the achievement of SDGs through a series of programs with the participation of chemists, chemical industries and government agencies as well as international organizations. Already several programs have been initiated. The Institute will also take the lead in IYBSSD 2022 based on its experience gained in the successful implementation of IYC 2011as its Adhering organization in Sri Lanka.

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Themed Collection

Science Education in Sri Lanka: Current Status and Challenges Ahead

Sumedha Madawala

Chairperson, Board of Study in Science Education, Postgraduate Institute of Science, University of Peradeniya

The recent pandemic and the following economic turmoil have challenged all sectors including the education. The Covid – 19 outbreak numbs entire nations across the world, affecting both teachers and students alike. Of all major areas, Science Education seems to be the worst affected as Science is best taught in face-to-face mode. Once the teaching-learning process was switched to online mode overnight, the teachers struggled to convey important scientific concepts to their charges through these digital modalities that are new to them as well as for their charges. In comparison to western countries, developing countries like Sri Lanka faced even worst consequences due to lack of resources and infrastructure facilities to adjust to this new mode of teaching-learning process. Despite all these consequences of the pandemic, the importance of science literacy has never been highlighted as much as it was during the Covid era. Science literacy helped people to better understand the Covid-19, its origin and mutations, its spread, long-term health consequences, the significance of the vaccination program etc. For example, the health authorities managed to get rid of the peoples' fear of the vaccination drive through awareness programs, where people with strong scientific literacy were able to grasp the importance quickly that prompted the rest to follow. Furthermore, this understanding also helped authorities to make people conscious of preventive measures to control further spreading. The preventive measures of Covid-19 such as social distancing, personal hygiene such as hand washing, wearing masks etc. and their importance were effectively conveyed to the general public with the help of their sound knowledge in science.

As the pandemic is creeping away from our horizon, the country is facing now the worst economic turmoil since the independence in 1948. Corruption, long-term mismanagement of public funds, unsustainable developmental projects, and ill-conceived policies are some of the contributory factors for the present debacle. To make things worse, the economic crisis is bringing new challenges to the education sector. In order to bring the national economy back on tracks, some short- and long-term progressive measures should be taken. Science Education has long being recognized as a key indicator of the economic and social growth of a country. Education is known to increase productivity and creativity, thus triggering entrepreneurship and technological innovations. Therefore, it is crucial to allocate more resources to secondary education to boost the economic development. This impact is much higher than what could be achieved by primary education alone (Grant, 2017). Accordingly, the Sustainable Development Goals (SDGs) have earmarked education targets to include that 'by 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes'. Especially for poor countries, the right investments in the education sector can lessen the poverty notably. As a fitting step towards this future goal, the United Nations General Assembly adopted a resolution proclaiming the year 2022 as the year of Basic Sciences for Sustainable Development, highlighting the decisive role of Basic Sciences for sustainable development as well as the vital link between Science Education and Sustainable Development Goals. Taking into consideration all the challenges faced by Sri Lanka in recent times, it is a timely action to identify issues and challenges related to Science Education and bring some progressive reforms to rectify them. If the authorities and policy makers have taken timely decisions and policy directions, this could be the first step in steering the country towards the economic prosperity.

Current challenges

The report released by the National Institute of Education (NIE) in 2018 has clearly identified the issues that the country's overall education system face. This comprehensive report also proposed some productive and far-reaching reforms to resolve some of these long-lasting issues. The proposed reforms are imperative in facilitating the rapid advancements in science and technology and, also to inculcate useful skill and knowledge in students that required beyond the 21st century. In the Sri Lankan context, the lack of equal access to quality education is one of the huge impediments in the Education sector, which is not yet addressed appropriately. According to Abayasekera and Arunathileke (2018), the schools with better allocation of physical and human resources perform better at the G.C.E. (O/L) examination. According to a report released by the World Bank in 2011, the G.C.E. (O/L) pass rate in Science has declined from 55% to 48% during a time span of 7 years (from 2002 to 2009), largely owing to high province-wide disparity with 20% difference in the year 2009 alone. The Western Province recorded the highest pass rate and the lowest in Uva Province. Furthermore, out of the 93 education zones in Sri Lanka, Colombo zone ranked top with a pass rate of 68%, while the Madu Education Zone trailed behind with a mere 9%. According to a National Cognitive Achievement Test conducted by the University of Colombo for grade 8 students in 2005 and 2008 also revealed an achievement gap between urban and rural schools as well as between school types. In urban schools, the level of achievement has risen from 57.5% to 58% from 2005 to 2008, while rural schools it was 52.4% to 55.1% for the same time period. Significant differences were also noted for between school types, 1AB, C and 2. All these evidences suggest the inequalities exist in schools in terms of infrastructure facilities and human resources. The lack of monetary strength of the country could be one of the major impediments to improve infrastructure facilities and share resources in an equal manner, which is expected to be further strained by the current economic crisis. Sadly, the dearth of budgetary allocations is not the only reason behind these disparities. The lack of unbiased policies to share resources in a fair manner between schools irrespective of their locality and school categorizations also have contributed to this plight in rural schools. While some urban schools receive politically-motivated galore of resources and infrastructure facilities, schools in rural areas are even without basic necessities. In comparison to other subjects, the shortage of Science teachers is another chronic issue in provinces including North-Central, Northern and the Central. Therefore, it is crucial for the policymakers to take some progressive steps to address and rectify these issues in the education sector. Ignoring these issues may lead to more serious social consequences in the future.

According to the current Science curriculum, both teachers and students are unnecessarily overburdened by its exceptionally high content and coverage. The curriculum reforms and syllabus revisions that have been carried out from time to time add more content to the existing syllabus making things unendurable for teachers and students. With the rapid development of Information and Communication Technology, the facts are easy to gather, thus spoon-feeding facts is not necessary anymore. Instead, the rote learning should be encouraged and the teachers should guide students to search knowledge. It is important to enhance their skills to gather and collate relevant information, analyze and interpret them logically and communicate the findings to a relevant audience. Unfortunately, the students are overburden with facts with less or no attention given to improve their soft skills. Interactive sessions and hands-on practicals are far behind, which are crucial in the teaching-learning process in Science Education. Though teachers are encouraged to use novel methodologies in teaching, the enormousness of the syllabus may not give them a chance or time to follow them. Furthermore, the current curriculum is designed mainly to face national examinations rather than steered towards meeting the objectives of national goals and 21st century skills. As the global labor market is changing rapidly, it is the responsibility of the education policy makers to adjust the education system not only to cater the national economic goals but also the global labour market.

In science education, laboratory work and practical play an important role in conveying scientific concepts to children effectively and also to get some hands-on skills. However, these hands-one activities receive less attention in today's school education system in Sri Lanka. Despite rightly introducing student-centered, activity- and competency-based teaching and assessment strategies in 2007 with the aim of developing personal, inter-personal and higher order thinking skills, it is worth checking that these are actually practicing in schools, especially in G.C.E. (O/L) and (A/L) classes (World Bank Discussion Report, 2011). Teachers are busy completing their bulky syllabi, thus have little time to spend on laboratory activities and practical with zero contribution to final grades at national competitive examinations. Lack of laboratory facilities and poor student attendance are also known reasons for not undertaking laboratory activities in schools. Thus, in order to make a significant impact of the practical component in the school curriculum, it is vital to make it a compulsory component in the final assessment with some contribution to the final grade. However, in order to make this a reality, the laboratory facilities need to be developed in all schools, to make it a fair judgement.

The lack of well-trained teachers is another obstacle that needs urgent attention from relevant authorities. Rural schools are generally constrained by lack of well-trained teachers or even no teachers at all. Even if teachers are available, sometimes the quality of Science teachers is questionable. Due to the lack of trained Science teachers, sometimes the school authorities are compelled to assign Arts graduates to teach Science, and is a common occurrence in rural schools. On-going training programs are crucial to update teachers with new information, teaching methodologies, new syllabus revisions etc. The lack of ICT literacy among teachers is another drawback especially in an era where virtual and/or hybrid modes of teaching are in the forefront. In-service teacher education programs for Sri Lankan teachers are broadly classified into long- and short-term programs. The long-term training programs are mainly conducted by universities, National Institute of Education and Teacher Training Colleges in Sri Lanka. Of them, universities are especially aiming graduate teachers, while the NIE and Training Colleges conduct training programs for non-graduates as well. The short-term in-service programs (ranging from one day to 7 days) are conducted by provincial level by in-service advisors and Subject Directors of the Zonal Education Departments attached to the Ministry of Education (MoE). These short-term programs help teachers to broaden the understanding of curriculum reforms, innovative teaching methodologies etc. Despite this well-structured mechanism and some benefits, the effectiveness of these in-service programs has shown some limited outcomes. Lack of human resources, monetary incentives, issues related to coordination, and lack of enthusiasm of the teachers are some of the reasons for making this system somewhat ineffective.

Measures taken and Challenges ahead

Reforming the education system of a country from time to time is crucial to make it align with rapidly changing global educational trends. Through many stakeholder discussions and research, the authorities have rightly identify the drawbacks in the existing system, and even proposed some progressive measures to rectify them (NIE, 2018). So far, key reforms to the Science curriculum and, teaching-learning methodologies have been introduced in 1999 and 2007 with the prime aim of improving Science Education. Even at present, the NIE is in the process of reforming the school curriculum with the aim of switching from teacher-centric and examination-oriented education to a more dynamic system of student-centered and skill-oriented education, which is a much-needed step in the education sector in Sri Lanka. In addition, teacher training is also needs careful consideration from the authorities to make it more effective. Over the years, Sri Lanka has taken steps to bring reforms to the curriculum of the Science Education to achieve future goals of the country. In addressing these reforms and bringing new policies, the National Education Commission and the National Institute of Education are in the forefront. Some of the aims of these reforms are that students should give opportunities to master skills and knowledge and attitudes required for higher education while acquiring practical competencies and soft skills (NIE, 2018).

During the last decade, reforms have been introduced in the science curriculum and new teaching-learning strategies with the aim of improving the learning experiences and outcomes. Competency-based teaching, learning and assessment practices were introduced to enhance students' skills, while novel teaching methodologies were announced to improve student-centered learning and student-teacher interactions. Despite taking some progressive measures over the years, some issues are still lingering due to various reasons. Introducing new teaching-learning methodologies is definitely a positive outcome of identifying the lapses in the existing system. Despite introducing activity- and competency-based teaching and assessment approach to the Science teaching-learning process, their actual practice in schools is questionable. Identifying reasons for this lack of consistency among teachers and their reluctance to implement them is crucial to bring remedial measures in the future. The lack of initiative, knowledge and hands-on experience to implement these new teaching approaches are some of the reasons pointed out by teachers for not adhering to the instructions given by the education authorities. Despite providing pre- and in-service training opportunities for teachers to disseminate this information, the lack of motivation of the teachers to learn new teaching methodologies can be a major hurdle to overcome. Due to the lack of transport facilities, monetary incentives and other day-to-day hindrances, teachers are reluctant to learn and employ new teaching interventions, and thus stick with conventional teaching methods. Lack of time to complete the syllabus before national examinations can be another setback to implement new teaching-learning approaches. In new interventions, the teachers need to spend some quality time to organize activity and lesson plans prior to the class, which could be another reason why some teachers shy away from implementing them. The exam-oriented education system is another major setback in implementing activity- and competency-based teaching and assessment strategies as well as laboratory work.

The state-owned universities can be a major partner in assisting training teachers in a methodical manner. The postgraduate Institute of Science (PGIS), University of Peradeniya and also the Science Education Unit, Faculty of Science, University of Peradeniya is doing a noteworthy contribution in training teachers in Science Education. The PGIS offering two programmes; Postgraduate Diploma in Science Education and Masters' degree programme in Science Education (SLQF Levels 9 and 10) for science teachers since 2006. In addition, the Science Education Unit of the Faculty of Science, University of Peradeniya conducts 'Science Camps' in schools to popularize Science, enhance students' attitudes and interest in Science. The Ministry of Education (MOE), Sri Lanka Association for the Advancement of Science (SLAAS) and National Science Foundation (NSF) also undertaking many activities to popularize and develop Science Education in the country. The projects such as Olympiad, School Science Projects and School Science Days are some of the projects that attract interest from the students and teachers alike.

Concluding Remarks

Covid pandemic has changed the world where there is no return to as it before. The economic crisis that followed the pandemic made things even worse for countries with fragile economies like Sri Lanka. These new changes have brought new challenges and issues that countries never undergone before. Of many sectors, Education is one of the worst affected sectors with long-term negative impacts on economic development. Learning losses and their consequent impacts are not yet known. At the same time, the Covid pandemic reminded us how important the Science Education is for societies and communities, despite negative impacts. Covid-19 has transformed the education sector profoundly, and broaden the inequality while enhancing the gap between the poor and the rich in the society. In developing countries, education unravel new opportunities for individuals, and provide a chance to safeguard against inequalities prevail in underprivileged societies. In addition to pandemic-driven challenges face by the Education sector in Sri Lanka, new challenges are also in the horizon due to the ongoing economic crisis. These new challenges can make things even more challenging in addressing equality and quality of education in Sri Lanka. Due to the economic crisis, further spending cuts in the education sector can be expected in the coming years. Thus, the policy makers and education authorities need to revisit the education system and its organizational framework to identify issues and address them in a conducive manner. Achieving short- and long-term goals can become a nightmare for education authorities, thus careful planning and policies will be crucial to get through this most challenging era.

In addition to learning losses, social lockdowns imposed long-term impacts on social and emotional development of children. Recent studies emphasized a close association between social lockdown during Covid pandemic and mental health symptoms (i.e. distress, anxiety) and health behaviors (lower physical activity, more time on computers, bad dietary habits) among school children and adolescents. Therefore, in addition to academic drawbacks, educationists and policy makers should also pay more attention on social and emotional shortcomings among children and to uplift their well-being.

Despite online teaching-learning process was in the forefront in maintaining some form of continuity of the education system worldwide during the pandemic, studies confirmed that a majority of the main stakeholders (teachers and school children) did not relish on that process. However, online teaching-learning process is not just an option, but it is the 'only option' in a pandemic situation in the future too. Therefore, it is important to make this virtual teaching-learning process more interactive, and interesting to reach effective academic outcomes. Adoption of new teaching/learning strategies, and new means of evaluation of knowledge and skills can make this virtual experience more effective and stimulating to both parties. Therefore, it is the responsibility of the educationists to explore new vistas in virtual or hybrid teaching-learning process to transform it into a more thought-provoking experience for its stakeholders.

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What does it take to thrive in the Spice Business?

Amila Siriwardhana

Managing Director, New Lanka Cinnamon (PVT) Limited

1. **Tell us about yourself and a bit about your background.**

I'm Amila Sirwardena and from Karandeniya, Galle. I went to Karandeniya Central College and graduated with a second upper class from the University of Peradeniya after following the Chemistry Special course. Afterwards, I did several jobs in Sri Lanka. In 2010, I started up a spice export business and I realized I lacked some marketing and financial management knowledge as I followed the science stream. Therefore, I obtained a Masters degree in Business Administration at the University of Sri Jayewardenepura and currently I am following a course in business law at the Open University of Sri Lanka. In 2010, we started mainly with cinnamon and in 2018 we expanded our exports to clove, pepper, nutmeg, mace, and other spices. Currently, we are the second-largest spice export business in Sri Lanka, exporting to over 20 different countries.

2. **When did you start your business and what was your inspiration to get into the spice export business? How does your knowledge of chemistry help you with your business venture?**

When I was a student at the University of Peradeniya, I was not very interested in the business field, and my main target was to graduate and get a job. Then I started working in two companies, namely Ansell Lanka (Pvt) Ltd., Biyagama, and Brandix Lanka Ltd., but I wasn't completely satisfied with what I was doing and wanted to try something else. Another source of inspiration was my father-in-law. He is a businessman and told me several times to start an exporting business. In 2009, I worked hard and studied how to initiate and carry out exports, and finally, after much research, we started exporting cinnamon in 2010. We collected cinnamon, did small value additions, packed it, and sent it to relevant countries. But just doing so didn't feel enough, we were educated and had the ability to think differently, so there was no point in doing what everyone else in this field was doing. So, after that, we focused mainly on the value addition sector and started directly contacting international supermarkets like Costco, Walmart, and others. These supermarkets needed retail packs and brought more foreign exchange than when exporting spices in bulk.

Talking about Chemistry, we have a new project involving essential oil extractions, using steam distillation. A reason to start this is that there is a lot of wastage collected when considering the solid and dry products like cinnamon and pepper, so these can be used in the extraction of oil, as they can't be sent to current buyers due to impurities present. But when extracted, we can get the pure essence, and value is added to the wastage. Most other companies use whole spice products to extract the essential oils, while we only use waste products for this purpose. The waste from which we get essential oils must be processed separately. We maintain an in-house laboratory to check where we stand in terms of standards. But for reports, we send samples to external laboratories.

3. **What is the current situation of spice exports in Sri Lanka? What are the products that you export and are there any products that have a higher demand compared to others? And how can we compare it to the local market?**

Comparing the yield to minor crops like tea, rubber, coconut, and spices, cinnamon earns more than 250 million USD per year. But when considering spices like pepper, and clove, we have to compete with the international market. This is not the case with cinnamon because it is only grown in Sri Lanka, and it falls under a monopoly market. Other spices have to compete with the foreign market. In Sri Lanka, the quality of cinnamon is excellent, but the main issue is marketing the worth of these spices as not many people are aware of it. Because consumers mostly focus on the price over the quality, due to the current economic crisis, this period has a major impact on our business.

An issue being faced is that during the processing, some primary-level farmers dry the product on the floor and impurities could be added therefore we have to maintain a good hygiene control when it comes to the laborers. Even if the product quality is good, it is equally important to maintain the processing steps up to the standard, as well.

We export fresh green and black pepper for a specific order to Australia, and we wash and dry these using our own dryers. In Canada, Sri Lankan pepper is sold for 6 dollars/ kilo and Vietnamese pepper for 3 dollars/ kilo, so we need to maintain our standards and hygienic control, as we're competing with the foreign market. In general, 30% is added for the cleaning section. In Sri Lankan pepper, the piperine content is greater, 7-8%, than that of Vietnamese pepper, which has a lower value of 2-3% piperine, thereby governing the level of spice of the pepper. This content depends on the soil conditions, climate, and many other factors.

4. **What makes Ceylon spices special, when compared to other spices of the world?**

   True Ceylon cinnamon is unique to our country, while other countries produce cassia cinnamon, so we have no competing parameters to look into when marketing the product. Cassia cinnamon is brown in color and is hard, while true cinnamon has a gold-yellow color, is soft, and has approximately 70% cinnamaldehyde content. When considering pepper, clove, etc, quality-wise we normally check the oil content. The spice level of 5 seeds in Vietnam is approximately equal to 2 seeds in Sri Lanka, but people are unaware of this and use the same amount from both products. This should be marketed more because it is impossible to promote this fact on such a large scale as an individual business, as we don't have a large network as such. Yet, we do attend related food exhibitions and try to market this factor as much as possible. Some European countries only check the quality using our certifications. The chemical composition is not checked that much by consumers, and they focus mainly on the nutrition facts, like sugar, fiber content, *etc*.

5. **This year was named the international year in using basic sciences for sustainable development. Does your business promote sustainable development? What are some good practices that industries should be following, considering the environmental impact and sustainability?**

   When considering sustainability, we have to consider the three 'P's - Profit, People, and Planet. When you're running a company, it should be profitable. It should have an environmentally friendly production that is safe for the planet and also CSR projects for the betterment of people. In our company we follow the 3 'P's. We don't release any waste to the environment and we also do so many things to enhance the personal life of the people who work in our company as well as the farmers. Therefore, we parallelly follow the 3 'P's.

   There are not many chemical processes that take place in our company that involves harmful chemicals. But we carry out a sulfuring process to give color to the cinnamon bark. Sulfur is burned which causes sulfur dioxide to form, which is a temporary bleaching agent. We use SO_2 to bleach the cinnamon surface of the bark, and that gives cinnamon a very nice color and inhibits fungus growth as well.

   An aflatoxin test must be done for every spice we export from Sri Lanka. The tests are carried out by external laboratories such as bureau veritas and ITI.

   However, in Europe, they don't accept test reports that are done in Sri Lanka as they are only accurate up to two decimal places. And most foreign countries require accuracy up to three or four decimal places. Therefore, I believe that the laboratories should be upgraded, but then the cost of analysis of samples will be very high. Some European countries like France, Netherlands, and Germany are very strict that they don't even recognize the Indian test reports. Recently, I sent samples of white pepper, cinnamon, and nutmeg to a German Laboratory to check Aflatoxins and some other chemicals,

- nutmeg failed and cinnamon and white pepper were passed. So, the order for nutmeg got rejected. It is very difficult to control the fungus growth of Nutmeg. If the nuts get too brown, it producing aflatoxins. We mainly get nutmeg from Kandy and Matale area and harvesting must be done with care, because the contact of Nutmeg to the ground also accelerates the production of aflatoxins.

6. **What are the obstacles you may have faced in the recent past with regards to running the business? (*e.g.*, during the pandemic, or economic crisis)**

   The main obstacle we had to face is inflation. As inflation keeps increasing in our country, the price of every packing material and raw materials increases. However, with the dollar depreciation, we have some benefits to control the price in dollar terms. In the past year, it was $10, and we still try to control the price at $10, but as a country, it is not good. The problem is that all the materials have increased in price compared to last year. I think a lot of SME companies will be bankrupt by the end of the year. We are also surviving due to the exports. If you go out, you will be able see how many shops have closed down. We don't know how long we can stay open as the situation is very bad. At least we need to have political stability in the country which we don't have now. Investors aren't coming into the country; foreign workers aren't sending their money and there is no tourism. So, what all we have is only the exports, but it is difficult to export goods when the inflation is high. However, compared to last year our export income has increased due to depreciation. But due to the high cost of living, we can't benefit much from it.

7. **And how have you incorporated value addition to your business?**

   Our company targets supermarkets. Value addition is done through improved packaging. Earlier, we used to send bulk quantities and the supermarkets in foreign countries did the packaging for us. But now we are exporting the packed product so we can earn more. We have an order of one million packs per month for Walmart in Mexico.

   Value addition can also be done through other products infused with cinnamon or any other spice. For that, you need large amounts of product stocks but through that pathway, only small quantities of spices go into the market. But by sending the spices itself we can earn more and we can meet our targets.

   For example, Coca-Cola uses cinnamon in its formula. But cassia cinnamon is used instead of Ceylon cinnamon. However, if Coca-Cola wanted Ceylon cinnamon, the Sri Lankan supply would not meet the demand.

8. **Do you have any other future plans for the development of the company?**

   We have to improve our value addition. That is a priority and an avenue where we can earn more. We also have a 10-year ongoing project to develop our brand in a way that people would recognize us to have our own identity. A good example is Dilmah, where people recognize them not only for their tea but as an identity.

   We also have hopes of gaining market shares for our brand.

9. **What message do you have for the chemists & future chemists of Sri Lanka?**

   My advice for undergraduates would be not to target a conventional job. Instead, be a person who creates jobs. Also, think differently. Starting a business doesn't mean you have to have a lot of startup resources. Use the fact that you are a science graduate to your advantage. A lot of people asked me why I started a business after doing a chemistry special. That makes no sense, and there's a lot of stigma in our country about straying beyond traditional paths. Our students have a lot of knowledge that they gain from A/L onwards. We can definitely use that to improve our country. If you do plan on doing higher studies abroad, make sure you come back, and do something new and different.

Interviewed and written by, Yohara Ranasinghe, Ayesha Hettige and Mithuni Senadeera, CCS Media Circle

Mr. Amila Siriwardene *obtained his BSc degree from University of Peradeniya and Master of Business Management from University of Sri Jayawardene pura. He is currently the Managing Director of New Lanka Cinnamon (PVT) Limited, Sri Lanka.*

The reality of research and commercialization; a Sri Lankan story

Lakshitha Pahalagedera

Head of Business Development, Sri Lanka Institute of Nanotechnology (SLINTEC)

1. You have a lot of expertise in the field of nanotechnology. Do you remember when you first found yourself interested in this field and what got you into this field in the first place?

I think it was during my PhD because when I was at the University of Peradeniya, I was involved in a research project focused on coordination chemistry and I was clueless about nanotechnology back then. However, after I went to the US to do my PhD we were given a period of 6 months to select a PhD supervisor. It was at that time I was introduced to the field of nanoscience by the director of material science at the University of Connecticut and when I learned about all the possible applications and the impact that it could have on the future, I realized that this should be my area of focus. So that's how I got involved with nanomaterial synthesis and the design and fabrication of nanomaterials and their applications.

2. That's quite an interesting story. Since then, you have come a long way and now find yourself being the Head of business development at SLINTEC. What helped you gain this position?

I got to know about SLINTEC while I was studying for my PhD at the University of Connecticut. I knew that I should follow a profession that could create change because with my personality I didn't want to be restricted to a laboratory for the rest of my life. After returning to Sri Lanka, I joined SLINTEC in late 2015 and in 2018 I worked as a postdoctoral fellow there and also gained some experience in dealing with the demands of the industry.

Ever since I started working on my PhD, I knew what the industry expects from research. When you compare the two types of industries we have in the States and SL, the expectations are somewhat different. In the US the target is for long-term research and high-value intellectual properties (IPs) that could be converted into a commercialized process someday. But in Sri Lanka, companies look for short-term benefits. They expect short-term outcomes through research to improve their current product without targeting any disruptive products or processes. Fortunately, I got the chance to experience both these two different types of industrial approaches to R & D.

In 2018, SLINTEC was looking to fill the position of head of Business Development and I was asked by our CEO and the head of HR whether I would like to take over the position owing to the prior experience I had gained in dealing with the industry. I had mixed feelings about it at that time. Because in one way I didn't want to end my scientific career and on the other hand I had an opportunity to make an impact in the commercialization and innovation process.

So, what I requested was one day to conduct research and to work on business development for the remainder of the week The CEO agreed and but when I got the job description, I realized that it was going to be full-time work and amidst it, I wouldn't be able to conduct hardcore research. In the end, I took up the position full-time.

3. As the head of business development what challenges did you have to face and how did you approach them?

One of the main problems we face is finding the money to run an organization such as this. Although we are a public-private partnership, we don't get a recurrent budget from the government. We have a lot of very high-end equipment like the only TEM in SL, NMR, HPLC and XPS as well. So there's a huge overhead for the maintenance of this equipment.

The business model of SLINTEC is to do contractual research funded by the private sector or strategic research funded by the government. For these projects however we can only charge for the cost of the research and we can't charge huge amounts either for R & D because what we are selling are untested ideas and the industry is not capable of forecasting the end product. Even though the investment needed during the research phase is low compared to manufacturing and scaling up, companies are reluctant to invest because of the high risk. Finally, they don't get any incentives from the government such as tax concessions so there's no real appetite to do R & D for them. Most companies don't have a person dedicated to R & D in the company, who understands its value. Usually, our team deals with the CEO or the factory manager about the project but most of the time, they have other things to deal with making RnD a low priority to them.

So doing research and development in a country like ours is in itself a challenge. When you compare and consider other countries their industries are driven by innovation so there is a lot of competition between companies in the same kind of industry. They are always trying to acquire more patents and come up with more innovations or at least stop their competitors from getting ahead so there is a very high focus on R & D. But here in Sri Lanka, there is no necessity in the industry to conduct research because most of the time they just want to solve a typical issue in their factory or else they just want to improve their current product. Only a handful of companies are interested in coming up with new IPs, acquiring patents, and coming up with innovative, disruptive products.

Basically, our business model is to conduct R & D, cover the research cost by charging a research fee, and come up with a good IP (intellectual property) that can be commercialized, This is where we must innovate and come up with commercializable IPs which we can license to another party either exclusively or non-exclusively, transfer or use to form a joint venture. Attracting people to invest in research is a challenge. Doing research from the beginning to completion is a challenge because you can get an unexpected outcome. And once the research has ended the hardest part is to convert the outcome of the research phase into a refined product or a process. Then you have to think of everything from raw materials, government rules, shipping charges, to even electricity charges.

So, when I first started these were all the responsibilities I undertook. However, my CEO was kind enough to limit the pressure I faced since I also had to gain some initial experience in business development. Eventually, I had to come up with new processes, streamline everything, think of new marketing strategies, create and manage new social media accounts, and promote the message that we, SLINTEC, are ready to conduct R&D and that we are ready to do commercialization.

I also had to change the mindset of most of the scientists. As scientists, we always get fascinated by various research topics which sometimes aren't valuable from the perspective of a business. Sometimes a very simple process might be a better business idea than a complicated research project. So, it was a huge challenge to deal with scientists but with time the mindset changed and now everyone knows what the institute needs.

Simply put It all starts with ideas. These ideas have to be converted into proof of concepts, researched, and developed further to a point where they can be commercialized, a prototype made, the feasibility of scaling up is explored, and then finally the refined product is made. The ideas that have a very high feasibility of being converted to a product or process were picked and we started funding them internally. I created an internal program similar to shark tank called Innovation Pitching Session where scientists would get a few minutes to pitch their idea to all the scientists, and personnel from the business, finance, and technology transfer teams at SLINTEC. Their ideas were evaluated and if they were judged favorably, we would start funding them. In that way, we were able to change the mindset of the scientists towards commercialization and at the same time, we have a good set of ideas that even if we don't fund, we could pitch to a potential client who has the ability to invest in them. These are the challenges and some of the actions we have taken together as a team.

4. **Some of your most recent publications were on nanomedicine, which is somewhat of a novel field in the world and especially in Sri Lanka. What are some of the major obstacles you had to face with regard to implementing solutions and processes related to nanomedicine here?**

Personally, my first obstacle was that I didn't have any idea, even during my PhD time, on nanomedicine or on biomedical sciences since I was a materials scientist who was fabricating nanomaterials for catalytic applications. Sometime after I joined SLINTEC, they decided to come up with another entity called SLINTEC Academy which offers MPhils and PhDs. Through this program, I came across a student who had done his bachelor's in biomedical sciences. Eventually, I collaborated with him to conduct research as his experience in biomedical science completed my knowledge of material sciences. I began to learn about biomedicine from him and he learned about chemistry and materials science from me. And we began reading and also collaborated with some other people as well.

When it comes to biomedical science applications the main obstacle is the in-vitro studies and clinical studies and then the approval process. The approval process in biomedical science is very stringent and lengthy, which is good in one way as the country should have a safety process like that. However even at the research level, you have to do a lot of in vitro studies, so you need to have a good biological lab to perform these tests and, in some cases, you have to collaborate with others because SLINTEC mainly focuses on material science applications. This gave us a good opportunity to collaborate with other people and that was the main challenge that we had. I would say that there's still a long way to go because we just publish papers and compared to the other work that I have done the biomedical-related work that I am doing still has a long way to go with all the tests and approvals before we can get them commercialized.

I can relate one such experience I had at SLINTEC back in March 2020 when the country didn't have enough swabs to do COVID-19 tests. There was no way to get down the swabs from other countries because globally there was a huge demand for swabs and comparatively the Sri Lankan market is very small so nobody was interested in supplying swabs to us. The country also didn't have any equipment that could produce swabs although we were capable of producing the other liquids and chemicals we needed. So SLINTEC got to know about this through the task force and then within three days, our scientists had found a method to convert a machine that is being used in the textile industry into a swab-making machine and then we supplied more than 300,000 swabs saving about Rs.150 million to the country. Thanks to the scientists, at that emergency point we were able to supply swabs to the market. But even then, we had to go through all the approvals like in vitro studies and clinical trials even though this is a tool that was being used externally. Despite the emergency situation we had to go through the full process and obtain approval from the NMRA.

While working on that we did some real science and we came up with another technology called lamp PCR which can be used as a substitute for the current PCR method. At that time there was a huge queue for PCR tests and it took about six hours to get the PCR results and the cost was also high. So, in this case we collaborated with some European parties and we came up with this technology to do the test within about 3 hours and at a lower cost too. We then formed a joint venture with the private sector after convincing them about the business potential behind it. We were targeting a profit of Rs. 36 million per month because the demand was huge. But in order to get all the approvals through NMRA it took more than 1 1/2 years. I don't say that we should not have any approval process but we should have an efficient approval process. By the time we got approval even the third wave was gone so there was no business at all and the private party was also not interested in doing this business as a joint venture because at that point, there wasn't any demand.

In summary, the main obstacles would be the time it takes for clinical studies as well as our need for good labs and an efficient approval process. Despite the research we do and the papers we publish, commercialization is still a very lengthy process with a lot of obstacles.

5. **With regard to collaborating with international organizations and dealing with foreign clients, what is the process like and are they receptive to joint ventures?**

   In some cases, we establish contact with a client through a middleman. This middleman will pitch a certain idea or a project proposal to a client such as an institute or a business entity. They undertake the project and then they hand it over to us. In other cases, we tried to form joint ventures with external parties or we directly wrote to them, and then after an evaluation and background check, they started collaborating with us.

   The technical capabilities that we have as a country wasn't a problem but building the network and reaching out to them is the hardest part. I think a national strategy is needed. I'm very worried about this and it's not all about SLINTEC but it's about the research community in the country as a whole. We spend a lot of energy, time, and money on research but sometimes we don't get the right problem statements, which is a huge issue. When it comes to fundamental research it's fine since you can read and understand by going through literature but when it comes to industrial applications and commercialization, we lack good problem statements because when we talk to the people in the local industry, they only what the pain points are. And those aren't real problems that scientists should get involved in. An engineer should be able to solve these problems.

   But if we can get connected with corporations like Toyota, Panasonic, Tesla or Pfizer for example, we might get the right problem statement. As a country, we don't have a proper idea of what the world needs so we do something that we think the world would buy but once we do the research, nobody buys it and we all get disappointed.

   I think we as a country should come up with a good national program to reach out to international entities, to get good problem statements to the country as a whole so that we have a set of problems that our scientists can focus on. Generating IP and transferring them or licensing them to other countries is also an export of a high value. At one point we came up with a slow-release fertilizer about 10 years ago and after we got the US patent, we had a discussion with an Indian party to transfer the IP which was valued at $3 million. So, what I suggest is we should come up with a mechanism to reach out to these big giant companies and get the right problem statements because otherwise, it's a waste of all the resources and capability we have here.

   Finally, when we market ourselves, we must be very specific. We can't simply list our published papers and PhDs and equipment and expect to gain their business. For example, when we market ourselves to Toyota, we should say how they can come up with a good composite material with high strength that can be used in their cars. Or if you are pitching to Panasonic as an example, we have to be specific and say that we can use graphene to increase their battery performance by a specific amount. Basically, the issue now is that we don't know what their problem is, that needs fixing.

6. **Not many professionals who do their doctoral studies and research abroad return back to Sri Lanka. What made you come back to Sri Lanka after your graduate studies?**

   I can't give a very direct answer for that but both my wife and I knew that we would come back after our studies. Even though many people said that we would change our minds after several years of study in the US, we didn't and after our graduation, we came back because we had already made up our minds, and also because I had gotten an offer from SLINTEC. But during our time there, we published papers, did our PhD work, and during weekends we always tried to travel and get the maximum experience that we could get within those five years.

   Deciding to return back to Sri Lanka is a personal choice. The people who do come back have the ability to join universities and generate graduates in the country and make a big impact. On the other hand, Scientists who stay back in those countries join companies like NASA and make a huge impact on the entire mankind. You can't really say which is right and which one is wrong because it's ultimately up to the individual. Even by staying in another country, you can still help your country and also serve the entire world. I believe that both kinds of people should be there; some people should come back here and some should stay there.

For me and my wife, we didn't have any regrets when leaving the states except the fact that we were very much attached to the people over there who were very nice and treated us like family. But then we still believe that we took the decision that is correct with respect to our measures. That's a very important thing because people have different measures of things to evaluate when making such a decision.

7. Do you have any words of advice or any words of wisdom for students who are interested in pursuing a career in nanotechnology as you have done?

In the 1950s, Richard Feynman said "there is plenty of room at the bottom," indicating that there was an area that was intact and undiscovered in this field. Then in 1974, the term nanotechnology was introduced. Then there was the discovery of electron microscopes, allowing the effective manipulation of stuff at this scale, even though nanotechnology has existed for several thousand years before. And then in 2010, they discovered graphene, another important point or milestone of the journey of nanotechnology.

When you start talking about all these discoveries, it gets people thinking about the commercial side, or the business aspects. And when new discoveries are made, people are amazed by what is theoretically possible, but more often than not there are several practical difficulties when it comes to that. After the discovery of graphene, people were amazed by its theoretical properties. Theoretically, graphene can be used to desalinate water. If you can desalinate with graphene, several problems in this world are solved. Even in Sri Lanka, there are villages that don't have access to clean drinking water. But now we know that it's very hard to achieve that, and the same applies to several of its theoretical properties too.

There is a very high potential in this field, but when it comes to real-world applications, there are several challenges. We already have several nanomaterials whose properties we know, but applying them in a real-world application and solving difficult problems for the entire world, is what the focus should be for students.

8. At SLINTEC do you get client-oriented industrial problems?

Yes, that's a major type of project that we undertake and its termed contract research. What happens is that the client either comes to us with their problem or sometimes, we go to them with solutions that we think could help them to increase their productivity. We do a lot of factory visits to understand the issues from the ground level itself by talking to the people who work in the factories. Even though we might not get good problem statements this way, it enables us to provide solutions within a short period of time. Another strategy we have is to try and identify viable areas. Currently, at SLINTEC we have six different research areas. Technical textiles, agriculture technologies, energy, printed electronics and sensors, natural medicine-related research, *etc.*, are some of these areas. We mostly come up with ideas that can lead business schemes applicable in these areas. These can then be pitched to local clients who are scouting for novel technologies.

For example, we are currently working on anti-corrosive paints. After we internally complete the project up to a certain extent, we would convert that technology into a product with the support of an industrial partner. After coming to a certain level of technology readiness, we then start pitching it to potential clients and have discussions with them to get their feedback.

9. Is the income obtained from such contract research projects sufficient to run the institute?

The income that we get is not sufficient. We can't be self-sufficient with such projects and we are currently pitching to the government, because our original mandate states that after a certain period of time we have to be self-sufficient. One strategy that we practice is to link up with other countries but that requires proper marketing and exposure, and you need to get a proper problem statement from the client too. Further, if the company doesn't generate a good high-value IP we cannot generate revenue through licensing. Say, licensing for five million, or 10 million rupees is not enough. The target should be around 100 million.

So our strategy is to collaborate with the industry, give them some incentives from SLINTEC and then get them involved in long-term research. The IP created could be shared because usually we focus on fully owned IP which we can't charge large amounts. Sharing an IP is better and the industry finds it more attractive if they have a real appetite for creating an IP. Joint IPs do come with their own set of unique problems and you must be ready for them but in the beginning, you can attract the industry for long-term research and generate high-value IPs. Having a 40 to 50% stake in an IP valued at Rs 100 million is much better than entirely owning an IP valued at only Rs. 5 million.

10. It is widely known that we have two major resources in Sri Lanka, Eppawala phosphate and vein graphite. As an example, we simply crush down the mined phosphate and export it without any value addition. However, if we had an H_2SO_4 factory we could make triple superphosphate. Even vein graphite is a valuable resource that can be used for several applications. If the government is unable, can SLINTEC collaborate with international parties to create processes that add value to these resources?

Let me start with vein graphite because that's something that we are currently working on. It was initiated as a government-funded project and then we got the US patent to convert it into graphene oxide and then reduced graphene oxide. Then in 2018 we started a joint venture and invested in the intellectual property/patent and we were able to get an investment on the plant from an external private sector entity. Right now, it's the only large-scale plant capable of producing graphene oxide in Sri Lanka. So, through this joint venture, we now have a plant that is capable of producing 10 metric tons of graphene oxide per annum. Right now, this joint venture is trying to attract markets by convincing buyers and showing that there are possible applications for this material. Currently, there aren't many applications in the world right now even though theoretically it has a lot of potential.

So, we do research with them and work on specific applications. It could be for water purification, an energy application, or a composite used in the rubber industry. With that, we are trying to produce data sheets and convince buyers to buy graphene from us. Creating the applicability creates the market.

Also, we have to face competitors from China. They have flake graphite which is near the surface so it's easy to mine and even though it has a lower purity, it's not a huge problem for them since it can be purified. The only advantage that we have is the aspect ratio because vein graphite gives very large graphene sheets compared to flake graphite. At the moment lots of countries have expressed interest in Sri Lankan graphite, to mine it or engage in value addition to it, because there is a high potential in using this graphite in lithium-ion batteries.

When it comes to rock phosphate, we just use it as it is and we export some amount. Here the soluble part is only about 2% so different approaches must be tested to solubilize it. One method is the microbial approach, but we are not sure whether we can get a high percentage of phosphorus, because it's very slow and the expected yield is about 20%. Other ways of getting phosphorus from rock phosphate include thermal methods and again you have to think about the energy balance and the amount that you have to spend on heating them. So, the only viable method currently is to use sulphuric acid which is what other countries do, and we have an advantage because we don't have many heavy metals or elements like arsenic present in the ore. At one point there was a discussion about having a plant for it, but the problem was coordination as the purpose of the plant should not be only for the solubilization of rock phosphate. There should be many other industries that can use the plant and if not, the investment made on this plant won't be sufficient enough to make a good business case.

There are many other opportunities as well, like ilmenite, which can be converted into titanium dioxide. At SLINTEC, we had a titanium dioxide pilot plant funded by a private facility, but it was stopped due to the cost of sulphuric acid. Another opportunity is getting titanium metal out of the produced titanium dioxide and that's the highest value addition that you can get. And once again you need sulphuric acid for that. Also, in the modified Hummer's method you use potassium permanganate and sulfuric acid. But right now, we have to import sulphuric acid as there is no domestic production.

This coordination must be carried out before you start a sulfuric acid plant. In any nation, the capability of production is measured by the number of sulfuric acid plants that they have and we have none right now. We used to have one but it was shut down due to various issues. If proper planning was carried out previously this could've been successful.

Thank you very much for that detailed answer. We certainly learned a lot about the industrial and academic climate in Sri Lanka.

Interviewed and written by, Jayath De Silva, Uthsara Malaweera Arachchi and Senan Alwis, CCS Media Circle

***Dr. Pahalagedera** currently serves as Head of Business Development, Sri Lanka Institute of Nanotechnology (SLINTEC), He obtained his BSc degree in Chemistry (Honours) from University of Peradeniya and PhD from University of University of Connecticut, USA.*

Webinars Organized by the Women Chemists Committee of Institute of Chemistry Ceylon

Theme of the year :

Achieving Gender Equality of Women – Challenges and Opportunities

The Women Chemists' Committee (WCC) successfully organized its first two webinar sessions in the council year 2022/23 under their main theme, "Women empowerment in chemical sciences in achieving sustainable development goals" on the 12th of October 2022 at 04.00 p.m. and 1st of November 2022 at 4.30 p.m *via* Zoom. The informative webinar, delivered by **Dr. Nilu Sivapragasam** focused on the topic "Hormonal Imbalances at Various Stages of a Woman's Life: Changes and Remedies" and an interesting webinar, delivered by **Prof. Theshini Perera** focused on the topic "Women in Science; what goes on behind the scenes?".

Dr. Nilu highlighted the physiology and management of stress on women as they strive to find their work-life balance. She also stressed the 'symphony' of hormones, especially estrogen and progesterone, present in women and how they affect behavior, and mental and metabolic health. The facet of the talk emphasized dietary requirements for women when it comes to maintaining a healthy lifestyle, followed by advice regarding a smooth transition into menopause. Dr. Sivapragasam in conclusion drew attention to breast cancer, from its symptoms to diagnosis and prevention. The session successfully wrapped up with a productive question and answer session.

Prof. Theshini was mainly focusing on "How women balance their life by holding heavy responsibilities as a daughter, mother, wife, and worker. She talked about many role model characters in Sri Lanka and overseas in the chemistry field. She shared her past life experiences since her childhood to the professor. It gave a greatly remarkable experience to the audience of how she is managing her busy life schedule smoothly. She inspired all the women by highlighting her life achievements.

Guest Articles

Phytochemicals in Sri Lankan Curry Powder

K. Sarath D. Perera and A. D. Theeshya Dulmini

Department of Chemistry, The Open University of Sri Lanka

Nowadays people feel the need to enhance their immunity by consuming various nutritional food and beverages. From ancient times, Asian women have been using spices, not only to boost the taste and aroma, but also to add medicinal value to their cuisines. However, the types of spices, the mixing ratios, and the process of incorporating them to the dish, varies across regions and countries.

Sri Lankan housewives use unroasted yellowish colored curry powder to prepare mild vegetable dishes, and roasted dark brown colored curry powder to add an intense taste to dishes such as fish, meat and green jack fruit etc. The number of spice-ingredients in the roasted curry powder is usually higher than in the unroasted powder and dishes prepared using the former have a longer shelf-life.

Traditional Sri Lankan curry powder is known as "Thuna Paha". Literally, "Thuna and Paha" means 3 and 5 in English, respectively. It depicts a combination of 8 spices. But according to Sri Lankan ayurvedic medicinal texts, the original curry powder was composed of more than 40 spices. The recipe of the "Thuna Paha" mixture has been passed down from generation to generation (mother to daughter); hence, the composition of the mixture could change with the personal preferences and the availability the ingredients.

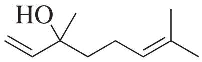
Every Sri Lankan curry powder mixture consists of coriander, cumin and fennel as the three key ingredients, and the rest of the ingredients are selected from cloves, fenugreek seeds, cinnamon, curry leaves, mustard seeds, pepper and chillies.

Chemical constituents of curry powder

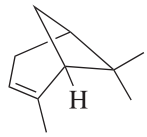
First, we will consider the chemical constituents of the three main spices.

Coriander seeds ("*Koththamalli*")

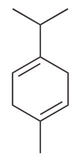
The pungent, citrus-flavored, round shaped seeds of *Coriandrum sativum* are dried and well-grounded to make curry powder. Linalool is the main phytochemical present in these seeds. Other compounds that can be found in coriander seeds are γ-terpinene, α-pinene, *p*-cymene and camphor. Antioxidant, antifungal and antibacterial properties of coriander are important as it increases the shelf-life of the curry powder mixture.



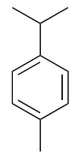
Linalool



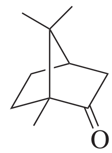
α-Pinene



γ-Terpinene



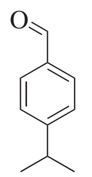
***p*-Cymene**



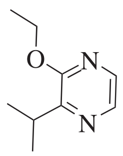
Camphor

Cumin seeds ("*Sooduru*")

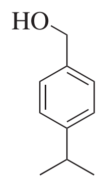
Rod-shaped cumin (*Cuminum cyminum*) seeds have a distinctive strong flavor. Cuminaldehyde and cuminic alcohol (cuminyl alcohol) give a unique aroma to these seeds. γ-terpinene, safranal, *p*-cymene, and β-pinene and substituted pyrazines such as 2-ethoxy-3-isopropylpyrazine, 2-methoxy-3-sec-butylpyrazine, 2-methoxy-3-methyl pyrazine, and vitamins B and E are the other compounds present in cumin seeds.



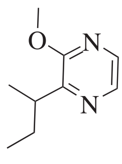
Cuminaldehyde



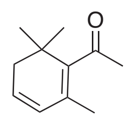
2-Ethoxy-3-isopropylpyrazine



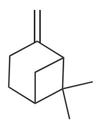
Cuminyl alcohol



3-sec-Butyl-2-methoxypyrazine



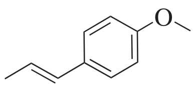
Safranal



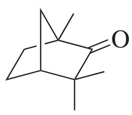
β-Pinene

Fennel seeds ("*Mahaduru*")

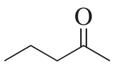
Fennel seeds consists of dried, ripe fruits of F*oenicum vulgare* and they are larger than Cumin seeds. 4-Methoxy benzaldehyde, fenchone, *trans*-anethole and 2-pentanone are the major compounds that are present in fennel seeds.



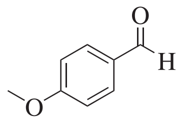
***trans*-Anethole**



Fenchone



2-Pentanone

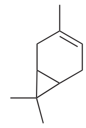


4-Methoxybenzaldehyde

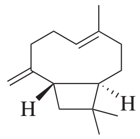
Other spices

Some of the following spices are used in both roasted and unroasted curry powder mixtures.

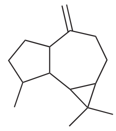
Spice	Edible part	Chemical constituents
Curry leaves	Leaves of *Murraya koenigii*	3-carene, β-pinene, β-caryophyllene, α-pinene, β-phellandrene, aromadendrene
Ceylon Cinnamon	Bark of *Cinnamomum zeylanicum*	*trans*-cinnamaldehyde, eugenol, safrole, cumin aldehyde, linalool
Mustard	Seeds of *Brassica juncea*	sinigrin, progoitrin, brassicasterol, campesterol, alinolenic acid
Cloves	Nuts of *Syzygium aromaticum*	eugenol, eugenol acetate, limonin, ferulic aldehyde, quercetin
Cardamom	Capsules of *Elettaria cardamomum*	1,8-cineole, α-terpinyl acetate, limonene, linalool
Pepper	Seeds of *Piper nigrum*	α- and β-pinene, myrcene, α-phellandrene, 2-isopropyl-3-methoxypyrazine
Chilies	Pods of *Capsicum frutescens*	9,12-octadecadienoic acid (Z,Z), 3-carene, palmitic acid, eicosane



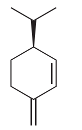
3-Carene



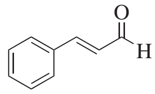
β-Caryophyllene



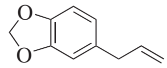
Aromadendrene



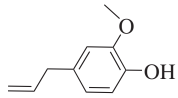
β-Phellandrene



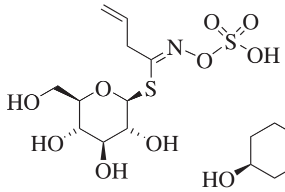
***trans*-Cinnamaldehyde**



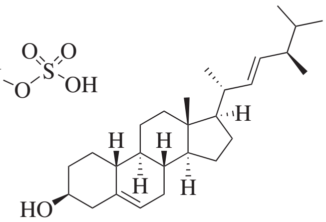
Safrole



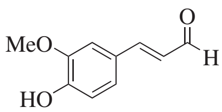
Eugenol



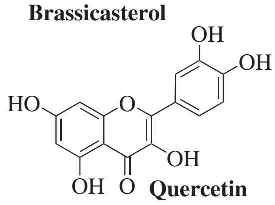
Sinigrin



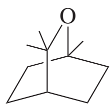
Brassicasterol



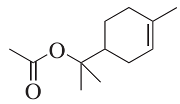
Ferulic aldehyde



Quercetin

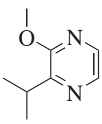


1,8-Cineole/eucalyptol

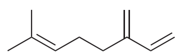


α-Terpinyl acetate

Limonene



2-Isopropyl-3-methoxypyrazine



Myrcene

Health benefits of curry powder

Almost all the spices in our curry powder mixture exhibit antioxidant, antimicrobial, and anti-inflammatory properties as they contain a large amount of phenolic and flavonoid compounds. Antioxidants are important to counter free radicals which can damage the living cells. Cumin, cinnamon, cardamom and clove show cardioprotective properties; especially 1,8-cineole in cardamom clears the bad breath by killing bacteria in the breathing passage. This phytochemical inherits hepatoprotective and anticarcinogenic properties. The use of cinnamon, fennel, and cumin is used in traditional medicines to cure diabetes as well. Neuroprotective properties of curry powder are mainly due to the presence of cumin, fennel, and cardamom. The phytochemicals in mustard, cinnamon, curry leaves, cloves, and cumin are important to decrease the low-density cholesterol level in the body. Curry powder is a good medicine to maintain a proper digestive system. Sometimes, consumption of roasted curry powder in excessive amounts can cause gastritis.

Recently, scientists have discovered that curry powder is a good treatment for respiratory diseases related to particulate matter, with aerodynamic diameters less than 2.5 micrometers. These particles are generated by combusting fossil fuels and their higher penetrating ability enhances the health risk as they can circulate through the bloodstream.

Iron is a crucial element to our body. It is essential for the production of hemoglobin which carries oxygen in the blood. Some researchers have proved that curry powder acts as a suitable vehicle to transport iron in the body. They suggest that the addition of NaFeEDTA to curry powder is the most convenient way to increase the iron content, as this mixture of spices is being consumed regularly.

However, there are a lot of forfeited and adulterated curry powder mixtures in the market. They can cause diseases, instead of providing health benefits. For better health benefits, it is always advisable to prepare the curry powder mixture at your home with fresh ingredients. It will give a pleasent taste to your food as well as a healthy life.

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Guest Articles

Neglected Treasure for a Better Future

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Living in Sri Lanka has become a question to many Sri Lankans today due to the hardest economic crisis that we as a country are facing currently. It is hard to balance the terms of each requirement including the main needs, food, and medicine. Therefore, to facilitate the quality of living people leaves the country. Let's stop and look back at ourselves. Have we done our duty for the country? Sri Lanka the pearl of the Indian ocean attracted many foreign invaders including Portuguese, Dutch, and Great Britain due to the treasure inherited by the country. However, after the independence, have we valued our tressure, and the answer is probably not. In this article, it is intended to discuss such neglected treasure from a chemist's point of view.

Minerals

Ilmenite and rutile, the black sand available in coastal regions of Sri Lanka in the areas of Pulmodai, Induwara, Kokkulai, Kokkuthoduvai, Nayaru, Muhathuvaram, and Chemmalai *etc*. are being exposed to other countries such as Australia, China, India e as the main way of earning foreign exchange. Ilmenite and rutile are the main raw material to synthesize pure TiO_2, the white colour pigment being used worldwide for many industries including paper, paint, plastic, coating, food and cosmetics and pharmaceuticals as well[1]. Isolating pure TiO_2 from ilmenite mainly involves chemical treatment in which mostly hazardous chemicals like hydrochloric acid, sulfuric acid, phosphoric acid, ammonium hydroxide, and sodium hydroxide are being used. The lack of such facilities to handle these chemicals and their waste have led to the export of the minerals as it is to other countries without any value addition. However, researchers have concentrated their researches'only on obtaining pure TiO_2 neglecting the acid leachate as the waste product. A value has been added to the whole process where new binary and ternary nanocomposites including Fe_2TiO_5/ TiO_2, Fe_2O_3/ Fe_2TiO_5/TiO_2, Fe_2O_3/TiO_2, Fe_3O_4/TiO_2 have been fabricated using the acid leachate[2–4]. Further, novel nanocomposites have been developed using sucrose as the carbon source with the product obtained from neutralizing acid leachate.

Iron present in the product catalytically graphitized the sucrose forming TiO_2-Fe_3C-Fe-Fe_3O_4/graphitic carbon composite[5]. Similarly, chitosan extracted from shrimp shells was mixed with the same ilmenite product and produced Fe_2O_3-TiO_2/N enriched graphitic carbon. These nanocomposites have shown excellent photocatalytic activities in degrading methylene blue under sunlight and visible light. Dyes in wastewater cause severe health effects to all living beings and additionally they prevent light penetration through the water body limiting the photosynthesis by aquatic plants. Further, as they persist in the ecosystem because they are not readily degradable and therefore, they degrade the aesthetic value of the water bodies and increase biological and chemical oxygen demand. Therefore, the removal of dyes is essential. Among the already existing methods for removal of adsorption, filtration, coagulation, and oxidation advanced oxidation process are more prominent as it degrades the dye molecules into harmless products.

Zircon sand is also present along with ilmenite and rutile which could be used to synthesize zirconia nanomaterials and to produce porcelain goods, and wall & floor tiles.

Graphite

Ceylon vein graphite has attracted tremendous attention due to its high purity in the the world. Though graphite itself does not sound worthy, modified graphite or graphene oxide or reduced graphene oxide have promising applications. Graphite is widely used in lithium-ion batteries, and in many consumer products including mobile phones, laptops, tablets and media players. Further, graphene oxide and reduced graphene oxide prepared from graphite are used in applications such as conductive transparent coatings, flexible electronics, water electrolysis, water filtration and purification, and some medicinal and biological applications. Moreover, graphene oxide and reduced graphene oxide have been coupled with semiconductors such as TiO_2[6], ZnO[7], Fe_2O_3[7] as effective catalysts for water splitting in the generation of H_2 as green energy and, also for degradation of contaminants like dyes, pesticides *etc*.

Quartz, Feldspar, Clay

Vein quartz of high purity with over 98% of silica is found in many areas including Galaha, Embilipitiya, Balangoda *etc*. Though pure quartz is clear, quartz with impurities appears in different colours. Purple colour quartz is due to the "holes" in the crystal with some iron impurities while yellow and green? colour quartz contains iron as the impurity. Grey quartz which is called smoky quartz is due to the "holes" present in crystal with aluminum impurities. Quartz is being used in many applications such as manufacturing ceramic products, Jewelry production, glassmaking, production of refractory bricks *etc*. Feldspar which is used in glass and ceramic industries is an aluminosilicate of potassium, sodium and calcium and is found in areas including Namaloya, Rattota, and Balangoda. Clay which is hydrated aluminium silicate is comprised of minerals such as kaolinite, montmorillonite found in areas like Nattandiya and Meetiyagoda. Clay is mainly used in water purification through ion exchange.

Agricultural waste

Coconut is one of the main crop items being exported by Sri Lanka in the last few decades. Use of the waste material for numerous applications has been well-researched and commercialized. For example, coconut shell is being widely used to generate activated carbon which could be used for water treatment. Further, coconut shells are being used to make commercially viable handmade products which have entered the local and foreign markets generating more foreign exchange. Meanwhile, coconut husk has also been used to produce activated carbon by nitric acid activation[8]. In addition, it is used as coco peat, coco husk chips, coco crush and coir fibre. Rice the main meal of Sri Lankans is produced in metric tons annually and generates paddy husk and paddy straw as the waste material which is not used for any applications. Paddy husk functionalized with nitric acid has been used to remove Rhodamine from wastewater8. Moreover, rice husk has been used as the raw material to synthesize silica nanoparticles to remove textile dyes such as Rhodamine and methylene blue 9,10. In addition to coconut husk and paddy husk, other agricultural waste materials including tea waste, banana pith, and fruit peel like oranges, bananas, mango *etc*. have also been tested on their activity for environmental remediation.

In addition to depolluting the environment agriculture waste has been used for other applications as well. Cellulose and Lignin have been successfully extracted from paddy straw adding more value to the waste product[11,12]. Paddy husk has been incorporated into concrete and bricks because it reduces the cost while improving the strength and again reducing the weight.

Conclusion

There are many sources in Sri Lanka including minerals such as ilmenite, rutile, zircon, graphite, Quartz, Feldspar, Clay, and agricultural waste which have not been widely explored in terms of applications. Adding value to these products would be of great interest to opening the door to the avenue of the horizon.

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Food sustainability and nutrition during economic crisis

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Risk factors for non-communicable diseases are unhealthy dietary pattern, lack of exercise, heavy alcoholism, smoking, hypertension, diabetes, overweight and obesity, mental stress and some drugs. Most prominent non-communicable diseases (NCDs) are kidney disease, strokes, cancers and cardiovascular disease. Diet-related NCDs includes cardiovascular disease such as heart attacks, diabetes, high blood pressure and cholesterol. Unhealthy diets and poor nutrition are among the top risk factors for these diseases globally. Cardiovascular diseases are a group of disorders of the heart and blood vessels. Main factors that affect the cardiovascular diseases are age, gender and genetics. Coronary heart disease and cerebrovascular disease are the two most common conditions.

Major risk factors of cancers are harmful rays, genetic problems, mobile phones, smoking and heavy alcoholism, poisonous chemical compounds, mental stress and high consumption of red meat. NCDs has made a harmful impact on our life due to the wrong life style. It's important to identify the disease cause, regular medical checkups for weight, blood pressure, blood sugar level and cholesterol level, basic tests for cancers, self-tests as well as prevent the risk factors of NCDs to maintain our health.

A healthy lifestyle will result from waking up early and engaging in daily exercise for 30 minutes at least five days a week. It's essential to drink at least three liters of water per day in order to prevent dehydration, kidney damage and to reduce tissue injuries during sports. The majority of chemical processes that take place inside the body use water as their primary medium. It's important to have a well-balanced diet with high protein and less carbohydrates at a preplanned time frame which is appropriate to the body. Apart from that it is preferred to give a resting period for the stomach between 8pm to 4 am. Energy saving can be promoted as well by reducing the regular cooking.

Required energy or daily calorie take for a medium sized body frame with an approximate weight of 70 kg and a height of 1.65 m is defined as 2100 kcal. All the nutrients, including carbohydrates, proteins, lipids, vitamins, minerals, non-nutritive compounds such as phytochemicals and high-fiber foods like fruits, vegetables, nuts, whole grains (*e.g.*, unprocessed maize, millet, oats, wheat and brown rice), and legumes (*e.g.*, lentils and beans), should be present in the diet composition of an adult, with the intake of sugar and salt kept to a minimum. The intake of fruits and vegetables should be nearly 400 g per day excluding potatoes, sweet potatoes, cassava and other starchy roots. Salt should be iodized and amount of consumption should be less than 5 g per day. The diet should include less than 10% of total energy intake from free sugars which is equivalent to 50 g for a person of healthy body weight consuming about 2000 calories per day. It is suggested that the intake of saturated fats be reduced to less than 10% of total energy intake and trans-fats to less than 1% of total energy intake. In particularly, industrially-produced trans-fats are not part of a healthy diet and should be avoided. For a normal, healthy person the energy of the macro nutrient in a diet should be compromised as 45%-60% of carbohydrates, 10%-25% of protein and 10%-30% of fat/oil. Lauric acid contain in the virgin coconut oil is really good for the kidney patients.

Fast foods are having excessive oil, salt, sugar and artificial flavor that is harmful foe the body conditions. It also possesses a high calorie density, empty calories, and a low nutrient density.

The serving size of cooked long-grain white rice is half of a cup (79 g) and same amount goes with vegetable curry and green leafy salad. A weight of 50 g of fish/meat would be sufficient for a meal. Different types involved in cooking are coconut oil, palm oil, olive oil and soya oil.

Coconut oil can be produced using copra. The quality of the coconut oil can be dropped under below circumstances. When the copra produced through smoking there can be harmful gases such as hydrocarbons causing the destruction of nutritive value of natural coconut oil. Contamination of animal dung can happen when the copra stored in dirty places like breeding places of rats and insects. The low-quality coconut oil produced when copra stored in a one place for a long period of time with poor dehydration as well as fungus contamination namely aflatoxin. Oxidation of fatty acids in copra can occurred when storing unclean copra for so long. Excessive exposure of copra to heat can cause the health beneficial fatty acids of lauric acid in the coconut oil to get oxidized reducing the quality of coconut oil. Thus, in production of physically refined coconut oil copra should be heated up to 180 °C to protect lauric acid (boiling point of lauric acid > 180 °C). All the harmful compounds like peroxides, free fatty acids and impurities should be removed and should confirm that no free radicals or carcinogenic compounds have been produced.

Health benefits of tea can be listed as anti-carcinogenic effect, controlling blood cholesterol level, boosting the immunity, controlling the blood sugar level, boosting the activity of insulin hormone and controlling the weight gain. It says that three cup of tea per day help to reduce the risk of cardiovascular diseases. When having meals, it's recommended to have snacks in between breakfast, lunch and dinner.

Consumption of alcohol and cigarettes cause fatal diseases like cancers and cirrhosis. Alcohol is a psychoactive substance with dependence-producing properties that has been widely used in many cultures for centuries. The harmful use of alcohol causes a high burden of disease and ha significant social and economical consequences. Drinking alcohol is associated with a risk of developing health issues such as mental and behavioral disorders, including alcohol dependence and major noncommunicable diseases such as liver cirrhosis, some cancers and cardiovascular diseases. A significant proportion of the disease burden attribute to alcohol consumption arises from intentional and unintentional road traffic crashes, violence and suicide causing difficulties to family, co-workers and strangers. Worldwide, three million of deaths result from harmful alcohol annually representing 5.3% of all deaths. Fatal alcohol-related injuries tend to occur in relatively younger age group. Smoking can cause lung cancers if the health limit was exceeded. More than 7 million of deaths are the result of direct tobacco use while around 1.2 million of deaths are the result of non-smokers being exposed to second-hand smoking.

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XVIIIth Convocation of the College of Chemical Sciences Institute of Chemistry Ceylon

The 18th Convocation of the College of Chemical Sciences, Institute of Chemistry Ceylon was held on the 19th of September 2022 at the Bandaranaike Memorial International Conference Hall (BMICH). Mr. M. Nihal Ranasinghe, Secretary of the Ministry of Education graced the occasion as the Chief Guest. This event marked the graduation of the first batch of BSc (Hons) in Chemical Science graduates which comprised of 41 graduates, 86 graduates from the Graduateship in Chemistry (GIC) program, 51 Diplomates from the Diploma in Laboratory Technology in Chemistry (DLTC) and two diplomates from Diploma in Chemistry.

The convocation ceremony was declared open by Mr. N. M. S. Hettigedara, the president of the Institute of Chemistry Ceylon. Two minutes of silence was then observed in par with the demise of Her Majesty Queen Elizabeth II. It was followed by the distribution of certificates and medals for the GIC and BSc (Hons) graduates and DLTC diplomates. The chief guest Mr. Nihal Ranasinghe then addressed the gathering and highlighted the significant role the Institute of Chemistry and its graduates play in uplifting Chemical Sciences in Sri Lanka. The audience was then addressed by Ms. Pujani Usliyanage, Ms. Nisali Mendis and Ms. M. N. A Hanee who delivered their valedictory speeches for the GIC and BSc (Hons) graduates and DLTC programs respectively. The Council Members of the Institute of Chemistry Ceylon, Emeritus and Senior Professors, Senior Lecturers, Administrative staff of the Institute of Chemistry, Teaching Assistants, Parents and well-wishers were among those who attended to witness this momentous occasion.
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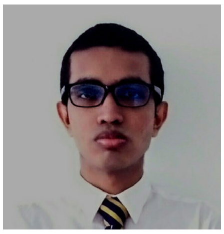
COSL
Chemistry Olympiad Sri Lanka
International Chemistry Challenge

Sri Lanka won a silver medal and three bronze medals at the 54th International Chemistry Olympiad 2022

Nelushi Vithanachchi of Visakha Vidyalaya, Colombo won a silver medal while three other team members; Benuljith Mindula Karunarathne of Royal College, Colombo, Vasanthamohan Sasangan of St. Michael's College, Batticaloa and Ranasinghege Kavinda Chathuranga of Nalanda College, Colombo 10, won a bronze medal each at the 54th International Chemistry Olympiad (IChO) Competition 2022 hosted by China. In addition, all four team members won the "Golden Monkey Award" for their outstanding performances in the virtual simulation experiment examination. This is one of the best team performances displayed by a Sri Lankan team at any International High School Olympiad competition held in the stream of Mathematics/Science held so far.

Nelushi Vithanachchi
Visakha Vidyalaya, Colombo 05
Silver medalist

Vasanthamohan Sasangan
St.Michael's College, Batticaloa
Bronze medalist



Benuljith Karunarathne
Royal College, Colombo 07
Bronze medalist

Kavinda Chathuranga
Nalanda College, Colombo 10
Bronze medalist

This year's competition was held during the period from 10th July to 18th July and the theory examination was conducted as a remote examination on 13th July 2022. A total of 323 highly talented high school students from 84 countries participated in the IChO 2022. The remote theory examination for Sri Lanka was conducted at the Headquarters of the Institute of Chemistry Ceylon (IChemC), Rajagiriya. This is the third time a Sri Lankan team participated in the IChO. In both previously held competitions, Sri Lanka won 3 Bronze medals and an honorable mention.

Chemistry Olympiad Sri Lanka Committee of the ICHEMC, which locally organizes this event, heartily congratulates the winners of the IChO 2022 for bringing glory to our country.

Dr Ireshika De Silva
Chairperson/ Chemistry Olympiad Sri Lanka Committee

Student Corner

Introduction to Coordination Chemistry

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Senior Professor in Chemistry, Department of Chemistry, The Open University of Sri Lanka

Coordination chemistry of transition metals is very important as it helps students to understand various industrial, chemical and biological processes. Hemoglobin and chlorophyll are the two most important compounds found in nature containing Fe^{2+} and Mg^{2+}, respectively. They are responsible for the existence of life on earth. Vitamin B_{12} contains a cobalt center. Cisplatin, *cis*-$[PtCl_2(NH_3)_2]$, is used for the treatment of cancer.

Coordination compounds

When a **metal** (M) is bonded to *n* number of **ligands** (L), then the resultant compound can be represented as $[ML_n]$. A coordination compound consists of a central metal center surrounded by one or more ligands (molecules or ions) containing a donor atom(s) such as N, O, C, P and S. Some examples are $[CoCl_3(NH_3)_3]$, $[Fe(CO)_5]$, $[PtCl_4(NH_3)_2]$ & $[Ag(NH_3)_2]Cl$. The formula of a compound (or complex ion) should be always written inside a **square bracket**. The constituents in the square bracket (*e.g.*, NH_3) belong to the **inner-coordination sphere**. The molecules and ions written outside the square bracket belong to the **outer-coordination sphere**, *e.g.*, Cl^- in the salt $[Ag(NH_3)_2]Cl$. Generally, a ligand donates an electron pair to the metal center. To accept these electrons the metal center should contain vacant orbitals of appropriate energy.

d-Electron configuration of a metal center

The *d*-electron configuration of V^+, V^{2+}, V^{3+} and V^{4+} ions are $[Ar]3d^4$, $[Ar]3d^3$, $[Ar]3d^2$ and $[Ar]3d^1$, respectively. Note that 4*s* electrons are removed before the removal of 3*d*-electrons. The reason for this is that in a **metal cation** the energy of 3*d*-orbitals is lower than the energy of the 4*s*-orbital. In the **free metal**, the energy level of the 4*s*-orbital is lower than that of the 3*d*-orbitals.

Group Number of a metal center

The Group number of a *d*-block element is equal to the sum of *s*- and *d*-electrons in the *free metal* (*i.e.*, zerovalent metal or M^0). For example, the electron configuration of Sc is $[Ar]3d^1 4s^2$, thus, the Group number of Sc is 3. Thus, the elements Sc, Y and La belong to Group 3.

Coordination number of a metal center

The number of monodentate ligands (or electron pairs) coordinated (or donated) to a central atom/ion is called the **coordination number** (C.N.). It depends on, (i) the **oxidation number** (O.N.) of the metal center, (ii) the nature of the coordinated ligands, and (iii) the size of the metal center and ligands (steric factors).

The most common coordination numbers in transition metal complexes are **four** and **six**, although coordination numbers from **two** to **twelve** have been reported.

Types of coordination complexes

There are three types of complexes called neutral, cationic and anionic depending on the charge of the complex or the complex ion; $[Fe(CN)_6]^{4-}$ is an anionic **homoleptic** complex anion, $[CoCl_2(NH_3)_4]^+$ is a cationic **heteroleptic** ion, and $[CoCl_3(NH_3)_3]$ is a neutral compound. The coordinated ligands within a complex or complex ion do not easily dissociate when dissolved in a solvent: *e.g.*, $[Fe(CN)_6]^{4-}$, $[CoCl_2(NH_3)_4]^+$ ions and $[CoCl_3(NH_3)_3]$ remain intact upon dissolution. In a neutral complex, $[CoCl_3(NH_3)_3]$, the number of monoanionic ligands coordinated to the metal center is equal to its oxidation number, *i.e.*, +3.

Mononuclear complexes are those with one metal center while complexes with two, three or more metal centers are called bi-, tri-, or poly-nuclear complexes, respectively.

Ligands

Ligands are simply anionic or neutral molecules bonded to a metal center *via* a coordinate bond. They can either be neutral or anionic. Each ligand has at least one pair of unshared electrons, which can be donated to the metal center. Some examples for anionic and neutral ligands are given below.

Anionic	Cl^-, CN^-, HO^-, SCN^-, SO_4^{2-}
Neutral	H_2O, NH_3, CO, PPh_3, NO, O_2

Ligands are classified according to the number of coordinating atoms within the ligand as given in Table 1.

Table 1: Classification of ligands

Ligand Type	C.N.	Example
Monodentate	1	NH_3, H_2O, CO, Cl^-, PPh_3
Bidentate	2	Ethylenediamine (en), bipyridine (bipy), CO_3^{2-}, oxalate (ox^{2-}), acetyl acetonate ($acac^-$)
Tridentate	3	Diethylenetriamine (dien)
Tetradentate	4	Triethylenetetraamine (trien)
Hexadentate	6	Ethylenediamine tetraacetate ($EDTA^{4-}$)

The process of metal center being bonded by more than one coordinating (or ligating) atoms to form a **ring structure** is called **chelation**. Such ligands are called **chelating ligands**, *e.g.*, $H_2\mathbf{N}CH_2CH_2\mathbf{N}H_2$ (en), oxalate (ox^{2-}). Hydrazine ($H_2\mathbf{NN}H_2$) is a bidentate ligand but two nitrogen atoms are not sufficiently far apart to form a stable chelate. Bridging (μ) ligands (Cl^-, SCN^-, H_2N^-, CO *etc.*) can link two or more metals.

Some ligands contain **more than one atom or group** capable of donating electrons to a metal center. Ligands which can form more than two points of attachment to the metal center are termed **polydentate** (Figure 1 and Table 1).

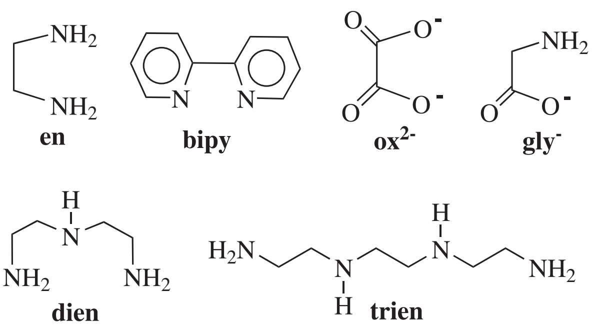


Figure 1: Some polydentate Ligands

Some simple ligands have two different coordinating atoms where only one can bind with the metal center at a time. They are called **ambidentate ligands**. For example, SCN^- ligand can bind *via* nitrogen or sulfur.

Geometry of coordination compounds

The **spatial arrangement of ligands** around a metal center defines the geometry of a compound. The geometry varies with the **number** and **type** of ligands attached to the central atom. The common geometries of coordination compounds are given in Table 2.

Table 2: Geometries of complexes

C.N.	Geometry	Example
2	Linear	$[Ag(NH_3)_2]Cl$
3	Trigonal planar	$[Cu(PPh_3)_3]^+$
4	Tetrahedral	$[FeBr_4]^-$
	Square planar	$[Ni(CN)_4]^{2-}$
5	Trigonal bipyramidal	$[Fe(CO)_5]$
	Square pyramidal	$[NiBr_3(PPh_3)_2]$
6	Octahedral	$[Mo(CO)_6]$

Note - d^6 metal centers prefer **octahedral**; d^8 metal centers prefer **square-planar**; d^{10} metal centers prefer **tetrahedral** geometries.

Structures of some compounds or ions are shown in Figure 2.

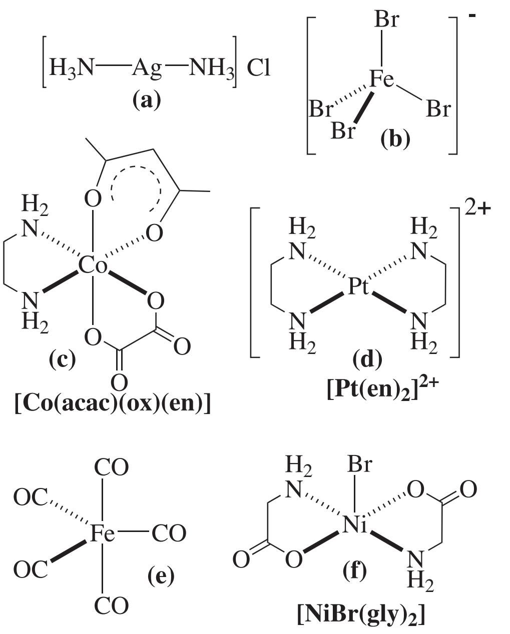


Figure 2: (a) Linear; (b) tetrahedral; (c) octahedral; (d) square-planar; (e) trigonal bipyramidal; (f) square-pyramidal geometry

Sometimes the energy difference between two isomers can be quite small and the compounds can interconvert between them (*e.g.*, square pyramidal ⇌ trigonal bipyramidal). These molecules are known as fluxional molecules.

Werner's Theory

This theory describes the binding of ligands in coordination compounds. According to Werner's coordination theory, a metal has two different types of valencies, which are primary valency and secondary valency. The primary valency is the oxidation number of the metal center. The number of ligand atoms bound to the metal center or the coordination number is defined as the secondary valency. The primary and secondary valencies of Co in $[Co(NH_3)_6]Br_3$ are +3 and 6, respectively.

The Effective Atomic Number

The electron pairs from ligands can be added to the central metal until the metal center has the same number of electrons as in the next noble gas. The total number of electrons on the central metal center including those gained from ligands is called the Effective Atomic Number (EAN) of the central metal center. In many cases, the EAN is equal to the atomic number (Z) of the next noble gas. The EAN of Co(III) in $[Co(NH_3)_6]^{3+}$ = 27-3 + 2 x 6 = 36; which is equal to the atomic number (Z) of Kr. However, there are few compounds which do not obey this rule.

The valence electron count (VEC) and the 18e rule

The valence electron count is equal to the sum of *d*-electrons in the metal center (*i.e.*, the Group number of metal) and the electrons donated by the ligands.

For example, the VEC of $[Ni(CO)_4]$ is equal to 18e (= 10 + 2x4).

The 18e-rule says that any transition metal center would form a stable compound if the VEC of the metal is 18. Thus, these complexes are **coordinatively saturated**. The complexes with incompletely filled valence shells (*i.e.*, VEC < 18e) are called **coordinatively unsaturated** complexes. A metal center would prefer to take up a ligand(s) in order to fulfill the 18e-rule.

Molar conductivity of compounds

Werner prepared a series of cobalt-ammine complexes, and studied their properties. He found that when $CoCl_3$ was reacted with different amounts of NH_3 yielded a set of new compounds with different compositions :- $CoCl_3{\cdot}6NH_3$ (**A**), $CoCl_3{\cdot}5NH_3$ (**B**), $CoCl_3{\cdot}4NH_3$ (**C**), $CoCl_3{\cdot}5NH_3{\cdot}H_2O$ (**D**) and $CoCl_3{\cdot}3NH_3$ (**E**). He studied the molar conductivity and the number of Cl^- ions given by each of these complexes. His observations are presented in Table 3.

Table 3: Characterizing data for (**A**) - (**E**)

	X	Y	Z	Ionic information
(**A**)	3	430	4	$[Co(NH_3)_6]^{3+}(Cl^-)_3$
(**B**)	3	430	4	$[Co(NH_3)_5(H_2O)]^{3+}(Cl^-)_3$
(**C**)	2	250	3	$[CoCl(NH_3)_5]^{2+}(Cl^-)_2$
(**D**)	1	100	2	$[CoCl_2(NH_3)_4]^+Cl^-$
(**E**)	0	0	*	$[CoCl_3(NH_3)_3]$

X = Number of Cl^- ions precipitated as AgCl
Y = Molar conductivity in $m^2\ \Omega^{-1}\ mol^{-1}$
Z = Total number of ions present in the solution
* = non electrolyte

The characterizing data suggest complexes (**A**) - (**D**) to be salts and (**E**) a neutral compound. The molar conductivity values are in good agreement with the ionizable chloride ions present in (**A**) - (**D**). In all of these complexes, cobalt shows the primary valency (oxidation number) of +3 and the secondary valency (C.N.) of 6.

Nomenclature of coordination compounds

You have learnt nomenclature of coordination compounds for the A/L examination. Some names of the ligands and compounds are given below.

1. $[CoCl(NH_3)_5]^{2+}$
   = Pentaamminechloridocobalt(III) ion
2. $K_4[Fe(CN)_6]$
   = Potassium hexacyanidoferrate(II)
3. $[CuCl_2(CH_3NH_2)_2]$
   = Dichloridodi(methylamine)copper(II)
4. *cis*-$[Pt(gly)_2]$
   = *cis*-Diglycinatoplatinum(II)

5. $[Pt(acac)(py)_2]^+$
   = Acetylacetonatodi(pyridine)platinum(II)

6. $[Os(C_2O_4)_3]^{2-}$
   =Trioxalatoosmate(IV)

7. *fac*-$[Mo(CO)_3(PMe_3)_3]$
   = *fac*-Tricarbonyltris(trimethylphosphine) molybdenum(0)

Problems

1. (i) What is the oxidation number of Fe in $[FeSO_4(gly)(bipy)]$ (**A**)?
   (ii) Give the IUPAC name of (**A**).
   (iii) What is the coordination number of Fe in (**A**)?
   (iv) Determine the Effective Atomic Number (EAN) of Fe in (**A**).
   (Atomic number of Fe is 26)
   (v) Write the chemical formula of glycenatodicarbonyldichloridocobalt(III)

2. The substance with the composition $FeCl_3{\cdot}5NH_3{\cdot}H_2O$ has a molar conductivity of 430 $m^2ohm^{-1}mol^{-1}$ (*i.e.*, 1:3 electrolyte). Write the molecular formula of it?

3. A neutral mononuclear 16e-complex (**B**) containing a Co(I) center is coordinated only to chloride and CO ligands.
   (i) What is the molecular formula of (**B**)?
   (ii) Comment on the geometry of (**B**) and draw the structure of (**B**).

4. What is the molecular formula of diamminebromidocarbonyloxalatocobalt(III).

5. (i) Give the IUPAC name of $[Co_2(\mu\text{-}Cl)_2(CO)_4]$ (**C**).
   (ii) (**C**) is a symmetrical molecule without a metal-metal bond. Draw the structure of (**C**).

Student Corner

Introduction to Polymer Chemistry

K. Sarath D. Perera
Senior Professor in Chemistry, Department of Chemistry, The Open University of Sri Lanka

Polymers play an important role in our day-to-day life. In Greek, poly means "many" and mer means "parts". Polysaccharides, proteins and nucleic acids are the main **bio-polymers/macromolecules**. A large number of industries (*e.g.*, packaging, textile, automobile, paper *etc.*) are based on **synthetic polymers** such as polyethylene (PE), poly(vinylchloride) (PVC), polyesters, nylon, *etc.*, and **natural polymers** such as rubber, cellulose, *etc.* Joseph Priestly discovered "**natural rubber**", a natural **polymer** derived from the **monomer** 1,3-*cis*-isoprene. **Bakelite** was the 1st **synthetic polymer** prepared by Leo Baekeland in 1907 from **phenol** and **HCHO**.

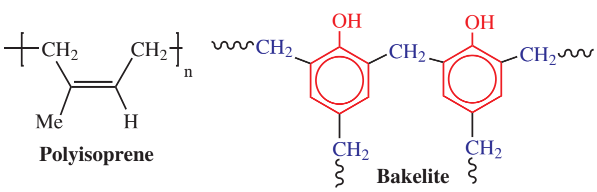


Figure 1: Natural rubber and Bakelite

Polymerization is the process which makes macromolecules by chemically bonding a large number of monomer units, consisting of two or more functional groups or reactive sites such as acid (-COOH), alcohol (-OH), amino ($-NH_2$) groups, halide, -SH, -NCO, C=C, C≡C, *etc.*

$$n\ \textbf{Monomer} \rightarrow [\text{Repeat unit}]_n = \textbf{Polymer}$$

$$n\ CH_2{=}CH_2\ (\textbf{Ethene}) \rightarrow \left[CH_2{-}CH_2 \right]_n = \textbf{Polyethene}$$

Ethene has two reactive sites (two radicals or cation and anion); it produces **linear** polymers.

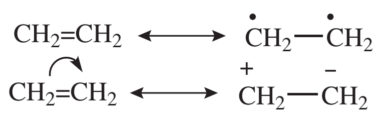


Figure 2: Reactive sites of ethene

Poly(pent-1-ene) $-[CH_2CHR]_n-$ can be considered as a **branched polymer** {R = $(CH_2)_2Me$}. **Hydroxy acids** (*e.g.*, lactic acid, HOCH(Me)COOH) and amino acids (*e.g.*, glycine, H_2NCH_2COOH) are bi-functional monomers, and *via* **condensation**, they produce linear polymers $-[OCH(Me)CO]_n-$ / $-[CH(Me)COO]_n-$ and $-[HNCH_2CO]_n-$ / $-[CH_2CONH]_n-$. 1,3-Diisocyanatobenzene is also a bi-functional monomer which can undergo addition polymerization with diamines or dialcohols as shown in Figure 3.

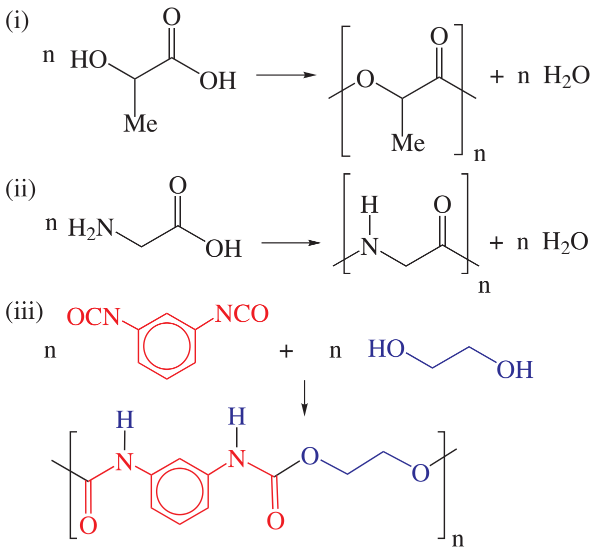


Figure 3: Polymers from hydroxy acids, amino acids and diisocyanates

Phenol can generate **three** active sites (two *ortho* and one *para*). 1,3,5-Triisocyanato-benzene and melamine are tri-functional monomers; they produce **cross-linked** polymers.

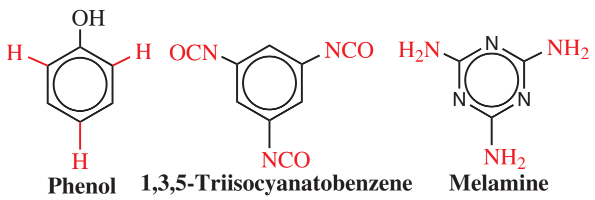


Figure 4: Tri-functional monomers

Classification of polymers

Polymers can be categorized by their origin into **organic** and **inorganic** polymers. Inorganic polymers or partially inorganic polymers are linked by covalent bonds, in the absence or near absence of hydrocarbon units in the main backbone. Some examples for such polymers are polysilanes, polyphosphazenes, poly(sulphur-nitride), poly(1,1´-ferrocene-silane), polysiloxanes, *etc.*

Organic polymers can be divided into either **synthetic** (*e.g.*, polyethylene (PE), polyurea, nylon, polystyrene (PS), Teflon, PVC, *etc.*) or **natural** (*e.g.*, cotton, silk, rubber, starch, cellulose, proteins, *etc.*) polymers.

By considering their applications and physical properties, polymers are grouped into **plastics** (become hard at ambient temperatures), **fiber** (strong threads such as nylon), **elastomers** (*e.g.*, rubber) and **adhesives** (*e.g.*, resins).

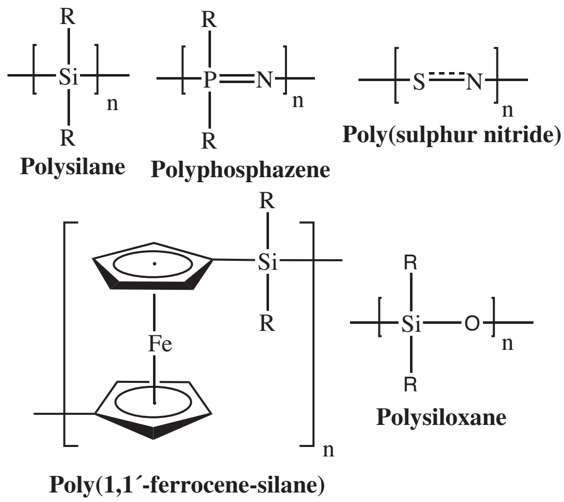


Figure 5: Examples for inorganic polymers

Branched and cross-linked polymers such as Bakelite and vulcanized rubber can be molded only once and are called **thermosets**, which cannot be recycled. Tri-functional monomers form irreversible cross-link/3D structures during the curing process. The other type is **thermoplastics** which are mostly linear polymers obtained from bi-functional monomers. They can be recycled and reshaped by heating and cooling (*e.g.* PE, PP, PVC, nylon).

Homopolymers have one repeating unit and are produced by polymerizing a single monomer or two parts of a pair. Some polymers have two or more types of monomers with different repeating units; which are called **copolymers**.

The **degree of polymerization** (DP = n) gives an idea about the number of monomer or repeat units present in the polymer.

$$DP = \frac{\text{Molar mass of the polymer}}{\text{Molar mass of the repeat unit}} = \frac{M}{m} = n\ (\text{integer})$$

Thermal stability, heat/fire resistance, conductivity, tensile strength, viscosity, solubility, fluidity, elasticity, molten/melting point, crystallinity/amorphousness, *etc.* are some of the properties of polymers, which depend on their chemical nature/bonding, structure, and size/molar mass.

Methods of polymerization

The three main methods of polymerization are (i) **addition**, (ii) **condensation**, and (iii) **ring-opening** polymerization.

Addition Polymerization

This is also known as chain growth polymerization. Monomers such as **vinyl** (CH_2=CH-R) (R = H, halogens, OMe, CO_2Me, CN), **allyl** compounds (CH_2=CH-CH_2R), and **dienes** (CH_2=CR–CH=CH_2) (R = an organic group) with reactive double bonds undergo **addition** reactions to form polymers (*e.g.*, PE, PS, PVC, polyisoprene *etc.*). The elemental composition of the polymer is similar to the monomer since by-products are not formed.

Mechanisms of addition polymerization

Three mechanisms are possible for addition polymerization depending on the nature of the substituents. They are (a) **free radical**, (b) **cationic** and (c) **anionic** polymerization. Each method is composed of three steps. They are 1) **initiation**, 2) **propagation**, and 3) **termination**.

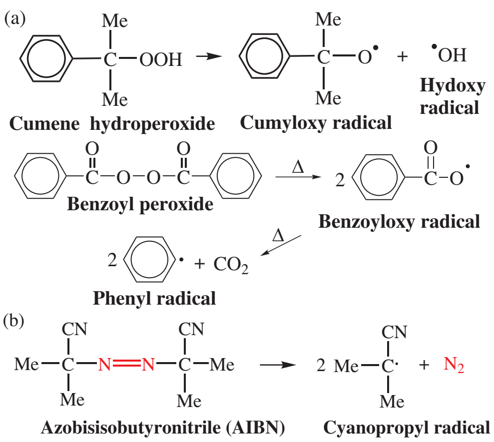
1. Initiation

The initiator can be a free radical - I•, cationic species - I^+, anionic species- I^- or a metal complex or catalyst.

Initiator → I• or I^+ or I^-

(a) Free radical polymerization using I•

Initiation is achieved by (a) decomposing a labile compound such as **peroxide** or **peracid**, (b) using an **azo-compound**, (c) *via* a redox-reaction and (d) using UV-light. Some examples are given below (I• = RO• or R• or HO• *etc.*).



(c) $HOOH + Fe^{2+} \rightarrow {}^{\bullet}OH + HO^- + Fe^{3+}$

$ROOH + Co^{2+} \rightarrow RO^{\bullet} + HO^- + Co^{3+}$

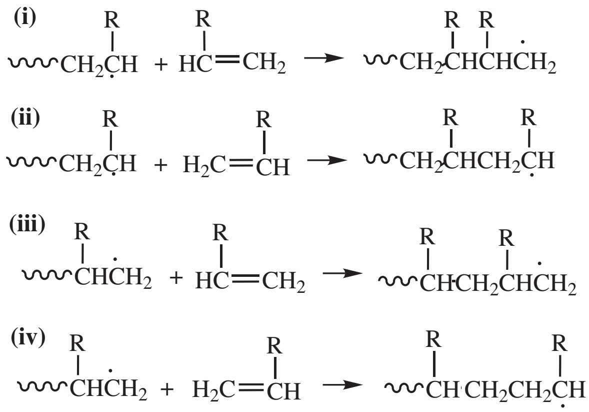
Figure 6: Formation of free radicals

The initiation step for a terminal olefin is as follows.

The stability of the free radical, reaction temperature and solvent determine the rate of initiation.

Modes of addition of free radicals

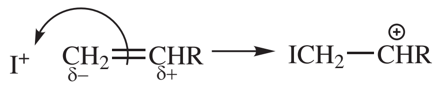
In free radical polymerization, the addition or coupling of free-radicals can take place in four ways: (**i**) head-to-head, (**ii**) head-to-tail, (**iii**) tail-to-head, and (**iv**) tail-to-tail as shown below.



The most favored addition is head-to-tail, which minimize the steric repulsion and produces a stable radical.

(b) Cationic polymerization using I^+

Electrophilic compounds particularly proton donor acids such as HCl, H_2SO_4, $HClO_4$, *etc.* and Lewis acids (*e.g.*, BF_3, $AlCl_3$, $TiCl_3$, $SnCl_4$) can act as cationic initiators as shown below (I^+ = H^+, for example BF_3 reacts with water to produce H[BF_3(OH)]).



R = H, Me, OMe, Ph *etc*

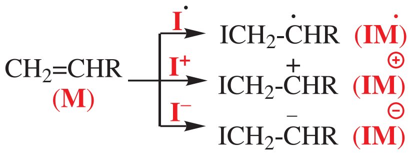
The stability of the carbocation determines the growth of the polymer.

(c) Anionic polymerization using I^-

In this case, a negative ion attacks the double bond of the monomer. Monomers consist of nitro, cyano, carboxyl, vinyl, and phenyl groups are more likely to produce more stable carbanions via resonance or induction. Triphenylmethyl potassium (Ph_3CK), NaH, KNH_2, KOH, BuLi, can act as anionic initiators (I^- = base, nucleophile, H^-, R^-, HO^- *etc.*).

R = Ph, CN, CO_2H, CO_2Me

The initiation step of olefin polymerization is abbreviated as shown below.



2. Propagation

This step is important to increase the length of the polymer chain.

(a) Free radical polymerization

$$IM^\bullet + M \rightarrow IMM^\bullet$$
$$I(M)_{n-1}M^\bullet + M \rightarrow I(M)_nM^\bullet$$

(b) Cationic polymerization

$$IM^\oplus + M \rightarrow IMM^\oplus$$
$$I(M)_{n-1}M^\oplus + M \rightarrow I(M)_nM^\oplus$$

(c) Anionic polymerization

$$IM^\ominus + M \rightarrow IMM^\ominus$$
$$I(M)_{n-1}M^\ominus + M \rightarrow I(M)_nM^\ominus$$

3. Termination

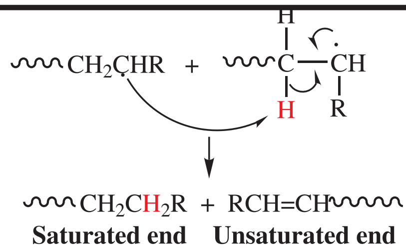
(a) Free radical polymerization

Polymer radicals can be ceased or quenched in several ways.

(i) By combining of two radicals

$$I\sim\sim M^\bullet + {}^\bullet M\sim\sim I \rightarrow I\sim\sim M\text{-}M\sim\sim I$$

(ii) By disproportionation

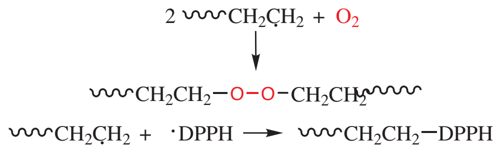


(iii) By chain/H atom transfer

$$\sim\sim M^\bullet + \text{Solvent-H} \rightarrow \sim\sim MH + \text{Solvent}^\bullet$$

(iv) By inhibition

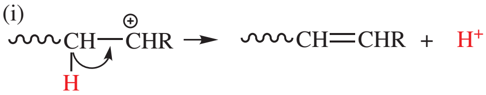
Dioxygen and inhibitors or radical scavengers such as diphenyl picryl hydrazine (·DPPH) can stop the polymerization process.



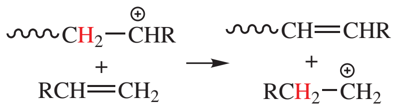
(b) Cationic polymerization

In cationic polymerization, termination can occur by (i) rearrangement or (ii) H atom transfer reaction with a monomer.

(i)



(ii)



(c) Anionic polymerization

The termination step of the anionic polymerization differs from the other methods since it gives living polymers. This means that the **carbanion** of the last monomer of the polymer chain-end remains potentially active. If one adds more monomers again to the polymer solution, it will continue to grow, provided that there are no more impurities/inhibitors.

Condensation polymerization

The polymers are built-up *via* step-wise reactions which occur between functional groups of the monomers; H_2O and HCl are produced as by-products. The rate of the reaction is slow compared to that of chain polymerization. The 3 main reaction types are: 1, polycondensation, 2. polyaddition and 3. ring-opening polymerization (ROP).

Both polycondensation and polyaddition reactions occur between monomers with two functional groups.

1. Polycondensation reaction

Polyamides -[HN$(CH_2)_x$NHCO$(CH_2)_y$CO$]_n$- are prepared by condensing diamines $H_2N(CH_2)_xNH_2$ and dicarboxylic acids $HO_2C(CH_2)_yCO_2H$.

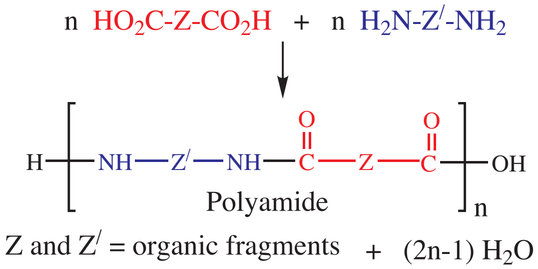


Figure 7: Synthesis of polyamides

Polyesters are prepared in a similar way. Condensation reaction between bisphenol-A and diphenyl carbonate or phosgene ($COCl_2$) produces polycarbonates.

2. Polyaddition reaction

Polyaddition of diamines to diisocyanates gives polyurethanes.

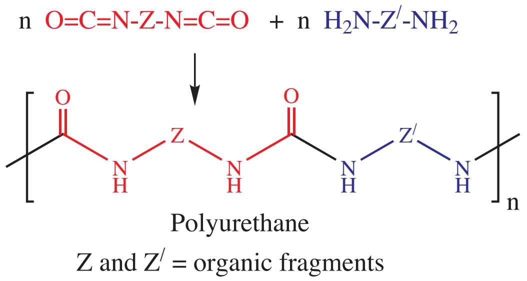


Figure 8: Synthesis of polyurethane

3. Ring-opening polymerization

The third method of polymer preparation involves a ring-opening polymerization (ROP) of cyclic monomers. Monomers having ring structures can be opened up to form polymers under favorable conditions. This type of polymerization can be achieved by thermally, photochemically (*e.g.*, trioxane) or using specific catalyst systems.

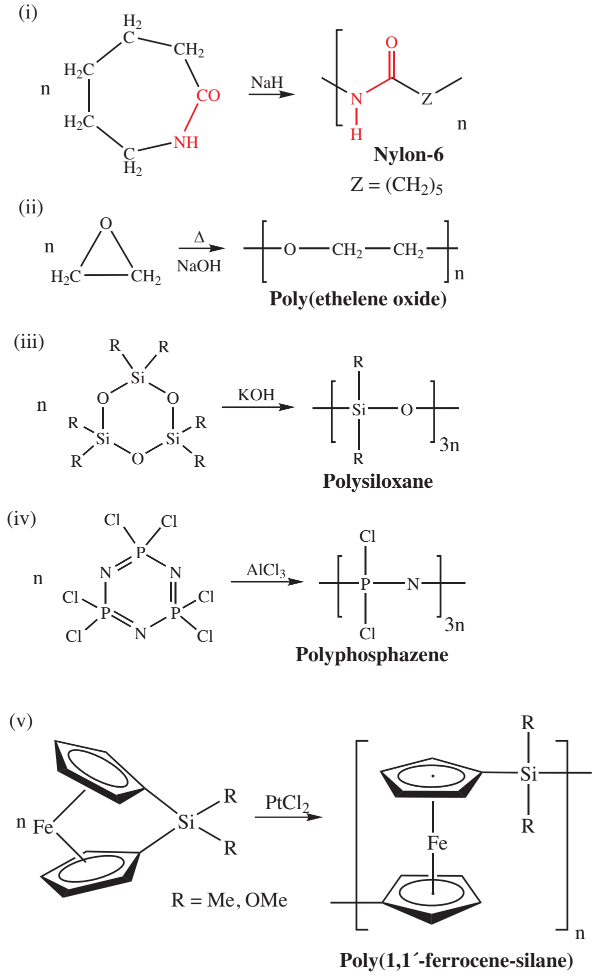


Figure 9: Some examples for ROP

Cyclic amides (lactams) and epoxides can easily be polymerized. It is important to note that all cyclic organic compounds cannot be converted into linear chains. Some examples of inorganic polymers include -$[SiR_2O]_n$-, -$[PCl_2=N]_n$- and -$[(C_5H_4)Fe(C_5H_4SiR_2]_n$-.

Coordination polymerization

Coordination polymerization uses organometallic compounds as initiators. Some examples include Ziegler-Natta catalyst ($TiCl_3/AlEt_3$), $Cp_2MCl_2/(MeAlO)_3$, (M = Ti, Zr, Hf; Cp = cyclopentadienyl), Schrock catalysts, Grubbs catalysts, *etc.*

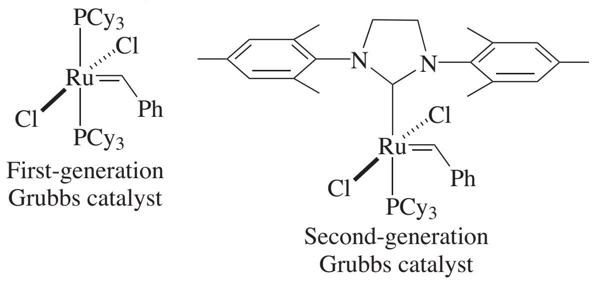


Figure 10: 1st and 2nd generations of Grubbs catalysts

Copolymers

Generally homopolymers are produced by addition and ring-opening polymerization of a single monomer. Polycondensation of two bi-functional molecules also results in homopolymers, which are consisting of one type of repeat unit, for example, nylon-4,6 $-[(HN(CH_2)_4NHCO(CH_2)_4CO]_n-$ can be considered as a homopolymer made from $H_2NCH_2CH_2CH_2CH_2NH_2$ and adipic acid, $HO_2C(CH_2)_4CO_2H$.

Addition polymerization of two or more monomers (*e.g.*, olefins) in different ratios yields copolymers. SBR is a copolymer $-[(CH_2CH{=}CHCH_2)_x(CH_2CHPh)_y]-$ made by polymerizing a mixture of styrene (25%) and butadiene (75%), (SBR = Styrene Butadiene Rubber = synthetic rubber). The copolymers are classified into 4 types: (**i**) random, (**ii**) block, (**iii**) alternate, and (**iv**) graft as shown in Figure 11.

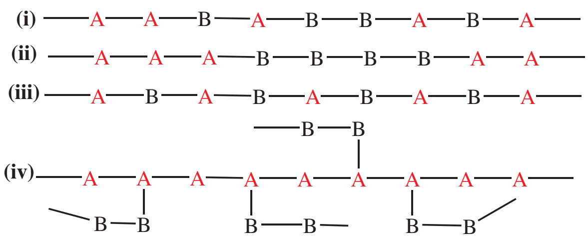


Figure 11: Types of copolymers

In a random copolymer, the monomers (**A** and **B**) are arranged in a random manner. The polymer $-[(CH_2CH_2)_n(CH_2CHPh)_m]-$ is a block copolymer made from ethene and styrene; **m** and **n** are integers. The polymer $[CH_2CH_2CH_2CHPh]_n-$ is an alternate copolymer made from ethene and styrene. The polymer $-[HN(CO)NHCH_2]-$ can be considered as an alternate copolymer made from urea and HCHO. Joining of styrene and maleic anhydride gives an alternate copolymer. Alternate copolymers have one type of repeating unit. The monomer **B** is grafted on to an existing polymer $-(\mathbf{A})_n-$, prepared from monomer **A**. For example, acrylonitrile can be grafted on to polystyrene. Methyl methacrylate can also be grafted on to natural rubber.

Student Corner

Metathesis and Polymerization of Olefins

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Senior Professor in Chemistry, Department of Chemistry, The Open University of Sri Lanka

Metathesis of simple salts is a double replacement reaction as shown below.

$$AX + BY \rightarrow AY + BX$$

In Greek, "Metathesis" is known as the change of position or transposition. **Olefin metathesis** (OM) is the catalytic **scission** and **regeneration** of C=C bonds as shown in Figure 1. This is a **reversible** process and the reverse reaction is called "**cross metathesis**" of olefins.

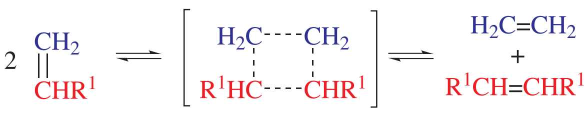


Figure 1: Metathesis of olefins

Ethene is a volatile molecule, thus, metathesis of a terminal olefin $R^1CH{=}CH_2$ produces a quantitative amount of $R^1CH{=}CHR^1$. Using this procedure tetra-substituted alkenes such as $R_2C{=}CR_2$ are obtained in good yields.

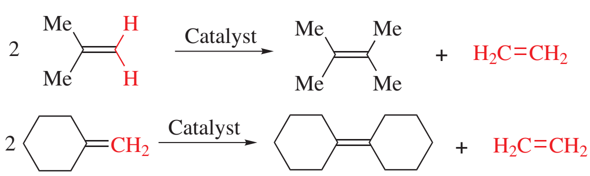


Figure 2: Synthesis of tetra-substituted alkenes

Catalysts for olefin metathesis

Olefin metathesis is normally catalyzed by homogeneous catalysts. Homogeneous catalysis refers to reactions where the catalyst and the reactants are present in the same phase. Metal carbene or alkylidene complexes with the M=CR$_2$ moiety are used as catalysts.

The well-known metathesis catalysts are [{Me(CF$_3$)$_2$CO}$_2$Mo=CHCMe$_2$Ph)(=NAr)] (**1**) (Schrock), [(PCy$_3$)$_2$Cl$_2$Ru(=CHCH=CPh$_2$)] (**2**) (Grubbs), [(PCy$_3$)$_2$Cl$_2$Ru(=CHPh)] (**3**) (Grubbs-1), [(PCy$_3$)(L)Cl$_2$Ru(=CHPh)] (**4**) (Grubbs-2), (L = **N**itrogen**H**etero**C**arbene). Richard R. Schrock, Robert H. Grubbs and Yves Chauvin shared the Nobel Prize in 2005 for their extensive work on olefin metathesis and polymerization.

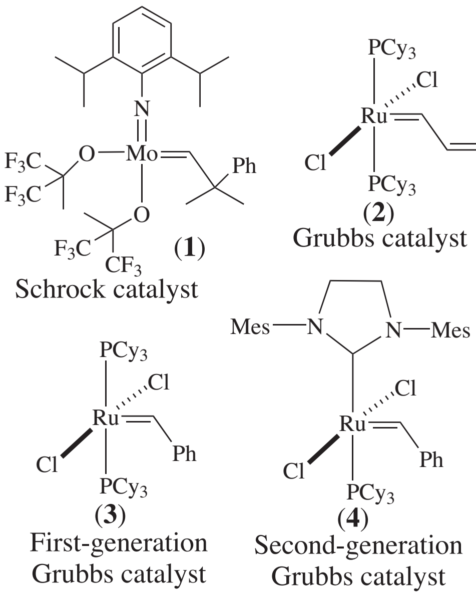
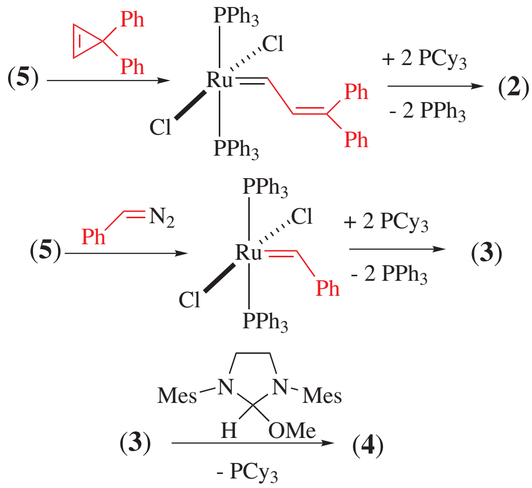


Figure 3: Olefin metathesis catalysts (Mes = mesityl = -C$_6$H$_2$-2,4,6-Me$_3$)

Schrock catalyst (**1**) has shown high efficiency towards OM but it is extremely unstable in air or in water. The efficiency of Grubbs-1 catalyst (**3**) is low but it is stable in air and in aqueous media. The Grubbs-2 catalyst (**4**) has shown increased reactivity, recyclability and stereospecificity. Grubbs catalysts tolerate a wide variety of functional groups.

Synthesis of Grubbs catalysts

The syntheses of Grubbs catalysts are quite easy from [RuCl$_2$(PPh$_3$)$_4$] (**5**) as shown in scheme 1.



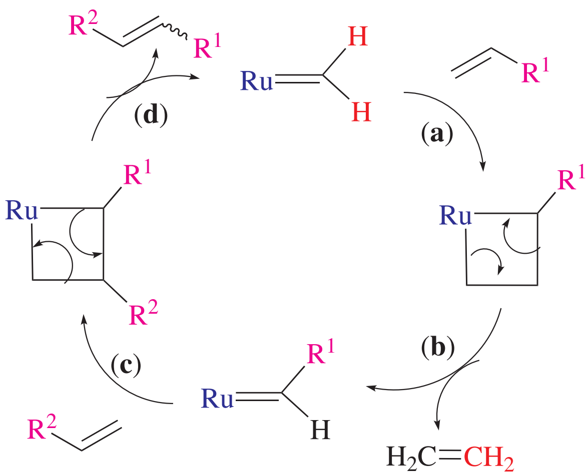
Scheme 1: Syntheses of Grubbs catalysts

Mechanism for cross metathesis

OM was discovered by Robert L. Banks in 1964. He reported the disproportionation of propylene to ethylene and butenes using [Mo(CO)$_6$] supported on alumina. It is an interesting process because there is no equivalent reaction in traditional organic chemistry. The mechanism for the following cross metathesis reaction using the Grubbs catalyst (**3**) is given in scheme 2.

$$R^1CH{=}CH_2 + R^2CH{=}CH_2 \longrightarrow R^1CH{=}CHR^2 + CH_2{=}CH_2$$

The complex [(PCy$_3$)$_2$Cl$_2$Ru(=CHPh)] (**3**) is an 16e-complex, it loses one PCy$_3$ ligand to give the reactive intermediate with 14e. One of the olefins joins on to this 14e-complex forming a "ruthenocyclobutane ring" which can generate Ru=CH$_2$ or Ru=CHR^1 or Ru=CHR^2 moieties as shown in scheme 2. Other ligands on Ru are not drawn for clarity.



Scheme 2: Mechanism for cross metathesis

The steps (**a**) and (**c**) involve the formation of the "metallocyclobutane" between $Ru=CH_2$ & $R^1CH=CH_2$ and $Ru=CHR^1$ & $R^2CH=CH_2$, respectively. In step (**b**), ethene is released giving $Ru=CHR^1$. The step (**d**) produces $R^1CH=CHR^2$ while generating the active catalyst $Ru=CH_2$. This is a random process and this mechanism is known as "**Chauvin Mechanism**".

Types of olefin metathesis reactions

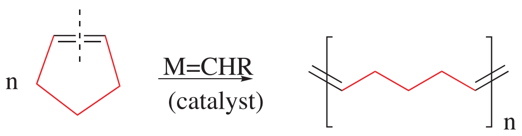
Olefin metathesis can be categorized as (i) **cross** (ii) **ring opening**, and (iii) **ring closing** metathesis reactions. All these reactions proceed *via* a **metallacyclobutane** intermediate.

Cross metathesis reactions

We have already looked at cross metathesis reactions involving terminal olefins. Metathesis of two symmetrical olefins, $R^1CH=CHR^1$ and $R^2CH=CHR^2$ gives a single product $R^1CH=CHR^2$ and vice versa. Metathesis of $R^1R^2C=CR^1R^2$ with $CH_2=CH_2$ gives a single product $R^1R^2C=CH_2$. Internal olefins ($R^1CH=CHR^2$) appear to undergo metathesis much faster than terminal ones ($R^1CH=CH_2$).

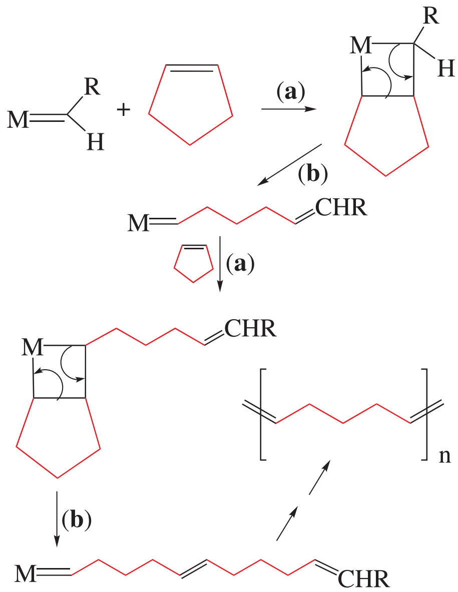
Ring opening metathesis (ROM) reaction

In this case, a cyclic olefin is opened up in the presence of a carbene catalyst to form a polymer, which is called ring opening metathesis polymerization (ROMP).



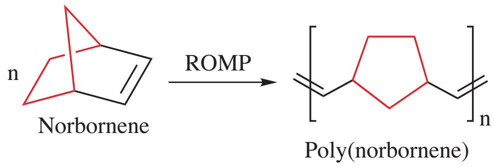
Scheme 3: ROMP of cyclopentene

The mechanism of the above reaction is shown in scheme 4. During step (**a**), the metallacyclobutane ring is formed. During step (**b**), the ring is opened up to give a metal carbene with a terminal olefin group. The resulting metal carbene continues to react with cyclopentene molecules leading to a polymer.



Scheme 4: Mechanism for ROMP, coligands on the metal M are not drawn for clarity

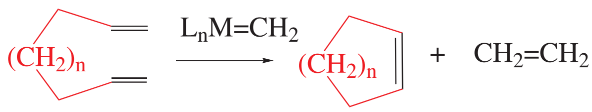
Poly(norbornene) is produced by ROMP of norbornene (scheme 5).



Scheme 5: ROMP of norbornene

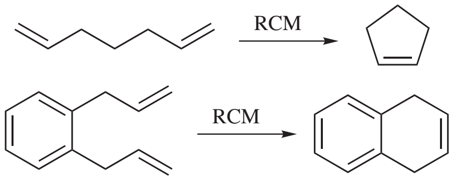
Ring closing metathesis reactions

In a ring closing metathesis (RCM) reaction, a **terminal diene** is converted into a carbocycle and an ethylene molecule is formed as a byproduct (scheme 6).



Scheme 6: Carbocycles from diolefins

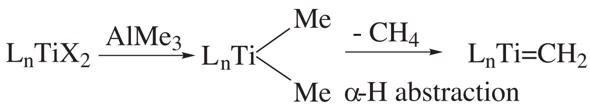
Some examples of RCM are shown in scheme 7.



Scheme 7: Examples for RCM

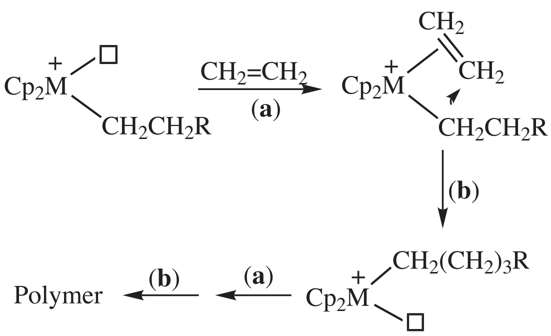
Olefin polymerization with other catalysts

Polyethylene (PE) and polypropylene (PP) are usually prepared using other catalysts. The Ziegler-Natta catalytic system {$TiCl_3$ or $TiCl_4$ with methylaluminoxane $(MeAlO)_n$, $AlEt_3$ or $AlEt_2Cl$} was discovered in late 1950s and it operates under mild conditions (at 25 °C and ethene pressure of 1 atm). Ziegler and Natta won the Nobel Prize in 1963 for the discovery of this catalytic system. The active catalyst is formed *in situ* and it could be an intermediate $[L_nTi{=}CH_2]$, $[L_nTi{=}CHR]$ or $[L_nTiR]^+$ as shown below.



Scheme 8: Formation of $[L_nTi{=}CH_2]$ from $[L_nTiMe_2]$

In the presence of $(MeAlO)_n$, metallocene dihalides (*e.g.*, Cp_2MCl_2, M = Ti, Zr or Hf) generate highly active homogenous catalysts for the polymerization of simple olefins. They are much better catalysts than Ziegler–Natta catalysts. The active catalyst is believed to be the cationic intermediate $[Cp_2MR]^+$ with one alkyl group and a vacant site. Coordination of ethene followed by migration of the R group on to ethene (1,2-insertion) generates $[Cp_2MCH_2CH_2R]^+$ ion. Propagation and polymerization steps are shown in scheme 9.

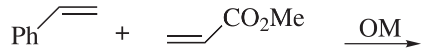


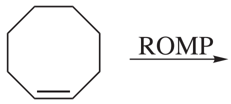
Scheme 9: Polymerization of ethene using the active catalyst $[Cp_2MR]^+$

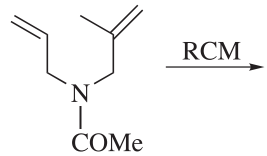
The step (**a**) refers to coordination of ethene to the vacant site and the step (**b**) refers to 1,2-insertion of ethene into M-alkyl bond.

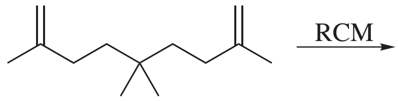
Problems

1. Predict the products of the following processes.

(i) 

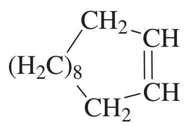
(ii) 

(iii) 

(iv) 

2. What is the major product/s formed due to metathesis of

$CH_3(CH_2)_7CH{=}CH(CH)_7CO_2Me$ and



3. Write the mechanism for the polymerization of prop-1-ene using Cp_2ZrCl_2 and $(MeAlO)_n$.

XVIIIth Convocation of the College of Chemical Sciences
19.09.2022 BMICH

Welcome address by the President, IChemC

Mr. N M S Hettigedara

Head Table at the Convocation

Convocation address by the Chief Guest

Mr. M Nihal Ranasinghe

Shireen Jayasuriya Gold Medallist - GIC

Ms. J P Usliyanage

Shireen Jayasuriya Gold Medallist - BSc

Ms. A N N Mendis

DLT batch top receives her award

Ms. M N A Hanee

Academic Procession

Part of the guests, invitees, graduates and diplomates

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