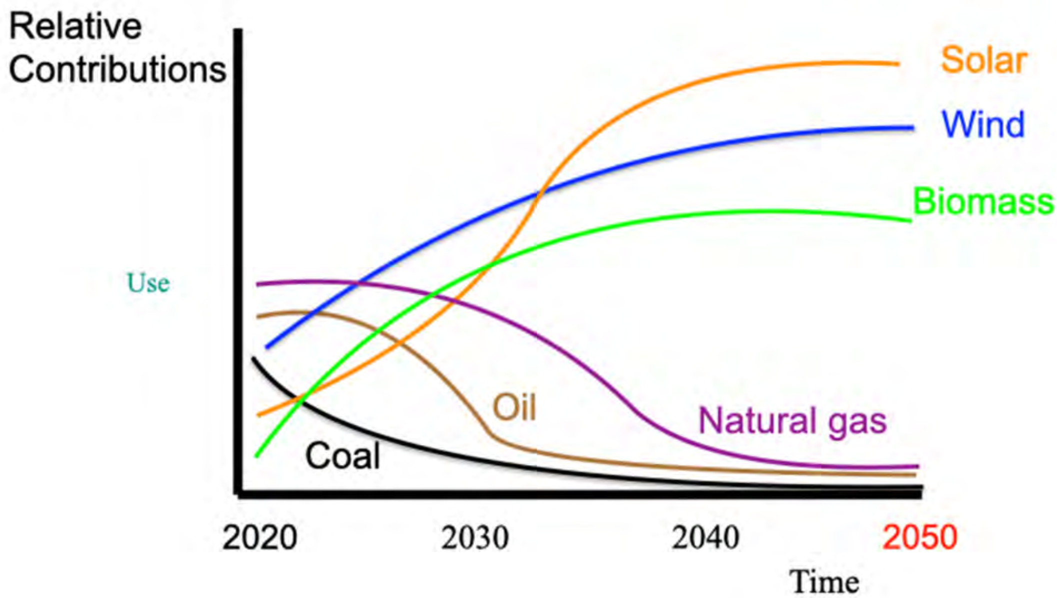
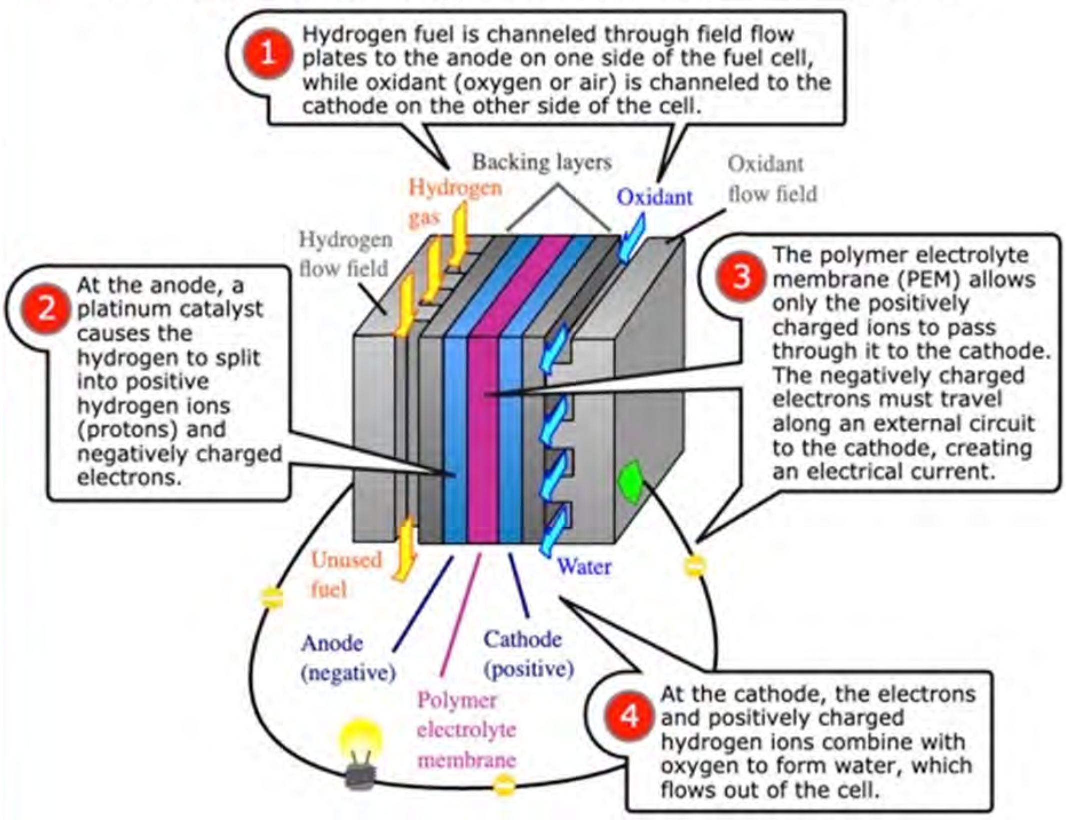
Chemistry In Action!

Issue No. 120
Autumn 2022

ISSN 0332-2637



Proton exchange membrane fuel cell



Sustainable energy - the challenge for the future

Contents

Contributions on any matter of interest to second-level chemistry teachers are welcome. Normally the results of research (chemical or educational) are **not** published, except in a general form or as a review. Articles should be submitted electronically (email or disc) to **peter.childs@ul.ie** together with a printed copy.

For general information, subscription details etc. see inside back cover.

Cover design: George Fitzgerald, Mobius Design, Limerick

Cover photo: **Two diagrams from the article by Professor Julian Ross on Sustainability (p. 28).**

Editor: Peter E. Childs peter.childs@ul.ie
Assistant editors: Marie Walsh, Maria Sheehan (web editor), Sarah Hayes, Anne O'Dwyer

Editorial #120

The challenge of climate change and sustainablity

The last 2 years have seen many changes which affect us all and affect science education: Brexit, the covid pandemic, the war in Ukraine, increasing energy costs and rising cost of living. We are all affected by these to one extent or another, but hanging over all of them, like a dark shadow, is the threat of climate change. Climate change due to our changing atmosphere is not new; scientists have been warning about it for decades, and I taught about it and its likely consequences in an Environmental Chemistry course I taught for many years until 2009. What has changed is that the scientific certainty has increased that it is happening and that it will have serious consequences. The growing evidence indicates that the world's climate is becoming more unstable than it has been. It is thus important that the science of climate change, and how we can ameliorate its effects and adapt to the changes coming down the road, should be part of the school and third level curriculum. Linked to climate change is the issue of sustainability: living in such a way that our future lifestyle is sustainable in terms of energy and raw materials. Professor Julian Ross has published an important book on sustainability and the role of chemistry and chemists in ensuring a sustainable future, and he has written a summary of the main themes for this issue (p. 28).

Dumbing down exams is not the answer

An issue I have covered more than once in *CinA!* is that of grade inflation, the lowering of standards, and the 'dumbing down' of education at school and at third level. The most obvious evidence of this is the increase in the number of high grades at LC and the percentage of 1 and 2.1 degrees from Irish universities. This is not just an Irish problem – the same issue has arisen in the UK both at school (A-level) and at third level (1 and 2.1 degrees), which has a similar educational system to Ireland in many ways. Norma Foley, Minister of education, made a political decision in the last school year to make the LC exams easier. This was a good political move to get students and parents on-side but it may turn out to have serious educational consequences. The number of topics to be examined was reduced, and the number of questions to be answered decreased, to allow for the disruption of the last 2 school years. However, despite pressure from students and parents it was decided that only formal examinations would be offered this year, a small step back to normality. In 2020 we had teacher-assessed grades; in 2021 a mixture of teacher-assessed and exam grades, where students got the benefit of the higher grade. This resulted, as might have been predicted, in massive grade inflation. This advantaged nobody: students applying for university from previous years were at a disadvantage as their grades were lower; current students had inflated grades so that too many were eligible for the high demand courses and well-qualified students faced a lottery to get in and many were disappointed, despite an increase in the number of places. Inflating the grades means that the discrimination usually offered by formal examinations was lost and the results made no distinction between excellent, very good and good students. Also it meant that average students would get into courses for which they were qualified on paper (from their higher points) but not by their intrinsic ability; one consequence of this is increased drop-out rates in first year. It should be obvious that this distortion of the examination system, a short-term response to the covid lockdowns, should be reduced or removed **as soon as possible** to restore the reliability and probity of the LC exams. What happened in 2022, as well as making the papers easier, is that the Minister promised that the 2022 LC results would remain the same as the 2021 results, in order not to disadvantage 2022 over 2021 students! In order to do this, the SEC actually had to increase the raw 2022 grades to bring them into line with 2021! **This is academic madness.** The same argument for keeping grades inflated and the problem compared to earlier years will arise in every subsequent year. The only solution is to gradually reduce grades back to their pre-pandemic levels over 2-3 years, as was it was decided to do with the 2022 A-level results. This adjustment had actually happened naturally this year, evidenced by the fact that the SEC had to increase results to bring them into line with 2021 results. But the Minister had made a commitment and so many more students continue to have maximum points, and many will lose out in the inevitable lottery. The relevant 2022 statistics are given in the next section (see p. 8). If we aim to have a world-class education system then grade inflation and dumbing down the curriculum and examinations is not the answer.

Peter E. Childs

Hon. Editor

In this issue: #120

As you will see from the cover art, a major article by Professor Julian Ross in this issue looks at the important topic of Sustainability and the role of chemistry, based on his new book. Chemistry already plays an important part and will play a crucial role in energy, materials and health in the future. (p. 28)

A short analysis of the 2022 LC results in science subjects is given on p. 8. There seem to be a lot of educational reports this year and we have included a synopsis of several. An interesting report on Gender Balance in STEM education appeared in March 2022 (p. 11). There is also a summary of a report on Girls in STEM (p. 22) and some resources on women in STEM (pp. 20-21.)

On p. 23 there is a summary of an interesting report on Immersive STEM Learning Experiences to Shape Shared Futures.

STEM has now been replaced by STEAM in many contexts, including the Arts along with Science, Maths, Engineering and Technology. On p. 25 we have a summary of a literature survey on STEAM in the curriculum by a team from MIC, Limerick. John O'Donoghue, RSC Education Officer, tells us about the launch of Current Chemistry Investigators, a joint venture between TCD and AT Sligo (p. 14). Geraldine Mooney Simmie gives us an update on the work of Epi*Stem at the University of Limerick (p. 16), where she is now Director, and the new project to provide CPD materials online should be of interest to teachers. The reform of the LC curriculum continues and the revision of the LC science subjects continues. The TUI made a submission on STEM Education in Jan. 2022 (p. 6).

Our historical figure in this issue from Adrian Ryder is someone I hadn't heard of before, Samuel Guthrie, an American chemist who discovered chloroform (p. 41).

Two new series start in this issue: one on Amazing Minerals focusing on iron Pyrite, notorious in Ireland from the cracking of blocks and foundations (p. 48). It's not called fool's gold for nothing. We have the first article on sulphur, looking at where we get this important element from (p. 45). A few years back we ran a series of articles on the chemistry and uses of phosphorus and its compounds, and this will be a similar series. Following the sulfur theme, Chemlingo looks at the naming of sulfur/sulphur (p. 60).

Peter Davern gives another two of his Quirky Elemental Facts in verse on p. 39-40.

Electrochemistry is known to be a difficult topic at all levels, where students and teachers have misconceptions about basic ideas. It is a very abstract subject in many ways and the latest Chemical Myths Exploded (#5) revises the basic ideas of electrochemistry, and identifies a number of common misconceptions (p. 52).

Education News and Views

The Editor welcomes contributions and news of interest to chemistry teachers in this section.

41st ChemEd-Ireland

TUS
Technological University of the Shannon: Midlands Midwest
Ollscoil Teicneolaíochta na Sionainne: Lár Tíre Iarthar Láir

The 41st ChemEd-Ireland was held on Saturday 15th October 2022 at the Moylish Campus of TU Shannon. The conference was organised superbly by Marie Walsh and her colleagues in TUS. The theme of the conference is **'Renewal and Reinvigoration in Chemistry Teaching and Learning'.** The event was supported by RSC, PDST, JCT and SSPC. Talks and workshops covered aspects of practical and classroom practice.

It is hoped to publish the Proceedings in the Spring 2023 issue of *Chemistry in Action!*

*****

ChemEd-Ireland conferences

This is an annual conference for chemistry teachers, which started in 1982. Future venues:

2023 42nd TCD

21st October at TCD

"Green chemistry in the classroom"

2024 43rd UCC

2025 44th TU Dublin

2026 45th UL

2027 46th DCU

*****

Senior Cycle Reform

In the last issue (*CinA!* #119, p.6) we published the recommendations for the revision of Senior Cycle (Leaving Certificate.)

gov.ie - Senior Cycle Redevelopment (www.gov.ie)

Comment

There are a number of important points in this document. The revised LC science subjects are due to be introduced in September 2024 but only in network (pilot) schools. This is progress as they will be tested out first before being rolled out to every school.

The new subject of **Climate Action and Sustainable Development** will be piloted from September 2024.

The Transition Year Option is to be made available to all students in all schools.

For LC Irish and English, paper 1 will be taken at the end of first year.

Breda O'Brien commented on this and the lack of consultation with teachers on such an important change, in the *Irish Times* (3/9/22). She made an important point, worth quoting.

"A botched reform is worse than no reform."

Breda O'Brien: Botched Leaving Cert reform is worse than no reform – The Irish Times

There is also a proposal to move to 40% continuous assessment in all LC subjects (not in the above document), which will have major implications for how subjects are taught and for student and teacher workload.

(See Irish Teacher: The move to 40% continuous assessment in the Leaving Cert is a good thing. But will it even happen? (irishexaminer.com) for a comment on this.)

See also the NCCA Senior Cycle Advisory Report 2021.

Senior Cycle Review Advisory Report | NCCA

This will presumably mean revisiting the proposal to have assessment of practical work in the LC science subjects

*****

A new LC science subject?

The Physics with Chemistry syllabus is the oldest STEM syllabus and has the lowest uptake (430 students in 2022). Its purpose is to allow small schools to offer the physical sciences, where they are not able to offer Physics and/or Chemistry separately. One wonders whether this course has had its day, despite the support of the TUI, given its low uptake and old-fashioned syllabus. A revised, updated and modernised syllabus would be more attractive and would probably attract a greater uptake. The NCCA did publish a draft syllabus several years ago but since then, nothing. Computer Science has since been added to the portfolio of STEM subjects. The 2022 LC statistics below continue to show the dominance and popularity of Biology as a LC subject. One wonders whether this would be so if students and schools had access to a modern LC Science course, following on from Junior Science, and with strands of Biology, Chemistry and Physics. This would be an alternative for some who now take LC Biology and don't do Physics or Chemistry. It would give them a broader foundation for tackling science-based courses at third level. Many universities now offer a general Science course, allowing for specialisation later, but many students find themselves taking courses in sciences they haven't met since Junior Science.

A general LC Science would be a good option for small schools with limited facilities, and would replace the Physics with Chemistry course. A new LC Science subject would enable new approaches to teaching science to be tried – context-based learning, interdisciplinary topics and projects.

There might even be a stronger case for a LC Environmental Science course, which would be a broadly-based science courses, including Biology, Chemistry and Physics, but within the context of the environment. Such a course would include coverage of Climate Science and Sustainability and could therefore replace the proposed new LC course, but with a strong science foundation. The topics of Climate Science and Sustainability cannot be understood properly without a good science base, but an Environmental Science course would allow for wider coverage and perspective on environmental issues. It would then be seen to complement the existing science courses. Such a course needs a good foundation in the basic sciences and should be evidence-based, providing a good foundation for understanding environmental issues. With a good science content, LC Environmental Science would provide a good subject for entry into third level science courses. It is to be hoped that the NCCA will consult widely on the proposed new course , especially with the ISTA, industry and third level scientists.

*****

Climate Change and Sustainability

A consultation document has been published on the proposed new LC subject on Climate Action and Sustainability (see link below.) The consultation closed on **October 28th** and I hope enough people were aware of this before the deadline. I only found out 3 days before!
[Background paper and brief for the development of Le... (ncca.ie)]

The development schedule is that the draft specification will be finalised by Autumn 2023, to be introduced in September 2024 in a number of network (pilot) schools. It will be available at Ordinary and Higher level and will be taught and assessed in 180 hours. This is a very tight schedule and from the background paper it seems that everything is almost signed and sealed. Even before the 'consultation'.
Peter Childs published a letter in the *Irish Times* (5/10/22) supporting an alternative broader, science-based LC in Environmental Science.
https://www.irishtimes.com/opinion/letters/2022/10/05/environmental-science-and-the-leaving/

*****

New STEM professor at DCU

Giving children a sense of the messiness of the world, and showing them how to solve problems with STEM-related reasoning is key to giving young students the best early start with STEM, according to Professor Hamsa Venkat, an expert in mathematics education, who this year has taken up the newly created Naughton Family Chair in STEM Education at Dublin City University and gave her inaugural lecturer in May at DCU.

Professor Venkat made the remarks at an inaugural lecture in the Seamus Heaney Theatre on DCU's St Patrick's Campus on 26th May 2022. Her role is the first in Ireland to focus on STEM (Science, Technology, Engineering, and Mathematics) education at primary level and in early childhood education, and she is based at DCU's Institute of Education.

As part of her new role, Professor Venkat will work with colleagues in the DCU Centre for the Advancement of STEM Teaching and Learning (CASTeL), DCU Institute of Education, DCU Faculty of Science & Health and DCU Faculty of Engineering & Computing to build up the competence and confidence of primary and early-years teachers and their students across STEM subjects.

"Better disciplinary and interdisciplinary learning may be achieved by more openness to 'non-disciplinary' approaches – where teachers offer problem situations with fewer expectations of students applying prior disciplinary learning," explains Prof Venkat. *"Instead, we place more emphasis on sense-making and creating problem-solving processes and solutions, through consultation and negotiation, while dealing with multiple variables and constraints"*

The Institute of Education at DCU is already home to the LEGO Innovation Studio, which leads pioneering work on robotics for girls and young women, and the world's only Minecraft Education Suite focused on the development of engineering mindsets.

Prof Venkat also spoke about the importance of group-based learning, drawing attention to evidence in early childhood literature that says communication in pairs and groups "produces richer images and language than working alone".

How messiness, imagination and group work can help young students have more positive experiences of STEM subjects | Dublin City University (dcu.ie)

*****

TUI submission on STEM education

January 2022

TUI submission to DE on STEM Education - Jan 2022.docx (live.com)

David Duffy (Education/Research Officer, TUI), dduffy@tui.ie, 01 4922588

Recommendations (p. 12)

The TUI would like to make the following recommendations to the DE and indeed also the DFHERIS:

- There needs to be more staff and smaller staff-student ratios in all sectors of the education system.
- Exchequer funding of the education system must be dramatically increased, starting with a gradual move, over three years, upward towards the international average for investment in education as a percentage of GDP.
- Greater recognition of, and visibility of, the FE sector is vital due to the essential role it plays in supporting under-represented groups to access levels 5 and 6 of the NFQ, and also frequently then accessing levels 7 and 8 of the NFQ.
- Additional staffing of guidance services in schools, FE colleges, HE institutions and in the Adult Guidance Service would be helpful.
- The combined Phys/Chem course in Leaving Certificate should continue to exist.
- The Points System needs to be reformed.
- More progression pathways should be recognised.
- The NCCA Senior Cycle review report should be published as soon as possible.
- More teacher CPD should be available within school time.
- Covid supports to schools should continue.
- There needs to be restoration of the quantum of middle management post which existed a decade ago, and also to be adjusted upward to account for the larger number of students in post-primary now.

*****

The process of creating new Leaving Cert subjects

'Parents shouldn't fear this course': Leaving Cert's newest subject could be a game-changer – The Irish Times

PE, computer science and Mandarin Chinese are just some of the newest subjects to join the Leaving Cert in recent years. But who decides on these new subjects? Who puts the curriculum together? And who decides how they will be assessed?

For starters the process of creating new curricula takes approximately 18 months. A background paper is written initially by the National Council for Curriculum and Assessment (NCCA). This paper sets the scene, considering where a subject might sit within the broader educational context. Primary school, junior cycle *and senior cycle provisions are taken into account, as well as international practice and relevant research. The background paper is then published for public consultation.*

Next a development group is assembled. The NCCA seeks nominations for this group from the Department of Education, the State Examinations Commission, teachers' unions, school management bodies, parent organisations and relevant subject associations. For the first time students are now formally represented on the NCCA and will play a greater role in future.

The NCCA also seeks other expertise via a co-option of two other members through a public call advertised on their website. The details of all members are shared with the public via the NCCA website.

Following months of deliberation, a draft specification is released for public consultation with a deadline for replies. The development group meets to discuss all feedback and the specification is reviewed and finalised and, when agreed by the NCCA council, is sent to the Minister for approval to be implemented in schools.

At least a year's notice is required for publishers before a new course is introduced, to give them time to produce new books. The Schools Examination Commission (SEC) is responsible for producing and marking the exams, based on instructions from the NCCA. CPD courses are the responsibility of the Department of Education and are organised and run through PDST.

In reality, no recent course has been designed and approved within 18 months. The process usually takes years and the revised LC science subjects, apart from Agricultural Science, have been under discussion since 2011, when the draft specifications were published. In April 2012 the report on the consultation was published.
senior_cycle_science_report_on_the_consultation_.pdf (ncca.ie)

The other main problem is that although the NCCA organises consultations, usually online but sometimes at a face-to-face meeting, they are not good at responding and listening to feedback. In any effective curriculum reform teachers' voices must be both heard and listened to. Failure to do this will inevitably lead to a botched reform and disaffection from the very people who are responsible for implementing new curricula. Lack of involvement of teachers and inadequate resources are major reasons for curriculum failure.

One good proposal in the Senior Cycle Reform report is the use of network schools to pilot new curricula, before they are launched fully.

*****

Senior Cycle Review, NCCA, 2022

This is a detailed look at the process of Senior Cycle Review which started in 2016.
scr-advisory-report_en.pdf (ncca.ie)

*****

Another Technological University

https://www.setu.ie
Waterford and Carlow ITs have merged to form the South East Technological University (SETU). It was officially launched on Oct. 24th 2022, with major campuses in Waterford, Carlow and Wexford. The new President is Prof Veronica Campbell.

There are currently five established Technological Universities:

- **Technological University Dublin**, established January 2019.
- **Munster Technological University (MTU)**, established January 2021.
- **Technological University of the Shannon: Midlands Midwest**, established October 2021.
- **Atlantic Technological University**, established April 2022.
- **South East Technological University**, established May 2022.

Technological Universities | Policy | Higher Education Authority (hea.ie)

*****

Women in university leadership

Two years ago, **no** Irish university had had a female President. Now the University of Limerick, Maynooth University, Trinity College Dublin, Munster TU, South East TU, and Atlantic TU all now have female presidents.
Women Leaders in Irish Higher Education (irelandseducationyearbook.ie)

*****

LC results 2022

Annual Exam Statistics - State Examination Commission (examinations.ie)

The Minister of Education, Norma Foley, said there would be no grade inflation in 2022. *Minister Foley in her announcement on 1 February noted "I am very conscious of student fears about competing with students from previous years, many of whose Leaving Certificate results have been higher than in an average year. To alleviate this concern, I have asked the SEC to put in place measures to ensure that the overall set of results in the aggregate for this year will be no lower than last year. This means that the class of 2022 will not be disadvantaged compared to the class of 2020 or 2021."*

This was correct as the 2022 were pegged to the inflated 2021 results, and so were not further inflated. However, to achieve this the SEC had to inflate the raw results by an average of 5.6% to maintain the inflated status quo. She has now said that a similar procedure will occur in 2023 – so the LC results will continue to be inflated compared to 2019, the last 'normal' year. This means that the results from 2020 onwards cannot be compared with results from 2029 and before. The 2022 exams were also made easier by giving students more choice, fewer questions to answer, a restricted syllabus and more time. So the exams were easier and the marking was also easier. Was this justified by the disruption of the last two years due to covid, lockdowns and school closures? Next year's LC cohort will have had 2 full years of schooling but will still be given he same accommodation. One wonders when and how the system will return to normal (pre 2020) as the longer the easier system persists, the harder it will be to change. In addition, major reforms of the LC are coming down the line (see below), with new science specifications and we haven't yet seen what effect the new junior cycle reforms will have on the LC.

More students get top grades

The maximum CAO points total is 625 – H1s in six subjects (6 x 100) plus a 25 points maths bonus. From the data below it can be seen that the share of top grades has declined slightly in 2022, but in 2019 only 207 students got maximum points, illustrating the size of the inflation.

	2022	**2021**
625 points	**1,122 (1.9%)**	**1,342 (2.3%)**
> 600 points	**3,205 (5.5%)**	**3,330 (5.7%)**

This inflation is also seen when we look at the % of H1s in selected HL subjects. (*Irish Times*, 2/9/22, p. 3)

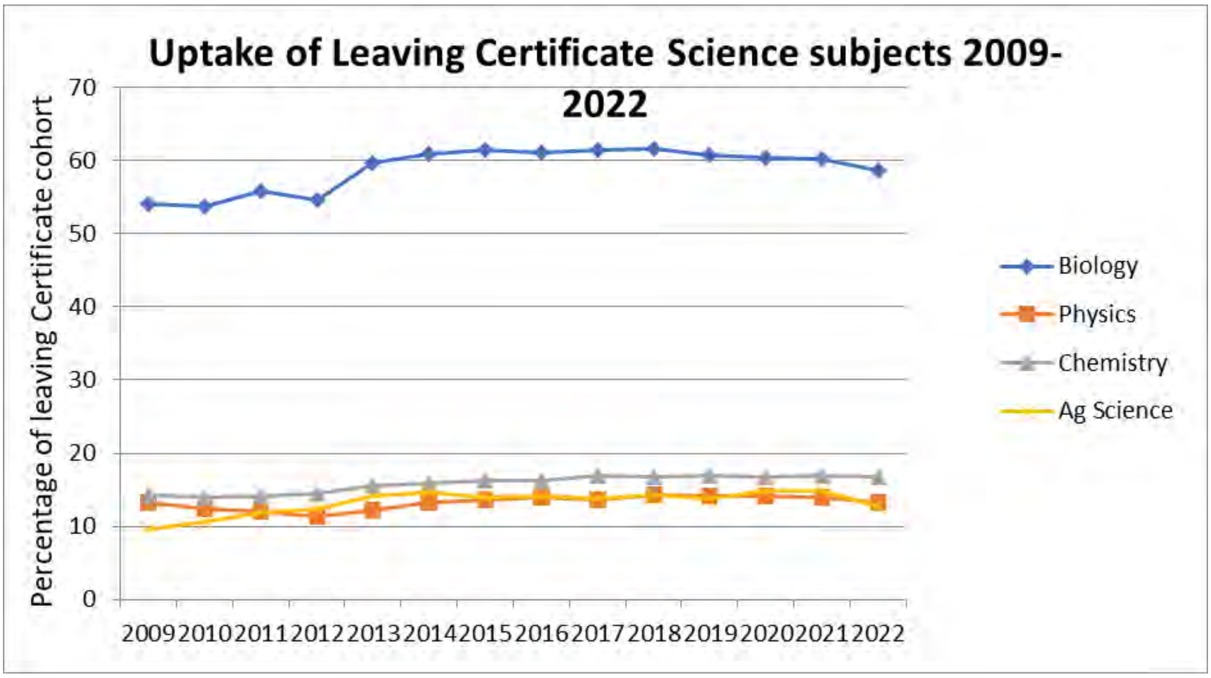
2019 was the last normal year – exam only. 2020 was teacher-based assessment only, 2021 a hybrid of teacher and exam-based assessment, and 2022 exam only but with revised papers.

Subject\Year	**2019**	**2020**	**2021**	**2022**
Maths	6.4	8.6	15.1	18.1
App. Maths	16.5	29.9	40.9	29.3
Physics	10.9	16.1	21.1	23.7
Chemistry	13.5	18.1	23.4	19.1
Ag. Science	5.0	9.5	11.3	5.8
Biology	8.2	11.6	17.4	17.6

The % of H1s has increased in all these STEM subjects from 2019, but there is clearly some reduction in 2022 for some subjects, especially Ag. Science. You were almost 3x more likely to get H1 in Maths (283%) in 2022 compared to 2019, more than 2x in Physics (217%) and Biology (210%) , and 41% more likely in Chemistry. Student ability does not change so dramatically from year to year so these changes are due to changes in the exams and marking.

Subject	Year	No.	Level	H1/O1	H2/O2	H3/O3	H4/O4	H5/O5	H6/O6	H7/O7	H8/O8
Maths	2022	21,265	HL	18.1	19.2	22.6	20.7	12.9	4.8	1.3	0.3
		32,792	OL	6.0	19.1	25.0	21.2	14.7	8.2	4.0	1.9
	2021	22,919	HL	15.1	17.5	20.6	20.2	15.8	8.4	1.6	1.0
		32,319	OL	7.2	15.1	21.9	21.7	18.2	11.4	2.9	1.7
Physics	2022	6,487	HL	23.7	16.6	14.6	13.4	11.5	9.4	6.1	4.7
		1,280	OL	9.1	14.9	20.6	17.3	14.9	10.9	6.9	5.4
	2021	7,210	HL	21.1	20.1	20.0	16.6	12.1	7.1	2.1	1.1
		778	OL	5.3	13.4	17.6	21.3	16.3	15.3	4.4	6.4
Chemistry	2022	8,481	HL	19.1	18.0	15.8	14.0	11.7	9.7	6.4	5.4
		1,198	OL	3.5	8.9	18.1	19.0	18.6	11.3	10.9	9.7
	2021	8,794	HL	23.4	21.6	19.4	15.2	10.4	6.1	2.5	1.4
		857	OL	5.0	10.9	17.3	20.9	15.8	17.3	5.4	7.6
Phys+Chem	2022	369	HL	15.4	14.6	12.2	17.6	16.0	10.0	7.3	6.8
		61	OL	8.2	3.3	9.8	21.3	23.0	13.1	4.9	16.4
	2021	382	HL	22.0	20.2	14.9	15.7	14.9	6.8	3.9	1.6
		57	OL	5.3	1.8	10.5	21.1	12.3	22.8	10.5	15.8
Ag. Science	2022	6,218	HL	5.8	18.3	24.8	23.4	16.6	7.8	2.4	0.9
		1,195	0.8	6.9	22.2	26.9	26.9	22.2	12.8	5.4	2.9
	2021	7,553	HL	11.3	16.6	22.6	21.5	15.7	8.8	2.3	1.2
			OL	0.8	5.7	14.2	20.8	23.5	21.0	6.6	7.5
Biology	2022	28,671	HL	17.6	17.4	16.2	16.4	14.8	10.8	5.3	1.5
			OL	2.2	11.1	22.8	25.0	19.8	11.1	5.2	2.8
	2021	30,677	HL	17.4	18.3	19.4	18.0	13.8	8.9	3.1	1.3
			OL	1.7	6.8	15.1	23.0	24.7	18.8	5.2	4.6

LC results in selected STEM subjects 2021-2022



Uptake of LC science subjects 2009-2022

The percentage uptake of the LC science subjects has been fairly consistent over the years as seen in the graph above. Biology retains the top spot by a large margin, just under 60% of the LC cohort.

Chemistry retains second place with just under 17%. Physics and Ag. Science compete for 3rd place and in 2022 Physics overtook Ag. Science slightly. This large disparity between Biology and the other sciences is unique to Ireland.

LC Science results 2022 (LC cohort 58,056) and 2021 (LC cohort 57,952)

Subject	Year	HL	OL	Total	% LC cohort
Maths	2022	21,265	32,792	54,057	93.1↓
	2021	22,919	32,319	55,238	95.3
Physics	2022	6,487	1,280	7,767	13.3↓
	2021	7,210	778	7,988	14.0
Phys+Chem	2022	369	61	430	0.74↓
	2021	382	57	439	0.77
Chemistry	2022	8,481	1,198	9,679	16.7↓
	2021	8,794	857	9,651	16.9
Ag Science	2022	6,218	1,195	7,413	12.8↓
	2021	7,553	915	8,468	14.8
Biology	2022	28,671	5,409	34,080	58.7↓
	2021	30,677	4,211	34,888	60.2

All the sciences show decreases in % uptake in 2022 but these are small. Ireland is also unusual in the large uptake of Maths until the end of schooling, so that virtually everyone does Maths. This is a good foundation for the science and technology subjects.

Gender balance in LC STEM subjects 2022

Gender balance in STEM subjects at HL and OL and % doing the subjects

Subject	Gender	HL	OL	Total	%
Maths	F	10740	16626	27366	51.6
	M	10525	16166	26691	49.4
Physics	F	1882	258	2140	27.6
	M	4605	1022	5627	72.4
Phys+Chem	F	149	21	170	39.5
	M	220	40	260	60.5
Chemistry	F	5174	619	5793	59.8
	M	3307	579	3886	40.2
Ag Science	F	2746	349	3095	41.8
	M	3472	846	4318	58.2
Biology	F	18451	2985	21436	62.9
	M	10220	2424	12644	37.1

Females are now a majority in Maths, Chemistry and Biology; males are a majority in Physics, Physics with Chemistry, and Ag. Science. It is interesting that the female share in Chemistry is increasing, and it is becoming less attractive to males. All the sciences have over 80% students taking the HL exam, whereas in Maths only 39.3% are doing the HL paper.

□

Gender balance at third level

A recent analysis looks at enrolments in STEM subjects in Irish third level institutions.

Microsoft Word - 2021_TR_03_Gender_Analysis_in_STEM.docx (lero.ie)

Female enrolment in 2018/19 in Natural Science, Maths and Statistics courses ranges from 45-57%; in Engineering, Manufacturing and Construction 17-38%; in ICT 10-24%. There is better gender balance in the sciences and worst in ICT.

□

Recommendations on Gender Balance in STEM Education

8th March 2022

218113_f39170d2-72c7-42c5-931c-68a7067c0fa1.pdf

This important report was a follow-up to the Government's STEM Education Policy Statement 2017-2026.

The Department of Education published the national STEM Education Policy Statement 2017-2026 (Policy Statement) and STEM Education Implementation Plan 2017-20191 in November 2017. This comprehensive policy statement was informed by extensive research and consultation. At its heart is the vision: In line with our ambition to have the best education and training service in Europe by 2026, Ireland will be internationally recognised as providing the highest quality STEM education experience for learners that nurtures curiosity, inquiry, problem-solving, creativity, ethical behaviour, confidence and persistence, along with the excitement of collaborative innovation.

The Policy Statement acknowledges that there is a need to increase broader participation in STEM Education and to enhance STEM learning for learners of all backgrounds, abilities and gender, with a particular focus on increasing participation in STEM by females. It identifies the importance of addressing any risks of disadvantage and underrepresentation in the implementation of the policy.

Phase 1 Recommendations

These recommendations are made to address equity of access and inclusion, rather than just gender balance. By addressing the wider diversity issue in STEM, gender balance in STEM will benefit.

It is acknowledged that there is a need to build knowledge, attitudes and skills in the STEM disciplines across early years and school communities to include leaders, early years educators, teachers, parents/guardians and learners. We must build on this through conducting research, ensuring the preparation of teachers who are STEM literate, the provision of experiential and inquiry-based teaching and learning and the use of innovative teaching and learning modalities to include technology-enhanced learning.
It is noted that specifics of all of these recommendations will be considered for inclusion in phase two STEM Education Implementation Plan 2022-2026. Their inclusion will also be assessed against available resources within the Department of Education. Allocation of responsibility and timelines for implementation will be detailed in the implementation plan.

Key areas for action

The four key areas for action, as set out by the Gender Balance in STEM Advisory Group, build on, and are additional to, the extensive actions identified in the STEM Education Implementation Plan 2017-2019 are:

1. Improve equity of participation across all STEM curriculum areas/subject choices by instilling whole school culture change, to include early years leaders and educators, school leaders, teachers learners and parents/guardians
2. Provide effective support in relation to practice in STEM for early years educators and teachers
3. Support equitable learner access to, and experiences of, STEM to inspire learning, foster creativity and prepare for later engagement and success
4. Support a societal and cultural shift to address current barriers to gender balance in STEM. These areas will be actioned by implementation of the recommendations set out below.

Recommendations:

Improve equity of participation across all STEM curriculum areas/subject choices by instilling whole school culture change to include early years/school leaders, educators/teachers and parents/guardians.

How STEM is taught in our early years settings and schools has an impact on the participation of young females in STEM. Factors such as the use of gender-inclusive language, visual prompts and examples in curricula and lesson planning can influence how our female learners perceive and relate to STEM. There is a need to build confidence at a whole school level so as to maximise engagement and exploration in STEM, both through formal and informal learning.

Specific actions to deliver:

1. Continued consideration of gender balance, equity and inclusion in the development and/or review of national curriculum specifications. This will include all Department of Education policies, strategies and resources.
2. Assessment practices that are aligned broader STEM goals (as outlined in the Policy Statement) and support for student-centred inquiry-based learning should be integral to the development of STEM education.
3. Explore the development, setup in schools and ongoing monitoring of a national accreditation framework for whole school culture change at primary and post-primary levels, to address gender balance, equity and inclusion actions.
4. Development of the SFI Discover Primary Science and Maths programme, to include consideration of gender equality and inclusion in the language, visuals and examples used throughout the programme and in professional development offered to teachers.
5. A study in relation to timetabling and availability of subjects at post-primary level should be undertaken to understand where, how and why barriers are present that prevent access to students to specific subjects. This study will inform the development of guidelines for schools in relation to successful strategies for schools to adopt to improve uptake and the provision of a wider range of STEM subjects.

Provide effective support in relation to practice in STEM for early years educators and teachers

Early years educators and teachers use their expertise and experience, as well as evidence, to make informed decisions about their practice so as to help learners achieve particular goals. It is vital that educators and teachers are supported in the development of these teaching practices.

It is important to highlight in the early stages of teacher education and with in-service teachers the influential role educators/teachers hold and to raise awareness of the many actions they can lead on, or contribute to, to drive change in their settings.

It is also important to provide the necessary supports to ensure increased numbers of qualified STEM teachers whilst also seeking to increase the diversity of STEM teachers in our schools.

Specific actions to deliver:

6. The Teaching Council should be invited to be a member of the STEM Education Implementation Advisory Group to ensure alignment of goals, realistic outcome setting and implementation of policy.

7. All programmes of teacher education and post graduate guidance counselling programmes across the continuum should include awareness raising training on the barriers to participation of underrepresented groups in STEM and the role of teachers in helping remove these barriers.

8. Develop a continuing professional development (CPD) programme in STEM for early years educators, by the National Síolta/ Aistear Initiative (NSAI) Resource Development Group, to include an introduction to the issues regarding gender balance, equity and inclusion, in STEM. The inclusion of Arts in STEM will be considered as part of this development.

9. Pre-service and in-service teacher internships currently in place in Ireland should be further supported, promoted and scaled up as a facility for student teachers/teachers to experience STEM as it is applied in the workplace.

10. Research to be conducted into developing a model to incentivise broader participation and diversity in teaching through a range of criteria, including an investigation into STEM scholarships and options for STEM specialism at primary level.

Support equitable learner access to, and experiences of, STEM to inspire learning, foster creativity and prepare for later engagement and success

It is important that all learners have equitable access to STEM experiences in order to inspire learning, to foster creativity from an early age and to set the stage for their later engagement and success in these fields. It is especially important that young females can see people like themselves in STEM roles. The many programmes already underway can support greater confidence, a sense of belonging and self-awareness for young learners and the part they can play in STEM. However, increased access nationwide to meaningful STEM role models and/or career awareness activity that challenge stereotypes is required. Awareness programmes that address gender balance in STEM careers targeting young people, parents/guardians and/or career guidance counsellors should be supported in addition to the building of knowledge-sharing networks.

Specific actions to deliver:

11. Increase equitable access nationwide to meaningful STEM role models and/or career awareness activity that challenge stereotypes. An evaluation of the provision already in place should be undertaken in order to make informed decisions on how to progress in this area. It is further recommended that the Department of Education should work with Science Foundation Ireland, under the SFI Discover Programme Call to progress in this area.

12. A pilot programme, STEM Passport for Inclusion, led by National University of Ireland, Maynooth, will recognise the experiences of girls from DEIS schools as they achieve micro-credentials in STEM, through mentoring and engagement with STEM content knowledge. The Advisory Group recommend engaging with this programme to assess its impact, with the potential to recommend further scaling of the programme if it is successful in its mission to break down barriers to girls in STEM.

Support societal and cultural shift to address current barriers to gender balance in STEM

Females in Ireland have access to the same educational and career opportunities as their male counterpArts and are well-represented in many fields. However, although there has been some improvement in female representation in STEM areas over the years, they still remain significantly underrepresented. Negative stereotypes and beliefs remain, reducing the confidence of females in STEM early in their education. We must support a societal and cultural shift in removing these barriers.

Information must be readily available to our learners to include guidance on STEM subject choices for primary school children and their parents/guardians, in advance of the critical transition to post-primary school. Awareness of the diversity of STEM professionals, pathways and careers for learners must be made available to parents/guardians, teachers, guidance counsellors and school leaders.

Specific actions to deliver:

13. Develop guidance, starting with STEM subject choices, for primary school children and their parents/guardians that can be provided in advance of the critical transition to post-primary school.

14. Deliver, in partnership with SFI, stakeholders and industry, a large-scale engagement campaign for learners, parents/guardians, teachers, guidance counsellors and school leaders, to raise awareness of the diversity of STEM professionals, pathways and careers. This campaign will aim to challenge stereotypes in STEM.

15. The SFI Discover Programme Call should target activity that supports engagement with parents/guardians and require funded projects targeting parents/guardians to specify the form of engagement, the objectives of the engagement and to evaluate the outcome of the engagement. Furthermore, these projects will be required to share the outcomes achieved to grow awareness amongst the STEM engagement community of best practices and lessons learnt.

16. A study should be undertaken to identify programmes, both formal and informal, that are engaging with young people and their families to build STEM capital and to encourage consideration of further and higher education opportunities. The outputs should be used to identify how to establish broader access to such programmes, that are fit for purpose for the young people and families they serve.

Monitoring:
It has been noted by the Advisory Group that it is of utmost importance from the outset that implementation of the recommendations must be closely monitored and an evaluation process put in place. This will allow for the assessment of the appropriateness, efficiency and effectiveness of each of these, as well as providing the information to inform the future direction of the recommendations.

It is also noted that implementation of the recommendations will take time to effect change and it is suggested that there should be an annual review of the data on female participation in STEM, held by the Department, followed by a three-year and five-year marker, in order to ascertain if the recommendations are having an impact on STEM from early years to post primary.

While not the only mark of success, an uptake in the number of young learners participating across the STEM subjects, and taking these subjects at the Junior and Senior Cycle stage, should be one indicator.

□

Current Chemistry Investigators (CCI) off to a flying start

John O'Donoghue
John.ODonohue@tcd.ie

Current Chemistry Investigators (CCI) is an informal Science Foundation Ireland (SFI) supported education project lead by Dr John O'Donoghue through a new partnership between the School of Chemistry at Trinity College Dublin (TCD) and the Faculty of Science at the Atlantic Technological University (ATU) in Sligo. Its primary aim is to spark conversations about the science of energy storage and increase the accessibility of electrochemistry education with schools and community groups.

The project has got off to a flying start, officially launching in June through a photoshoot with Ministers Norma Foley TD and Simon Harris TD at Dublin Castle. Almost immediately, our researchers dove straight into a busy summer campaign of public engagement, starting with the Cork Carnival of Science. This unique two-day outdoor event was attended by about 25,000 people and the CCI team engaged with about 3,000 people of all ages at our battery making tent. We had queues of people lining up to make coin-cell batteries to light up an LED. All participants received a take-home pack with everything they needed to make their own LED torch from coins, cloth, saltwater electrolyte and aluminium.

Hot on the heels of the Cork Carnival of Science we are out and about again for the Dublin Maker festival in Merrion Square. This time we had a great collaboration of researchers from both partner institutions. Our TCD researcher's setup the stand and sparked conversations for the morning part of the festival, while our ATU Sligo researchers took the train from Sligo to run the stand for the middle part of the day. This allowed the TCD group to take a break and catch their breath, after which the ATU Sligo group got a train back to Sligo again on the same day. It was a gruelling 7 hour round trip for a total of about 4-5 hours in Dublin. The TCD researchers finished off the day and packed everything up again. It was a fantastic demonstration of the unique partnership that this project facilitates between these two great institutions.

Our very busy summer of public engagement was capped off with the largest outdoor event in Europe. With nearly 300,000 people in attendance, the National and World Ploughing Championships in Laois did not disappoint! Returning after a 2-year absence, it was an absolute pleasure to join Science Foundation Ireland (SFI) at their stand in the Government Village to run short, snappy workshops about hydrogen fuel cells and batteries. The demographic of attendees was very wide with children, parents, teachers, retirees and more all sitting down with us to spark conversations with our PhD Researchers. We also had the pleasure of some high-profile guests which include the Provost of Trinity College Dublin, Prof. Linda Doyle, the Minister for State for Further, Higher Education, Research, Innovation and Science Niall Collins TD and the Minister for Further, Higher Education Research, Innovation and Science Simon Harris TD.

Well done to all of our PhD researchers from both TCD and ATU Sligo for such a hugely successful summer, but especially to our Schools Coordinator Natalia Garcia Domenech and to Áine Coogan who led the team at the Ploughing Championships. Our researchers engaged with over 5,000 people this summer and will now start into school workshops for the academic year. One of the key benefits of this project for PhD researchers is to provide an opportunity to come together from different institutions in an informal setting to share ideas and stories about their own research journey to date.

Both teams have already visited 10 schools in Leinster and Connacht, with another 10 planned before Christmas which include a trip to some Cork schools as well. There are also plans for more public engagement during Science Week so keep an eye out for our teams at the Sligo Science Festival and Cork Science Festival. Onward and upwards for the CCI teams.

Dublin Maker Photos by Conor Harford

□

Inspiring Chemistry Teachers in Ireland and the next generation of STEM Education Researchers at EPI·STEM

Geraldine Mooney Simmie
Director, EPI·STEM and Senior Lecturer in the School of Education, University of Limerick
Geraldine.Mooney.Simmie@ul.ie

In this article, I want to share my aspiration for my new role as Director of EPI·STEM, the National Centre for STEM Education at the School of Education in the University of Limerick. I will also share some of the research-led activities we are involved with at the Centre that aim to inspire Chemistry Teachers in Ireland and show how we are working to build the next generation of Science Education and STEM Researchers at EPI·STEM. Our activities align with STEM policies in Ireland and with many of my former and current roles as a science teacher, (science) teacher educator and researcher (see biography).

My Evolving Philosophical Positioning

I want to share my philosophical positioning in relation to science education in order to show how my constantly evolving reflexive story underpins my work as a science teacher educator and researcher. I understand the power of education comes from that special place where education can act as a carrier of hope and possibility for the next generation, within notions of a good life and a decent and just global world. The teacher, and the teacher educator therefore work in a pedagogical space, for a practice-in-motion that needs to recognise the task of passing on culture, heritage and the (ever-changing) canon of knowledge while, at the same time, making space for something new to emerge, new thinking and new ways of knowing (Mooney Simmie & Moles, 2020). This openness to what Biesta (2013) calls the 'beautiful risk' of education is what underpins my work in teacher education (Mooney Simmie, 2022).

My research studies show how teachers' practices, whether in teaching or in teacher professional development, are 'outrageously complex' (Shulman, 1989). In order to support science teachers, we need to pay attention to Shulman's (1989) argument that we need to raise standards in the teaching profession but make sure we don't fall into prescription and mandate and a narrow scientific approach that leads to a 'loss of soul' (p.10). Science education is about learning science today for a lifelong journey of human development and change. Pedagogy is as much about identity formation as it is about knowledge generation (Lingard, 2007). The science teacher is inviting the student to turn their gaze in supportive and challenging ways, to get to know themselves at a deep level and to learn to see the world differently, to open new possibilities and to have the wherewithal to live a good life and to contribute to making the world a better place. For that journey, we clearly need access to the philosophical ('why'?) and the critical ('who benefits'?) as well as the empirical ('what works best'?). The challenging question of the moment is how to teach chemistry and science in a highly scientific and technological world for science literacy for all and not just for a traditional privileged few.

The Gifts from Science

The notion that our work as science educators and as chemistry teachers is not about filling a bucket but rather in the words of WB Yeats about lighting a fire is an acceptable notion for most science teachers (imagination, curiosity, healthy scepticism, intuitive and counter-intuitive thinking, possibility). Of all teachers across the curriculum, the science teacher has traditionally relied on rich variety of pedagogical approaches to teach the big ideas and concepts in the science curriculum, such as, demonstrations, practical, interactive and experimental work, group work, inquiry based projects, ICT-inspired learning.

Science as a discipline has its own syntax and grammar and offers real rewards for science teachers and science educators. It brings the gift of scepticism to work practices, the capacity to nurture a curious and questioning mind and has a long-distinguished history of reliance on thought experiments as well practical experiments. This combination is in evidence in the history of the structure of the atom, the building blocks of chemistry – a 2,400 years-old story!

Keeping the 'door' open for new thinking to emerge rather than bringing closure to the field of science education where everything can be known and prescribed in advance, a consensus view where there are no affordances for the particular, for contrarian views, for new ways of knowing or even for surprises! Besides, the history of science, and many great scientific discoveries often reveal an all too human face and the struggle between the intuitive and the counter-intuitive (the artist and the academic). A history that defies the mainstream linear rational portrayal that is more often the accepted storyline.

Getting this storyline right, is more pressing today for science education than at any other time in the history of humanity, our collective dwelling home, planet Earth is on-fire (climate change) and we are beset with numerous and often insurmountable problems of vaccine justice etc. in a highly scientific and technological world where inequality is increasing at an alarming rate

EPI·STEM - a UL-hosted Research Centre at UL

EPI·STEM is a research centre in the University of Limerick since its foundation in the early 2000s. It has brought more than Euro 13 million in research funding to UL and houses the Professional Diploma in Mathematics for Teaching (PDMT) programme for upskilling out-of-field mathematics teachers as well as a number of science education, and engineering and technology education research-led projects and outreach activities to secondary schools. We continue to be supported by our former Directors and Chairs of STEM Education, who act as Adjunct Professor to the Centre, Professor Sibel Erduran from the University of Oxford, and Professor Merrilyn Goos from the University of the Sunshine Coast in Australia.

My aspiration as Director is to work with the team to support all aspects of STEM education and all fields of educational research, to inspire the next generation of STEM educators, teachers and researchers to make a difference to science education in Ireland and to keep offering better supports to science teachers to make a real difference in classrooms. This is a time when we urgently to shake up stereotypes about science education and to develop science literacy for all and not just for a privileged few. We need to find new approaches to reach those students who have traditionally been underrepresented minorities in science education (within questions of social class, gender and race). Respect for difference and the framing of problems is a vital question of concern in relation to the educative needs of our newcomer students in a pluralist and democratic Ireland. We need science teachers who are willing to interrogate themselves and their practices and to draw from the touchstone of research and theory. But we also need science teachers who can think for themselves and who can justify their autonomous judgements if we are to have any hope that they can educate a future generation of young people to think for themselves and to make a real and lasting difference to the world they live in! We need science teachers who have access to accurate scientific knowledge and who can access content knowledge throughout their lifetime. It is an exciting prospect to work with science teacher educators who are willing to open themselves and their practices to critical scrutiny.

We have a long history of supporting science education at UL and one with an open-minded approach and an open heart to the complexity of the problem. In the last year, we started a number of initiatives to begin a new dialogue with science educators and science teachers in Ireland. For example, we are running a series of Science Education Research Seminars Along the West Coast, where we showcase the

research work of Science Educators in the School of Education, the wider UL community and in neighbouring higher education institutes, such as Mary Immaculate College and the University of Galway. We have joined a national pilot project, led by DCU called the STiNT project, for science teachers in Initial Teacher Education to experience three months of paid internships in STEM related industry. Last semester, we were involved in the successful placing of five UL students in STEM internships with local industries. More recently, we are seeking new ways to collaborate within UL on many of the new science education projects supported by Science Foundation Ireland. For example, in recent days, EPI•STEM in partnership with science colleagues in the Bernal Institute (Dr. Sarah Hayes) in co-hosting an international science teacher educator conference concerned with inclusive education.

On-Line CPD Project

We are currently engaged in an EPI•STEM-HEA Initiative, funded by the HEA Performance Fund, to support science and mathematics teachers' CPD through the design and presentation of high-quality research-led on-line CPD resources. We have a team of science educators, researchers and research and development officers working with the Director of EPI•STEM to source and produce cutting-edge resources that can help teachers to teach science to young people using active pedagogies for co-inquiry and meaning making. Each resource package takes into account the learning outcomes indicated in the science curriculum of Junior Cycle and Senior Cycle and includes new innovative possibilities for co-inquiry in Transition Year and/or entry to the Young Scientist Competition. We have more than 1,000 teachers registered for access to our CPD science resources on our EPI•STEM website (www.epistem.ie).

We will be holding two Science Teachers' Conferences for registered science teachers to learn more about the on-line CPD resources. The Conferences will take place here at the Centre in UL on Saturday, 19th November 2022 and on Saturday, 10th December 2022. The science topics are based on findings from an earlier national survey of science teachers and include the following: ecology, electricity, earth and space, laboratory management, mechanics, light, waves, photosynthesis, chemistry of the atom, and electronegativity. If you haven't done so already you can join the project by registering on our website (www.epistem.ie) or by emailing Helen Fitzgerald, our senior executive administrator at EPI•STEM Helen.Fitzgerald@ul.ie. We look forward to hearing from you.

Biography

Geraldine Mooney Simmie PhD MSc HDE is a senior lecturer in education and Director of EPI•STEM National Centre for STEM Education at the School of Education, University of Limerick. Geraldine is a teacher educator and education researcher examining the topic of the changing nature of teachers' work practices and policies. Following completion of her Master's by research in Chemistry in the University of Galway, Geraldine worked as a science and mathematics teacher in secondary schools in Galway, Dominican College and Coláiste Iognáid S.J. She was an active member of the ISTA, worked on the BASF minilab project, and wrote textbooks ('Integrated Chemistry' by Folens and the 'Science Workbook' by School & College Publishing) and presented Chemistry videos and a Water video for science teachers, produced by Dr. Oliver Ryan at the Science Education Centre, University of Galway.

Working at UL, she has led or participated in teams that were awarded research funding from the European Commission Comenius 2.1 projects (Crossnet, Eudist and GIMMS), Erasmus+, Science Foundation Ireland, the

Department of Education and Skills and the Higher Education Authority.

References

Mooney Simmie, G. (2022) How can the philosophy of education inform STEM Education Policy in schooling and higher education in a post-Covid pluralist and democratic Ireland: Growing back better. In E. Costello, P. Girme, D. Hyland, T. Kaur, O. Kelly, T. McLoughlin, & P. Van Kampen (Eds) Proceedings of the CASTeL 9th STEM Science and Mathematics Education Research Conference 2022 Proceedings (pp. 66-78), Dublin City University. https://doi.org/10.5281/zenodo.6953886

Mooney Simmie, G. (2021). Teacher Professional Learning: a holistic and cultural endeavour imbued with transformative possibility. Educational Review. DOI 10.1080/00131911.2021.1978398 https://doi.org/10.1080/00131911.2021.1978398.

Mooney Simmie, G. (2009) The policy implementation process in the upper secondary education system (senior cycle) and videregående skolen in science and mathematics in the Republic of Ireland and the Kingdom of Norway from 1960-2005. PhD thesis. Dublin: Trinity College Dublin. http://www.tara.tcd.ie/handle/2262/90412

Mooney Simmie, G., & Edling, S. (2022) short videos for Democracy and Teacher Education: https://www.routledge.com/go/exchanges-with-authors-silvia-edling-and-geraldine-mooney-simmie-democracy-and-teacher-education

Edling, S. & Mooney Simmie, G. (2020). Democracy and Teacher Education: Dilemmas, Challenges and Possibilities. London: Routledge. https://www.routledge.com/Democracy-and-Teacher-Education-Dilemmas-Challenges-and-Possibilities/Edling-Mooney-Simmie/p/book/9781138593251

Mooney Simmie, G., & Moles, J. (2020). Teachers' Changing Subjectivities: Putting the Soul to Work for the Principle of the Market or for Facilitating Risk? Studies in Philosophy and Education, 39(4), 383-398. DOI: https://link.springer.com/content/pdf/10.1007%2Fs11217-019-09686-9.pdf

Shulman, L.S. (1989). Knowledge and Teaching: Foundation of the New Reform. Harvard Educational Review, 57(1), 1-21.

□

For more information on Epi*Stem contact:

https://epistem.ie/

SMEC 2022
24-25 June

DCU's Saint Patrick's campus

"Regenerating STEM Education – Growing back better"

The conference was opened by CASTeL director Assoc. Professor Cliona Murphy, who pointed to the legacy of CASTeL and the conference, as forces for STEM education research, highlighting its 21-year history. Professor Mieke de Cock of KU Leuven then gave her fascinating keynote address on the topic of representations in STEM education. Drawing on contemporary studies she showed how there are no purely abstract understandings of concepts – but always representations. She highlighted their critical role in STEM teaching and learning: and how being able to interpret and use different representations, and coordinate between them, can deepen student learning. After a full day of parallel paper sessions, day one closed with a keynote address by Assoc. Professor Maria Evagorou of the University of Nicosia, on scientific practices and socio-scientific issues as vehicles for responsible citizenship, that highlighted rich student situated practices of scientific inquiry.

Day two of the conference started with an address by Assoc. Professor Mica Estrada of the University of California at San Francisco. In an engaging presentation she talked about her work in which she longitudinally tracks and examines what types of mentorship, experiences and supports are more likely to result in students integrating into their professional fields and persisting in STEM career pathways. She touched on many aspects of how we can improve and enrich academic environments for underrepresented groups in STEM including a focus on affirming the dignity of others through kindness. A panel debate followed on the themes of diversity and inclusion in STEM, the tensions and complexity involved and the work we need to do in this area. Over the two days of the conference there were 45 presentations.

*****

Women in STEM: some quotes

"Life is not easy for any of us. But what of that? We must have perseverance and above all confidence in ourselves. We must believe that we are gifted for something and that this thing must be attained."

Marie Curie 1867-1934

[Marie Curie - Wikipedia]

Polish physicist and chemist who conducted pioneering research on radioactivity, and became the first scientist to be awarded a Nobel Prize in two different subjects, physics and chemistry.

"Science makes people reach selflessly for truth and objectivity; it teaches people to accept reality, with wonder and admiration, not to mention the deep awe and joy that the natural order of things brings to the true scientist."

Lise Meitner 1878-1968

[Lise Meitner - Wikipedia]

Austrian-Swedish physicist who discovered nuclear fission of uranium and many thought she should have shared the Nobel prize for this discovery with Otto Hahn.

"Don't be afraid of hard work. Nothing worthwhile comes easily. Don't let others discourage you or tell you that you can't do it. In my day I was told women didn't go into chemistry. I saw no reason why we couldn't."

Gertrude B. Elion 1918-1999

[Gertrude B. Elion - Wikipedia]

American Nobel Prize-winning biochemist and pharmacologist who developed medications to treat leukaemia, malaria, meningitis, herpes, and more.

"You look at science (or at least talk of it) as some sort of demoralising invention of man, something apart from real life, and which must be cautiously guarded and kept separate from everyday existence. But science and everyday life cannot and should not be separated."

Rosalind Franklin 1920-1958

[Rosalind Franklin - Wikipedia]

English chemist and X-ray crystallographer whose work contributed to the discovery of the structure of DNA.

"For a research worker, the unforgotten moments of his life are those rare ones which come after years of plodding work, when the veil over natures secret seems suddenly to lift & when what was dark & chaotic appears in a clear & beautiful light & pattern."

Gerty Cori 1896-1957

[Gerty Cori - Wikipedia]

Austro-Hungarian Nobel Prize winner in Physiology or Medicine for her work in metabolizing carbohydrates.

"I tell young people: Do not think of yourself, think of others. Think of the future that awaits you, think about what you can do and do not fear anything."

Rita Levi – Montalcini 1909-2012

[Rita Levi-Montalcini - Wikipedia]

Italian neurologist and Nobel Prize winner in Physiology.

"If you look at other countries, you'll find lots of girls doing physics, engineering, and science. It's something to do with the kind of culture we have in the English-speaking world about what's appropriate for each of the two sexes."

Jocelyn Bell Burnell 1943-

[Jocelyn Bell Burnell - Wikipedia]

Irish physicist who discovered pulsars while a graduate student but didn't share in the Nobel prize for the work.

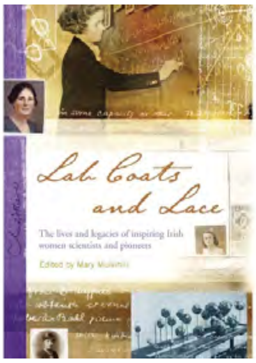
Teaching idea: Why not use these women scientists as the basis for a class project, perhaps in Transition Year. Ask your students to research their life and work and prepare a poster and a talk on it?

STEM Initiatives in Ireland

Since 1990 several important initiatives have been started in Ireland to improve the gender balance in STEM. Some of these are mentioned below, see also the IDA report for more.

WITS 1990-

Women in Technology and Science
www.witsireland.com
This is the longest established group in Ireland. It has published two books including *Labcoats and Lace*, available as an e-book for €4.50.



*****

WISTEM^{2}D

Women in Science, Technology, Engineering,Mathematics, Manufacturing and Design
This is a program initiated by the multinational Johnson & Johnson in 2015 and is active in Ireland. Through the initiative Johnson & Johnson support and inspire girls and women in their pursuit of STEM^{2}D studies and careers globally.

The 2021-2022 programme is open to women STEM students entering their second, third or fourth year of studies at NUI Galway. The programme was first introduced at University of Limerick in 2016 and at University College Cork in 2018.

WiSTEM2D | Johnson & Johnson (jnj.com)

Johnson and Johnson WiSTEM2D Programme | University of Limerick (ul.ie)

Johnson & Johnson WiSTEM2D Programme | University College Cork (ucc.ie)

September - University of Galway

*****

Women in STEM

www.womeninstem.ie
Inaugural conference held in 2022.
In the UK:
www.stemwomen.com

*****

WomenatSTEM W@STEM

Women in STEM (W@STEM) - Women at Stem (W@Stem) (ucd.ie)
UCD Women at STEM is a network supporting UCD women in science, technology, engineering and mathematics.

*****

Women in STEM 4/21

An overview by the IDA of 35 programmes and initiatives which attract, retain and promote gender diversity in science, technology, engineering and mathematics
IDA_STEM_V3 (idaireland.com)

*****

www.iwish.ie
I WISH is a community committed to showcasing the power of Science, Technology, Engineering, and Maths to teenage girls. We run outreach activities, mentorship programmes, TechForGood laptop donations, twinning programmes, further education programmes and showcase events reaching a global audience.
iWISH has conducted surveys of 2,449 girls' opinions in 2021. You can read the findings at:
I Wish 2021 Booklet RGB

*****

Girls in STEM: changing attitudes and increasing diversity

1/3/22
Girls in STEM: changing attitudes and increasing diversity | UCD Research

Summary

Researchers at UCD have developed and evaluated a new, creative approach to teaching STEM-related subjects (science, technology, engineering and mathematics) to young girls. This initiative contributed to the lives of 1,000 pupils in participating disadvantaged schools in Leinster. It has made STEM-related subjects more meaningful and accessible to this underrepresented group, and it has made them more confident about pursuing the study of such subjects in post-primary education and beyond.

Increasing gender diversity in STEM is now a Department of Education policy priority. In partnership with the Department, the planned expansion of the project will guarantee further impact on a national scale, through resources generated from the project that are freely available to all schools via the Girls in STEM website.

Research description

This project was motived by the systematic absence of women in narratives around STEM. There is some consensus among social scientists that negative stereotyping has deterred women from choosing science as a career. Furthermore, research suggests that for young women to pursue a career in this area, they must believe in the importance of STEM and believe in their ability to succeed in these subjects.

Storytelling plays a central role in fostering and deepening students' empathy and their overall engagement in wider society, and this is critical to their long-term engagement with STEM. The aim of this research was to develop and strengthen interest in and attitudes towards STEM subjects among young girls from disadvantaged backgrounds, as they are currently less likely to pursue STEM-related study beyond school, and are generally under-represented in the field.

Funded by Science Foundation Ireland in 2018, and supported by the Professional Development for Teachers, Professor Harford and Dr Farrell worked with a range of primary and post-primary schools, exploring girls' attitudes towards STEM and possibilities for increasing their engagement with it.

Presenting STEM as a creative process, which fosters inquiry and interpersonal connection, changes not only the narrative of STEM but the propensity for girls to relate to these subjects. The team therefore based their research around an approach to teaching called "philosophy for children" (P4G), which aims to develop pupils' critical thinking. Using this approach, pupils can pose questions, express concerns, and suggest reasons for particular phenomena, such as why women STEM leaders matter. They took a cross-curricular approach, focusing on a range of female STEM pioneers, both historical and contemporary.

From 2019 to 2021, the team engaged with over 1,000 pupils in Leinster schools, conducting surveys before and after using the P4G approach to measure various aspects of their relationships with STEM subjects, including:

- Their attitudes towards STEM
- Their intention to pursue STEM subjects at Leaving Certificate level
- Their aspirations, motivation and confidence to pursue a career in STEM
- Their familiarity with women in STEM

The surveys showed improved attitudes toward STEM-related subjects at post-primary level; increased awareness of the role of women in STEM; and an increase in confidence and interest levels in studying and pursuing a career in STEM

□

Immersive STEM Learning Experiences to Shape Shared Futures: Insights from the STEM Teacher Internship Programme

Nov. 2021

Mairéad Hurley, Deirdre Butler & Eilish McLoughlin

https://stemteacherinternships.ie/wp-content/uploads/2021/11/STInt_White_Paper_November_2021.pdf

This is a report on the STEM teacher intern programme run by DCU for the past 6 years.

Executive Summary

This White Paper presents an ambitious vision for the type of education system required to prepare learners for the future. It contains a strong focus on integrated science, technology, engineering and mathematics (STEM) education, essential for developing the necessary competences to thrive in our complex, ever-changing world. Within such a holistic and equitable education system, these learners will be equipped to realise a planet with thriving and sustainable societies, economies and environment.

We posit that teachers are the catalyst to realising this vision and ensuring that effective, sustainable systematic change happens. However, they cannot do it alone and will need the support of a range of stakeholders and actors to create this effective learning ecosystem. Considering this and also the point that the most impactful moment to influence the teachers of the future is during their initial teacher education - when they are fully immersed in the processes and practices of active, situated learning - designing an intervention that focused on working with pre-service teachers seemed the logical starting point. If these teachers are to design authentic learning experiences which integrate core STEM competences within real-world contexts, we believe it is essential that they have first hand experience in these contexts themselves. Only with such a rounded experience, will they be in a position to inspire truly innovative STEM learning in their classrooms.

These ideas are what led to the development of the STEM Teacher Internship (STInt) Programme, which encapsulates clearly how building partnerships between teacher educators, student teachers and industry can play a part in shaping the shared futures of the next generation of Irish students.

However, this is only the beginning, and in the process of working on the STInt Programme since 2016 we have come to realise with greater clarity that there are major challenges we still need to address within the wider ecosystem in realising our vision of designing innovative learning environments.

This White Paper argues that two major challenges are:

– Inequities in education broadly, and specifically issues of diversity, equity and inclusion in STEM education, which lead to inequities in STEM professions and careers.

– The need for consensus between research/higher education, policy and practice when it comes to STEM education, and the need for capacity-building measures to support teachers to deliver integrated STEM education.

We propose two recommendations for actions to address these challenges:

1 Build and deepen teachers' understanding of integrated STEM education through immersive professional experiences in real-world STEM contexts.

2 Develop and strengthen the connections across and between actors within the STEM learning ecosystem to improve learner outcomes.

Throughout this document, we present a number of "Spotlight on Practice" boxes – showcases of exemplary programmes, projects or approaches being developed and deployed in Ireland and internationally, which we believe have the potential to address these challenges and inform the proposed strategic actions. These two recommendations are designed to act at different scales, from that of the individual teacher, to the regional and national systems level.

******

A 12-week immersion in STEM industry is sufficient to give a pre-service teacher a transformative view of the transversal skills and competences needed for the future success of their students.

This maps directly onto the objectives of the STInt Programme, and its participating universities and host organisations. As the Irish Government heads towards Phase 3 of the implementation of their STEM Education Policy (2023-26), the STInt Programme, now in its sixth year, is primed to be extended into a nationwide programme including all institutes and universities offering science or STEM teacher education courses. It is timely for the Irish Government to invest in the STInt Programme to enable its scaling for nationwide adoption, therefore supporting the realisation of this important objective of the STEM Education Policy (2017 – 2026).

The testimonials shared by teachers Sam and Chris in this White Paper illustrate exactly how the STInt Programme can be successful and how a 12-week immersion in STEM industry is sufficient to give a pre-service teacher a transformative view of the transversal skills and competences needed for the future success of their students. Let's make sure every young person in Ireland gets the chance to be taught by a teacher like Sam or Chris! A 12-week immersion in STEM industry is sufficient to give a pre-service teacher a transformative view of the transversal skills and competences needed for the future success of their students.

Ministers Harris and Foley announce investment in 47 projects to help public understanding of STEM

Department of Education
Published on 1 June 2022

Minister for Further and Higher Education, Research, Innovation and Science, Simon Harris, and Minister for Education, Norma Foley, have today announced an investment in 47 projects aimed at improving public understanding of science, technology, engineering and maths (STEM).

The €3.7 million funding will be focused on encouraging diversity and inclusion in STEM, while also targeting a wide range of ages including young children, teens and adults.

Announcing the funding, Minister Harris said:

"I am delighted to announce today the 47 projects receiving funding through the Science Foundation Ireland (SFI) Discover Programme.

"These projects will have an invaluable impact, starting conversations about the role of STEM in society and inspiring our young people to explore careers in these areas.

"Through initiatives such as the SFI Discover Programme, we must support the public to have access to, and understand, the issues that impact our collective future, and the role science and technology can play in providing solutions. I wish all the recipients every success in the rollout of their projects."

Speaking of the projects co-funded by the Department of Education, Minister Foley said:

"We are pleased to collaborate with the Department of Further and Higher Education, Research, Innovation and Science by supporting five projects that will receive funding through the SFI Discover Programme.

"These projects are designed to grow and encourage participation in STEM education and public engagement, inspiring our young people to explore STEM roles in the future. I want to congratulate all of the individuals and teams involved in their work to date on these projects."

A full list of the projects supported can be found at:
gov.ie - Ministers Harris and Foley announce investment in 47 projects to help public understanding of STEM (www.gov.ie)

□

Review of Literature to Identify a Set of Effective Interventions for Addressing STEAM in Early Years, Primary and Post Primary Education Settings

This review was commissioned by the Department of Education in 2021 and carried out by a team in the STEM Department in Mary Immaculate College, led by Dr. Aisling Leavy. The review was launched in June 2022 by Minister for Education Norma Foley, and the full report is available online: https://www.gov.ie/en/policy-information/4d40d5-stem-education-policy/

Background

The last decade has been marked by a growing momentum to advance STEAM education nationally and internationally. This fast-evolving field is characterised by its efforts to incorporate the Arts into STEM (Science, Technology, Engineering, Arts, and Mathematics) education. Despite the popularity of STEAM education, there is an evidence-based disparity in relation to the crucial components that contribute to high-quality STEAM education experiences.

Advocates for STEAM education acknowledge the transformative learning potential of STEAM education. Some identify the pervasive need for improving STEM education, recognising that the Arts provide a compelling context and entry point to engage underrepresented groups in STEM. Many that hold this viewpoint also recognise the significant value that the Arts offer, including its potential benefits in developing 21st century skills, enhancing innovation and creativity in STEM, contributing to economic prosperity, feeding the STEM pipeline, and increasing global competitiveness. Unfortunately, one consequence of this perspective is that the Arts are positioned as providing value to STEM education without displacing the focus on the traditional STEM disciplines. This leads to positioning STEM as more important and locating the role of the Arts as integrating *into* STEM in the service of elevating STEM learning.

In contrast, other STEAM advocates see the Arts and STEM as co-equal. Within this perspective, STEAM education is considered a trans-disciplinary endeavour focusing on a hybrid creative and critical inquiry between the Arts and STEM that involves innovative, problem and project-based, high-quality learning experiences delivered in a collaborative and integrative manner. This view of STEAM education utilises Arts integration as an instructional approach, providing multiple entry points for students to engage in the creative process, thus meeting the learning objectives of Arts and STEM subjects. Within these spaces, all disciplines have equal value, the Arts and STEM are seen to make mutually beneficial contributions to teaching and learning.

The purpose of this systematic review of the literature is to review national and international STEAM literature and identify a set of effective interventions for addressing STEAM in early years, primary, post primary and non-formal education settings. The actions and recommendations arising from the review will contribute to developing STEAM education policy in Ireland.

Methodology

The review was conducted in three phases.

Phase 1 was concerned with protocol development, an electronic search of education databases and a manual search of targeted journals. To reduce the risk of publication bias, sources including unpublished or 'grey' literature were searched. Following the removal of duplicates, this phase yielded 2484 files.

Phase 2 focused on the formulation of five study exclusion criteria, a pilot study to test the efficacy of the criteria, study selection, and consistency checks of the screening process. The five exclusion criteria were applied, and 179 studies were extracted.

Phase 3 involved the analysis and synthesis of extracted studies where an array of relevant research studies was identified and described, including research involving STEAM education interventions across formal (early years, primary, post primary) and non-formal settings in addition to consideration of the landscape of initial teacher education.

Main Findings

There were few highly rigorous empirical studies of STEAM education interventions that featured randomisation, control groups and robust statistical analysis. This is understandable given that STEAM education is new, and there is still a level of ambiguity among practitioners and researchers as to what effective STEAM education entails.

Across all sectors, most interventions focused on one STEM discipline (science, technology, engineering, or mathematics) combined with one Arts-based domain (from the visual, performing, or musical Arts). There were consistent patterns in the integration and pairing of disciplines. Most studies integrate science with the visual Arts at the early years and primary level. In contrast, science was integrated with the dramatic Arts at post primary level, and few studies integrated visual Arts with any of the STEM disciplines. At post primary level, mathematics was most frequently combined with music. However, at the early years and primary level, mathematics was paired equally with the visual and performing Arts. Technology was integrated most often with the musical Arts or dance at post primary level and drama at the early years and primary level. Compared to the formal school sector, STEAM education interventions in the non-formal sector integrated the Arts with more than one STEM discipline. These patterns are plausible given the generalist context of early years and primary level, the subject specific nature and teacher specialists found at post primary, and the diverse educational landscape that is found in a myriad of non-formal settings.

The review of intervention studies at post primary highlights the need to broaden the domains of integration within STEM and across the Arts. That said, studies that tried to do too much, too soon, such as those that attempted to implement a whole school approach to STEAM, were counterproductive in some cases. Within the non-formal STEAM education landscape, there was a notable imbalance between the Arts and STEM subjects evident within interventions, where STEM subjects like mathematics received little explicit attention. Similarly, at the early years and primary level, relatively few studies explored the potential for music integration.

The enablers for effective STEAM education within formal education settings were consistent across the studies, with the importance of teacher professional development, the cooperation of an interdisciplinary team, connections with stakeholders inside and outside the school, adaptability of the formal curricular structures to facilitate projects, a constructivist approach to teaching and learning and the critical role played by meaningful and equal integration of the Arts-based elements of the intervention. Additionally, play-based approaches were identified as effective for successful STEAM integration in primary education settings, as was embracing young children's natural curiosity. For non-formal settings, enablers included access to relevant professional development courses, technologies and expertise, promotion of student-led learning, thus promoting agency, creativity, and the opportunity to develop both Arts and STEM understandings.

Barriers to effective STEAM education implementation commonly cited within both formal and non-formal education settings included an over-focus on the STEM discipline at the expense of the Arts, low levels of self-efficacy and expertise of educators implementing STEAM education initiatives, lack of time and scarcity of resources for projects within pressured formal curricula, alongside the absence of a unified and mutual understanding of STEAM education. There was also a lack of leadership and practitioner support for STEAM education in the formal education setting.

Conclusions

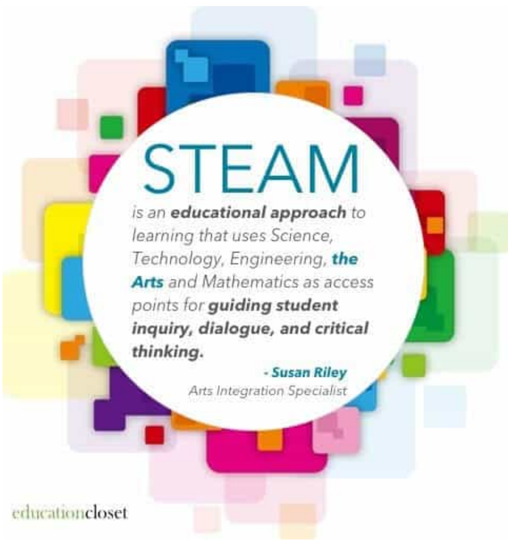
This review highlights that STEAM education is at a very exploratory and early phase. There is significant scope for innovation and creativity regarding research focus, design, and implementation of STEAM education interventions. The defining feature of STEAM education is the integration of the Arts. Consequently, explicit attention must be given to meaningful and authentic learning outcomes for the Arts arising from any STEAM education intervention. This is best achieved through collaboration between the Arts and STEM education communities in the design of high-quality STEAM curricula, the development of assessment strategies, and evaluation of outcomes. This can be guided by STEAM policy that promotes a shared understanding of what STEAM education entails and articulates a unified purpose for STEAM education. Such policy must provide a rationale for its use and not privilege one over the other, either the Arts or STEM. Furthermore, any policy initiative needs to be cognisant of the *learner* in terms of who they are, how they access

STEAM education opportunities, and the most appropriate pedagogies to support their learning. Investment must also be made into supporting the *educators* through the provision of high-quality initial teacher education and professional development that targets the development of knowledge, skills, and dispositions to support STEAM learning in classrooms and informal settings.

The following authors contributed equally to the report publication. Aisling Leavy, Claire Carroll, Edward Corry, Miriam Hamilton, Mairéad Hourigan, Rory McGann, and Anne O'Dwyer are all faculty members in the Department of STEM Education at Mary Immaculate College, Limerick. Michelle Fitzpatrick is a STEM teaching fellow at the Department of STEM Education. Gary LaCumbre is a librarian at Mary Immaculate College with expertise in information retrieval, management and literacy.

A link to the launch: gov.ie - Minister Foley welcomes new research on STEM and the Arts Education to inform future policy in this area (www.gov.ie)

□



STEAM is a way to take the benefits of STEM and complete the package by integrating these principles in and through the Arts. STEAM takes STEM to the next level: it allows students to connect their learning in these critical areas together with Arts practices, elements, design principles, and standards to provide the whole pallet of learning at their disposal. STEAM removes limitations and replaces them with wonder, critique, inquiry, and innovation.

What is STEAM Education? The Definitive Guide for K-12 Schools (Artsintegration.com)

*****

Home - STEAM Education (steam-ed.ie)
STEAM Education is a company linked to UCC which brings STEAM activities into primary schools.

WHY STEAM MATTERS?

Worldwide STEAM education is underfunded, under-resourced with regard to specialist skills, tools and equipment, appropriate, functional and integrated curricula, as well as continuity of education and engagement. Consequently the majority of our children, and indeed our society are not enabled to fulfill their potential in these areas. In industry, this manifests as a shortage of suitable STEM-enabled graduates, particularly those with the "softer" skills seen as key in 21st century learning. In society, it manifests as disconnection from fundamental aspects of our lives, the world around us, the resources on which we depend, and critical engagement in planning our future. We want to change the mindset in which individuals are "boxed" into assigning themselves to an individual subject area/career/talent. We believe that empowering children to be both creative and critical thinking humans, engaged and active citizens, who can collaborate and work in diverse teams will support a better future for us all!

□

"Sustainable Energy - towards a Zero-carbon Economy using Chemistry, Electrochemistry and Catalysis"

Julian H. R. Ross
Julian.ross@ul.ie

Your editor, Peter Childs, has invited me to write a short description of my new book *"Sustainable Energy - towards a Zero-carbon Economy using Chemistry, Electrochemistry and Catalysis"*. This was published by Elsevier at the beginning of 2022 and details are to be found at the website: https://www.elsevier.com/books/sustainable-energy/ross/978-0-12-823375-7. I have included the full sub-title here to emphasise that the book is written from the point of view of a chemist who has tried to outline some of the chemistry and related aspects of the topic. It is my hope that it will allow the scientifically-literate reader to obtain a greater understanding of the generation and use of energy and of some of the possible routes towards achieving a "green" economy in the future. The book is divided into eight chapters and the contents of each will be summarised in turn below.

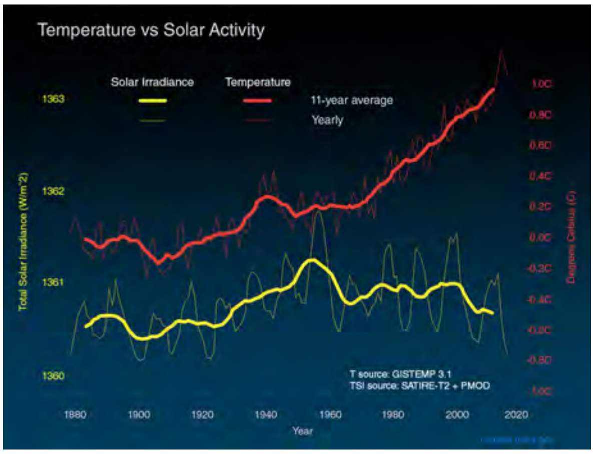


Figure 1. Global temperature and solar activity since 1880.
(Diagram reproduced from NASA's Global Climate Change website: https://climate.nasa.gov/)

Chapter 1 discusses the problem of global warming and some aspects of the greenhouse effect caused by the emission of so-called green-house gases, examples being carbon dioxide, methane, nitrous oxide and various chlorinated molecules.

Figure 1 shows the average global temperature and the solar activity as a function of time since 1880; the yearly variations of both these parameters are shown by the lighter curves which have then been averaged to give the more distinct curves. It is quite clear that the increased global temperature seen to the right of the diagram far exceeds any increase that could be caused by increases in solar radiation.

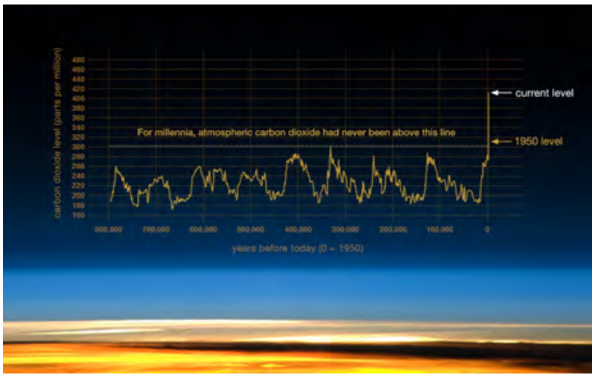


Figure 2. The concentration of CO_2 in the atmosphere as a function of time.
(https://climate.nasa.gov/resources/)

Figure 2 shows that there has been a dramatic increase in the level of CO_2 concentrations in the atmosphere since about 1950 and that this increase is well outside the normal temporal variations that have occurred over the previous centuries. It is now generally well recognised that all of the greenhouse greenhouse gases contribute to this increase in temperature and efforts have been made to decrease the emissions of these molecules.

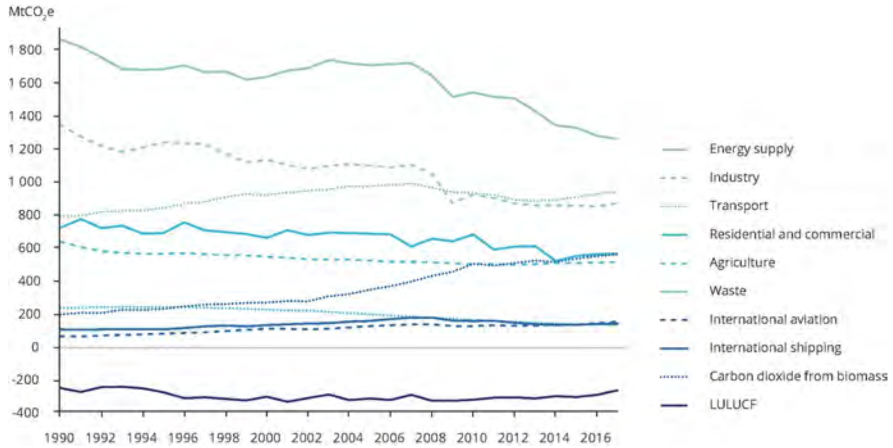


Figure 3. Contributions to greenhouse gas emissions from different sectors in the EU from 1990 to 2020.
Source: Europe environment state and outlook2020 (https://www.eea.europa.eu)

Figure 3 shows the CO_2 equivalent emissions from different sources for all the EU states since 1990. It can be seen that there have been significant reductions in the emissions from various different sectors as a result of efforts to reduce them, marked exceptions being transport, international aviation and shipping. However, these efforts to achieve reductions are now considered to be inadequate without further changes. Significant efforts must therefore be made to reduce the emissions from many sectors to a greater extent than has been achieved until now.

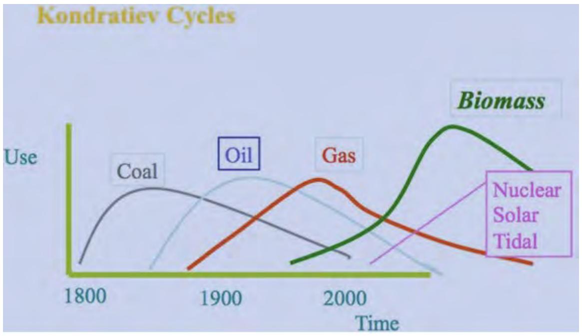


Figure 4. Kondratiev cycles associated with the use of energy sources. (Reproduced from *"Contemporary Catalysis"*, JRH Ross, Elsevier, 2018.)

Chapter 2 describes many of the conventional routes for the production and use of energy, the main raw materials used having been coal, crude oil and natural gas. As shown schematically in Figure 4, the use of these fuels has followed so-called Kondratiev cycles. It is to be expected that other sources of energy such as biomass, nuclear fission and fusion, solar energy and tidal energy will in due course take over from the carbon-based energy sources, as discussed later. This chapter also discusses some of the very significant industrial emitters of greenhouse gases such as cement production and iron and steel manufacture. It then goes on to discuss the production and uses of crude oil and of natural gas and includes a description of the fracking process used in countries such as the US for methane extraction.

Chapter 3 then discusses a variety of less conventional energy sources, the majority of which depend on the absorption of energy from the sun. (The main exception to this general rule is nuclear energy for which the origin is radioactive materials extracted from the earth's mantle. Another exception is geothermal energy.)

Figure 5 shows the life-cycle CO_2 equivalent emissions from different energy sources and includes data for coal and gas. These emissions include those generated during the various stages of the process required to produce the energy. For example, the value for solar rooftop includes the emissions occurring during the extraction, manufacture and assembly of the components of the solar cells while that for biomass includes emissions during harvesting, transportation and processing. It can be seen from this figure that coal is by far the most significant emitter and that this is followed relatively closely by natural gas. Nuclear energy includes both fission and fusion. Ireland has long decided that no nuclear fission facilities will be sited here but France has a thriving nuclear energy activity. Fusion is still far from being usable as a source of energy although it should be recognised that nuclear fusion within the sun's core is responsible for the emission of its energy.

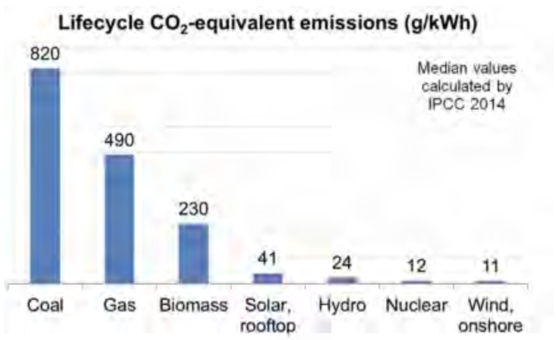


Figure 5. Life-cycle CO_2-equivalent emissions by different energy sources. (https://www.ipcc.ch/report/ar5/syr/)

Figure 6. Ardnacrusha Power Station. (Courtesy of ESB Archives)

Ireland has a well-established example of hydro-electric power in the form of the Shannon power station at Ardnacrusha; see Figure 6. Opened in 1929, this at that time generated much of the power required for the newly-founded state. Ireland is also well placed for the use of wind and tidal power as well as power derived from ocean currents and the potential of each of these is considered in this chapter. Solar power is also an important potential source of energy and this topic, considered later in more detail, is also introduced in Chapter 3.

Chapter 4 then discusses the production and uses of hydrogen. Figure 7 shows the steadily increasing global demand for hydrogen. The predominant uses of hydrogen are in ammonia production and in various processes in the petroleum refining industry, this category including methanol production.

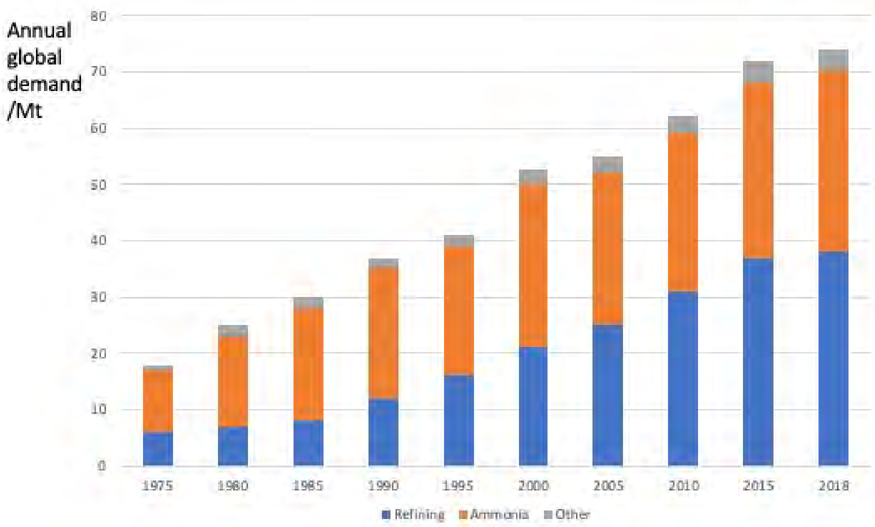


Figure 7. The Global Demand for Hydrogen since 1975
IEA, *Global demand for pure hydrogen, 1975-2018*, IEA, Paris https://www.iea.org/data-and-statistics/chArts/global-demand-for-pure-hydrogen-1975-2018

Almost all of the hydrogen used is produced using the so-called steam reforming of methane, a reaction which occurs according to the following equation:

$$CH_4 + H_2O \rightarrow CO + 3\ H_2$$

This catalytic reaction is followed by the water-gas shift reaction to convert the CO_2 to CO, producing more hydrogen:

$$CO + H_2O \rightarrow CO_2 + H_2$$

As the steam reforming reaction is highly endothermic and therefore must occur at high temperatures, the catalytic reactor for the reforming reaction is heated by the combustion of natural gas, this producing yet more CO_2 . (For every million tons of hydrogen produced, well in excess of 5.5 million tons of CO_2 are produced; the contribution to greenhouse gas emissions is even higher as there is an addition due to the occurrence of methane emissions at the gas wells and in the transmission systems used.) The construction of a plant used for the steam reforming reaction is shown schematically in Figure 8. The conventional steam reforming units used, for example in ammonia production, are very large and the emissions of CO_2 associated with their operation contribute a substantial proportion of the global emissions contributing to the greenhouse effect.

Chapter 4 discusses various improvements that have been made in the reactors used and also the development of smaller-scale reactors for the production of hydrogen for other uses. There is currently a great interest in the possibility of capturing the CO_2 formed in the steam reforming reaction, the CO_2 being stored in underground storage systems: the so-called “carbon capture and storage” (CCS) approach. Such an approach is still in the development stage and will have very limited application because of the scarcity of possible leak-tight storage sites.

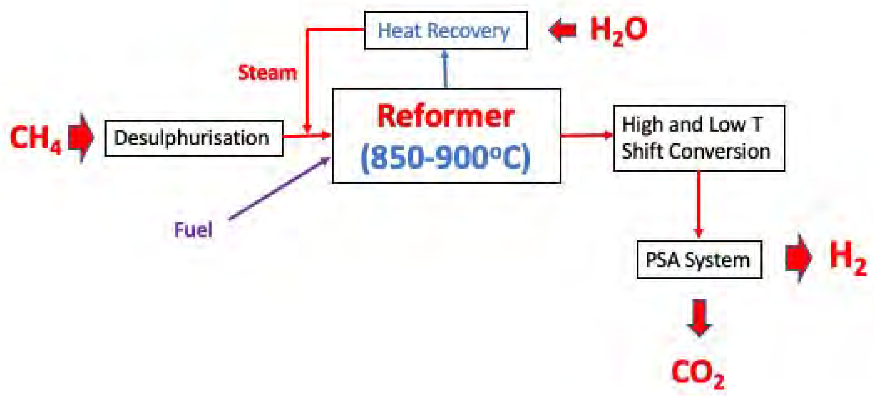


Figure 8: Schematic representation of a plant for the steam reforming of methane to produce pure hydrogen.

Hydrogen can also be produced using a number of other approaches. Before the ready availability of oil and natural gas, it was produced by the gasification of coal, a process that was practiced very generally in the production of towns gas. Production by the electrolysis process discussed in Chapter 3 has also been used but only for very specialised purposes as the electrolysis method is economically much less attractive than the use of steam reforming. Only if the electricity used in the electrolysis process is produced using a renewable source (wind, solar energy, etc.) in the hydrogen produced without CO_2 emissions. Although the hydrogen from all these approaches is chemically indistinguishable, a nomenclature has gradually crept into use as shown in Table 1.

Table 1: Hydrogen types depending on level of CO_2 emissions.

Nomenclature	*Process used*
Black hydrogen	Gasification of coal
Brown hydrogen	Gasification of lignin
Grey hydrogen	Steam reforming without CCS
Blue hydrogen	Steam reforming with CCS
Green hydrogen	Produced by renewable electricity

Chapter 4 goes on to discuss some of the most important chemical uses of hydrogen such as the production of methanol, synthetic fuels (by the Fischer Tropsch process) and ammonia.

Chapter 5 discusses the use of biomass as a source of energy and also of chemicals. Prior to the use of coal for combustion purposes, wood was the generally used only as fuel or as a building material. Its use in papermaking is a centuries old process that is still of great importance and some aspects of paper manufacture and recycling are therefore discussed in this chapter. Various methods for the conversion of various other organic feedstocks are then considered in turn: the use of organic residues, oil crops or oil-based residues, and cellulosic crops. The chapter ends with a description of hydrolysis, fermentation, pyrolysis and gasification processes for the conversion of biomass containing lignocellulosic materials to produce various valuable products as shown schematically in Figure 9

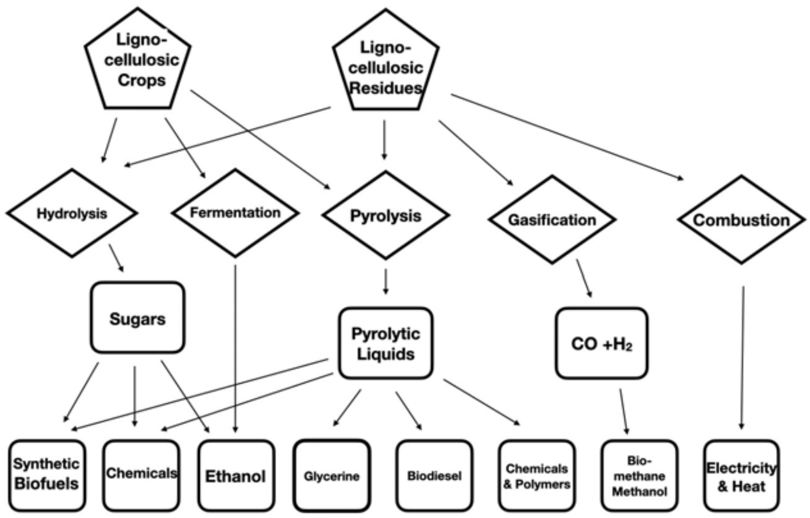


Figure 9: The conversion of lignocellulosic crops and residues to useful products

A significant proportion of global greenhouse emissions originate from transport. Chapter 6 discusses the history of the evolution of transportation methods and describes the operation of different types of engine as well as considering the emissions from petroleum and diesel engines. It then discusses various modern developments such as hybrid vehicles, plug-in hybrids and battery-powered vehicles before ending with a brief discussion of fuel-cell vehicles. Table 2 gives some typical data for the CO_2 life-cycle emissions of different types of vehicles. In particular, it shows the importance of the method of generation of the electricity used for an electric vehicle. If the electricity is 100% renewable, the electric vehicle is by far the most effective at reducing green-house gases. However, if the electricity is typical of the average found throughout the EU, the battery vehicle is less effective in reducing greenhouse gas emissions than is the plug-in hybrid shown in Figure 10.

Table 6.2: Life-cycle emissions of CO_2 for a series of different vehicles and fuel types.
Data from "The European environment - state and outlook 2020", European Environment Agency (2019), ISBN 978-92-9480-090-9 (http:europa.eu)

Vehicle type	Vehicle Production and Disposal /CO2 emissions (g/km)	Fuel Production /CO2 emissions (g/km)	CO2 Exhaust Emission /CO2 emissions (g/km)	Total Life-Cycle CO2 Emissions (g/km)
Petrol	40	25	170	235
Diesel	40	30	130	200
Plug-in Hybrid	55	25	90	170
Battery Electric /100% renewable	60	20	0	80
Battery Electric /EU average renewable	60	115	0	175
Battery Electric /100% coal generation	60	240	0	300

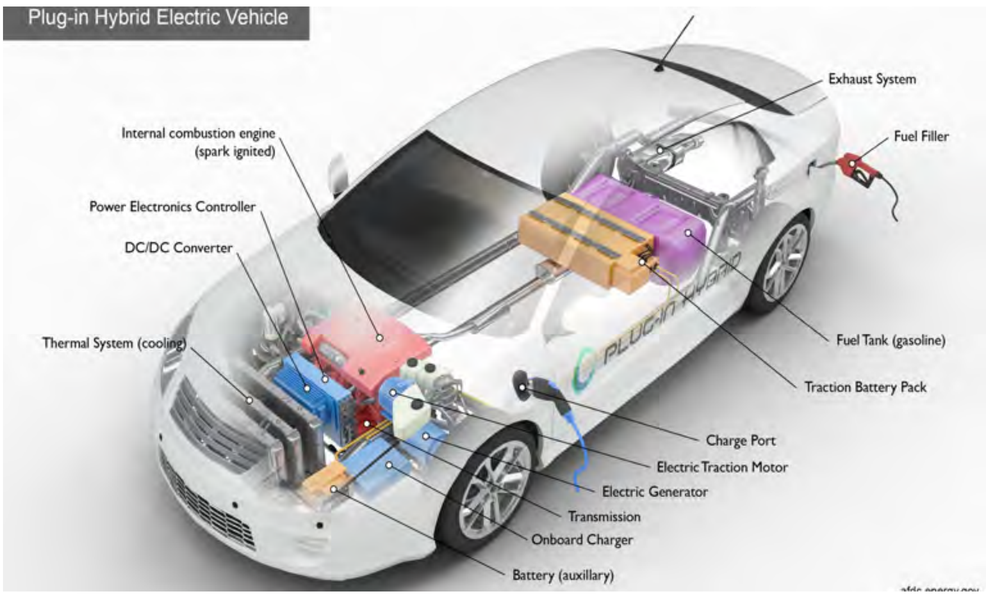


Figure 10: Schematic representation of a plug-in hybrid vehicle
http://afdc.energy.gov

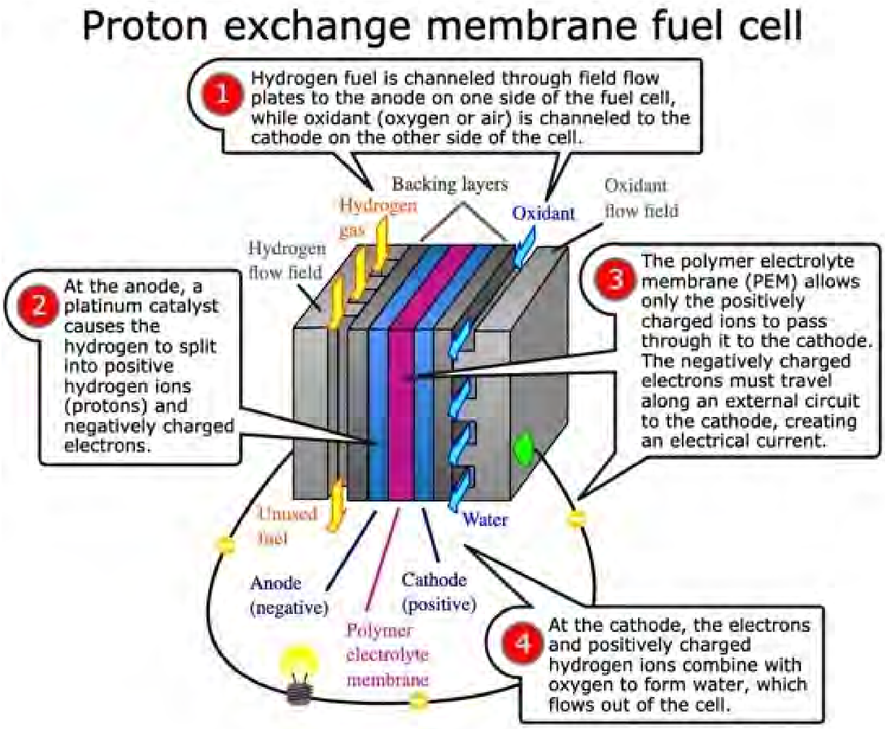


Figure 11: A cut-away diagram of a polymer electrode membrane fuel cell. (https://upload.wikimedia.org/wikepedia/commons/0/0d/PEM_fuelcell.svg)

Chapter 7 provides a description of the construction and operation of batteries, fuel cells and electrolysis systems. It includes discussions of the thermodynamics of the operation of a battery and of half-cell EMF's, describing the construction of some typical batteries in common use. Having discussed rechargeable batteries such as the Ni-Cd and Ni-MH batteries, particular attention is given to the development of Li-Ion batteries and Li-metal batteries. The chapter then goes on to cover the operation of fuel cells in which electricity is produced as a result of feeding hydrogen (or some other fuel) plus oxygen to a system which is similar in construction in many ways to a battery. As an example, Figure 11 shows schematically the construction of a proton-exchange membrane fuel cell in which the electrolyte between the anode and cathode is a polymer that allows only the transport of H^+ ions through the membrane. Chapter 7 ends with a discussion of the process of electrolysis. Electrolysis occurs by the application of a potential and can drive reactions that would not otherwise be thermodynamically feasible. The most relevant example of an electrolytic process is the hydrolysis of water to produce hydrogen and oxygen, a use that has been known for many years but which is currently uneconomical for the production of hydrogen compared with the other routes discussed earlier due to high electricity costs. However, its use becomes more and more likely if cheap renewable electricity becomes available, a topic that is discussed in Chapter 8 (see below). Electrolysis is also used industrially in several important industrial processes, examples covered being the chloralkali process for the production of chlorine and NaOH from brine, and the use of the Hall-Hérault cell for the production of aluminium. The final chapter (Chapter 8) discusses various ways in which "Net Zero" (an increase in global temperatures of no more than about 1.5°C above pre-industrial levels) could be achieved and describes some of the research and development work currently being carried out in an effort to reach it. Some of the conclusions of the International Energy Agency report from late last year (*Net Zero by 2050 - A Roadmap for the Global Energy Sector* https//www.iea.org/reports/net-zero-by-2050) are summarised, these including the recommendation that all new buildings should by 2030 be zero-carbon ready, 60% of car sales should be electric, that there should be significant progress in developing solar and wind generation of electricity, and that the use of coal without CCS should be terminated; the use of oil and natural gas should also be much reduced. Figure 12 summarises these conclusions.

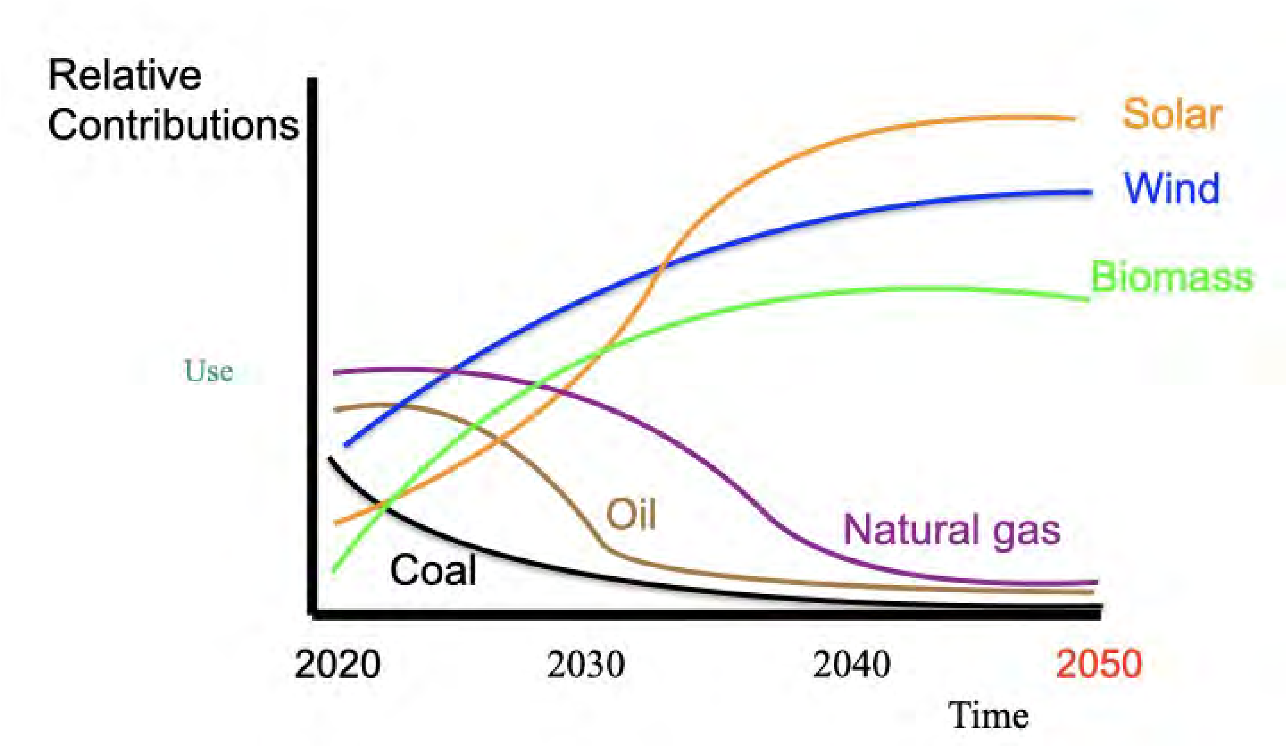


Figure 12: Schematic representation of the changes in the usage of different energy sources that will be required by the year 2050 to achieve Net Zero.

Chapter 8 returns to the importance of the various potential uses of green hydrogen produced by electrolysis. There are currently significant international initiatives aimed at using green hydrogen as an energy carrier and some of these are discussed. For example, several countries have initiated the introduction of hydrogen filling stations to enable the use of fuel-cell powered vehicles, but it appears that this initiative is not going to become universal as a result of the increased use of electric vehicles and improvements in battery technologies and battery charging rates. Green hydrogen will also become the choice for several important industrial processes and there are already initiatives to introduce “green ammonia”, “green methanol” and “green motor fuel” (produced by the Fischer Tropsch process discussed earlier).

A particularly interesting development is work on the development of electrolysis processes for the production of green ammonia using “Solid Oxide Electrolysis

Cells" (SOEC's). These cells, currently being used by the Danish chemical engineering company Haldor Topsøe, contain solid oxide membranes that permit only the passage of O^{2-} ions and a pilot plant has been constructed using a bank of these cells for the production of green ammonia. Haldor Topsøe has also done work on the production of green methanol using their SOEC electrolysis cells. For this application, they have shown that it is possible to electrolyse a mixed feed of water and CO_2 to produce the syngas required for methanol synthesis. This approach is shown schematically in Figure 13. Renewable electricity is either fed to the grid or to the SEOC unit where it can either be used to produce pure hydrogen or, when CO_2 is added to the feed water, to form syngas. Green hydrogen from such a system can also be used in steel production or in the preparation of cement, thus decreasing significantly the emission of greenhouse gases in these energy-consuming industries.

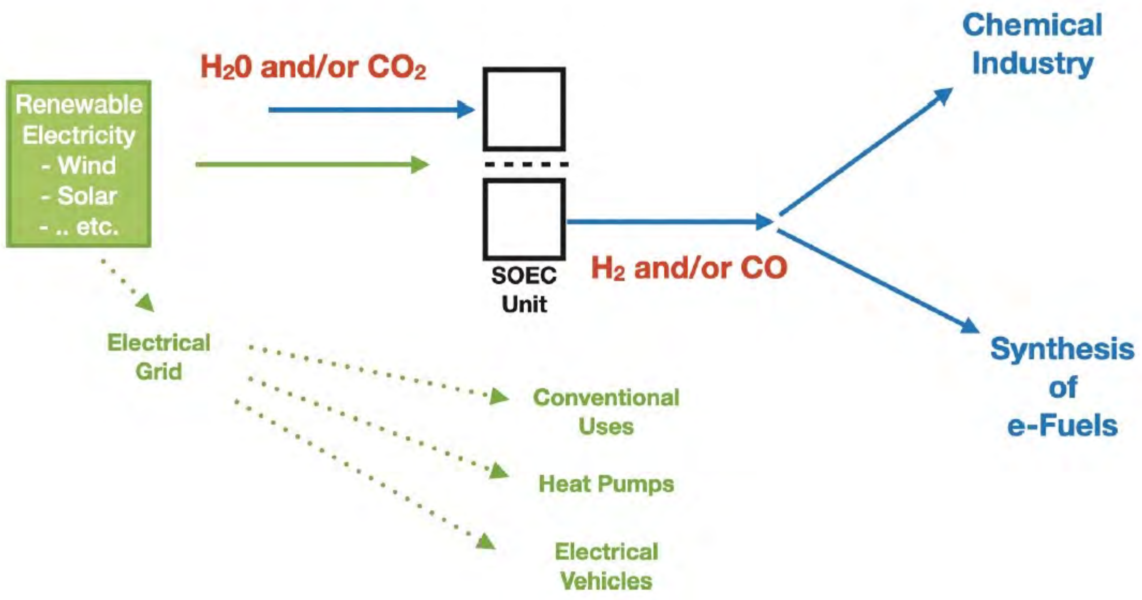


Figure 13: Schematic representation of the production and uses of hydrogen and/or carbon monoxide using an SEOC system.

In the Irish situation, significant improvements in green-house gas emissions can in the relatively short term be achieved in many areas as long as the electricity grid is supplied with largely renewable electricity. One method of helping to achieve this, in addition to the building of more wind turbines, is to encourage the installation of photovoltaic (PV) systems in both private and public premises. Figure 14 shows some data obtained during the first six months of 2021 from a PV system installed on a house in Co. Galway which generated the majority of the electricity required by the household in question from April until June, requiring minimal feedback to the grid. The system illustrated also involves battery storage and this ensures that there is a minimum level of feedback to the grid. (This author has suggested that if the Irish government was to subsidise the payment of a significant feedback tariff to domestic generators of PV power, thus avoiding the need for expensive and less reliable battery systems, the use of

PV installations could become much more widespread.) The agricultural sector also would benefit greatly from the installation of PV systems as well as a more widespread adoption of anaerobic digestion systems for the treatment of biological waste.

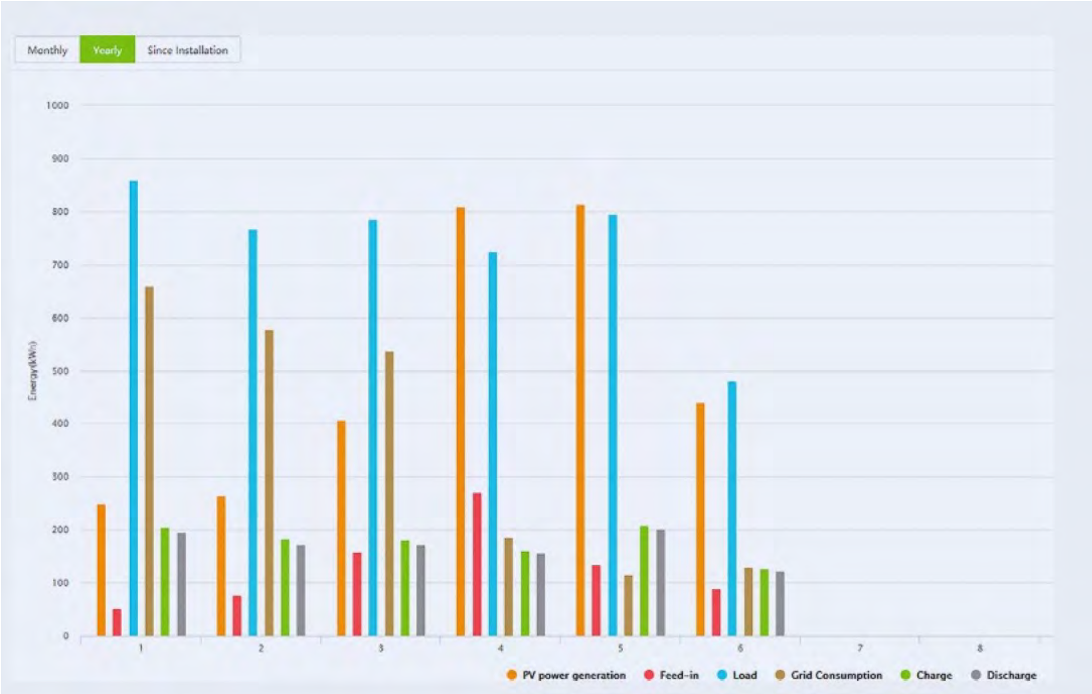
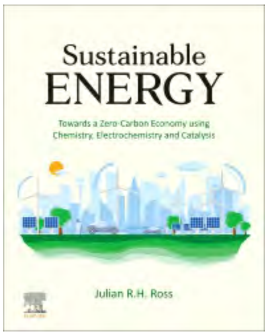


Figure 14. Data for the operation of a domestic Irish photovoltaic system from January to mid-June 2021. (Data kindly provided by F. Sheehan. Shown are the monthly figures for power generation (orange), feedback to the grid (red), household energy use (blue), draw-down from the grid (brown) and feed to (green) and from (grey) the battery storage system. The maximum household energy use in January 2021 was about 770 kWh.)



The book ends with two short sections added during the production process, these inspired largely by the wide press coverage during the COP 26 gathering in Glasgow held in November 2021. Sadly, a ban on the continued use of coal worldwide was not supported during the closing stages of the meeting by Australia, China and India. Nevertheless, the meeting achieved a great deal and it now remains to the politicians to work towards the COP 26 objective of accelerating reductions of greenhouse gases between now and 2030.

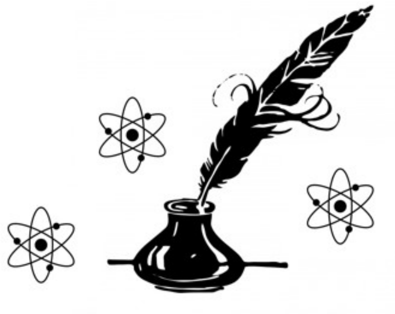
The author hopes that this book will help to inform the average citizen as well as our politicians about possible practical approaches to the reduction of greenhouse gas emissions. Now is a time for decisions, not just discussion, and a carrot and stick approach to the adoption of suitable methods is necessary.

□

Biography

Julian Ross is a Research Professor at the University of Limerick. Having completed his research doctorate at Queen's University, Belfast, he first moved to the University of Bradford and then to the University of Twente, the Netherlands, where became Professor of Catalytic Processes and Materials. He returned to Ireland in 1991 as Professor of Industrial Chemistry and became Dean of the then new College of Science in 1994. He is a Fellow of the Royal Society of Chemistry (FRSC) and a Member of the Royal Irish Academy (MRIA).

Quirky Elemental Facts in Rhyme



TIN, Sn

***In bronze 'n' solders, pots 'n' pans, soft tin's been such a must.
In truth, did great Napoleon's bright buttons turn to dust?***

Tin is the soft, silvery-white metal known since ancient times that helped shape early human history. The bronze produced when tin was alloyed in small amounts with copper transitioned human civilization from the Stone Age to the Bronze Age (around 3000 BCE). Pliable and easily worked, tin was also a popular material for household utensils and cookware during the Middle Ages. Today it's widely used in solders.

When a sample of pure tin is cooled below 13°C, its crystal structure slowly transforms from tetragonal to cubic. This causes the sample to physically change from its normal metallic form (known as *beta-tin*) to a powdery, grey solid (known as *alpha-tin*). This transformation has been observed during prolonged periods of cold, wintery weather. For example, the majestic tin organ pipes in some churches have developed unsightly grey patches (known as *tin plague* or *tin pest*) that crumble to dust when touched. The phenomenon was also implicated—more by way of folklore than fact—in the freezing to death of many of Napoleon's soldiers during their retreat from Moscow in the winter of 1812. The soldiers' uniforms' tin buttons were said to have crumbled in the cold!

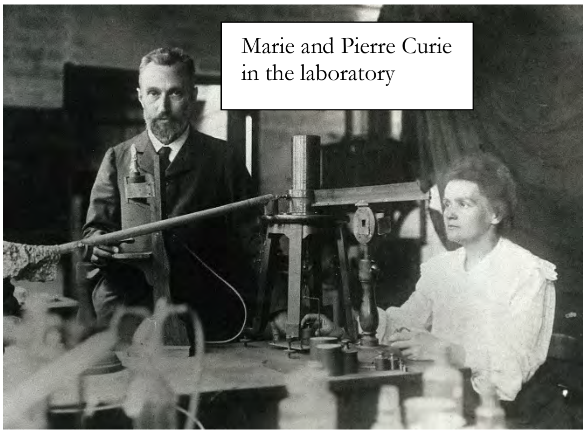
Quirky Elemental Facts in Rhyme

RADIUM, Ra

arr-ray

The Curies slaved o'er pitchblende (in their shed!) and found Ra,
Alas, its wondrous glow belied the harm of its decay.

Radium—a soft, lustrous, and radioactive element—is the heaviest of all the alkaline earth metals. The element was discovered in 1898 by Marie Skłodowska Curie with assistance from her husband Pierre Curie. Its discovery arguably owed as much to dogged persistence and hard labour as it did to the lofty principles of scientific rigour and ingenuity. Working in their laboratory (a cold, damp wooden shed at the School of Chemistry and Physics in Paris) and using rudimentary equipment, the Curies extracted milligram quantities of a pure radium compound from metric tons of spent pitchblende ore (this was a uranium ore from which the uranium had previously been extracted for commercial use in ceramic glazes; the radium that remained was slightly more concentrated as a result, although it was still very much a trace impurity). To achieve this feat, the Curies followed a tedious sequence of chemical recrystallization steps that spanned almost four years. Their considerable efforts, which also helped them discover the radioactive element polonium earlier that same year, were rewarded with a half share of the 1903 Nobel Prize in Physics.



Marie and Pierre Curie in the laboratory

The Curies chose the name radium from the Latin word radius (meaning ray), a reference to the soft, luminous blue glow that so enthralled them as it radiated from the samples they so painstakingly enriched. But the origin of this wondrous glow lay in the element's intense radioactivity, which was not known at that time. In fact, radium is the most radioactive substance found in nature. It decays aggressively via the emission of alpha particles (helium nuclei), which ionize the surrounding air to such an extent that it glows. As Marie Curie noted in 1911, upon receiving her second Nobel Prize (this time in Chemistry): "The radioactivity of radium in solid salts is [around] 5 million times greater than that of an equal weight of uranium. Owing to this activity its salts are spontaneously luminous." Curie pioneered the effective harnessing of this intense radiation to help destroy cancerous tumours, heralding the introduction of radiotherapy. Unfortunately, the potentially fatal consequences of overexposure to radium were not fully realized until later in the 20th century. Curie's own death from aplastic anaemia in 1934 was almost certainly due to her excessive exposure to radiation.

Chemists you should know #11

Dr. Samuel Guthrie 1782 – 1848

Adrian Ryder tutorajr@gmail.com

Introduction

The subject of this essay traces his ancestry back to early Scottish history. The family held the Barony of Guthrie in Forfarshire by Charter from King David II (1324-1371). We can trace later generations directly from James Guthrie (the Martyr) who was a Minister in Stirling in the 17th century and was executed in Edinburgh on June 1st 1661 on account of his theological writings. Due to this and the religious persecution aimed at their professed religion, three of the family, James, John and Robert set off to America to seek security and repose in this new world.
They first went to Boston, from where John went to Litchfield County, Connecticut, where he farmed and died about 1730. His son, again named John, moved to Stratford, Connecticut in 1726 where he prospered. He married twice, the first to Abigail Coe of Stratford in June 1727, with whom he had eleven children: John (1728), James (1729) who died in infancy, William (1730), another James (1732), Joseph (1733), Mary (1735), Ephraim (1737), Ebenezer (1740), Sarah (1744) and Lydia (1746). John died in 1756.

Our subject's grandfather, James (April 1732 – April 22nd 1804), the fourth child of John and Abigail Coe above, married (July 17th 1755) Abigail Betts (21st July 1742 – 1814) and had ten children, the eldest of whom was Samuel (May 23rd 1756 – August 23rd 1808), the father of the subject of this essay. Samuel married twice (first to a Sarah and then an Anna, surnames not found) and had, between them, four children: Samuel (1782-1848) (our subject) and James (1784) from the first marriage and Rufus and Alfred from the second.

Our subject Samuel married Sybil Sexton in 1804. On his father's death in 1808 Samuel found himself the recipient from his father's will of a dollar piece, Dr. Rush's *Enquiries* in 5 Volumes and a set of silver catheters.

The United States has not featured in any of the four series of articles in *CinA!* from this author, as the country was just beginning to find its feet following the war of independence (1765-1783).

Our subject in this essay is, perhaps, the first American chemist of note. Dr. Samuel Guthrie was born in Brimfield, Hampden Co., Mass. In 1782. His father, also called Samuel (23/May/1756 – 23/Aug/1808) farmed there and was a practicing physician and surgeon, dying in 1808. Two sons were born to Samuel Senior, Samuel Junior and James from the first marriage. James moved to Dayton, Ohio where he farmed and was known for his religious zeal, accepting every word of the Bible as of Divine origin. Samuel Senior married a second time and had two other sons. Rufus and Alfred, who went on to become physicians like their father. Following such elementary education as was given by the Brimfield village school, Samuel Junior became an apprentice to his father, this being the usual method of the time for becoming a doctor. Shortly after obtaining his MD he moved to Smyrna, Shenango Co., N.Y., some 223 miles away, where he opened his medical practice and at the age of 22 married Sybil Sexton (1788-1840), who was originally came from Connecticut.

The family home of Guthrie's parents in Brimfield, Massachusetts.

The couple had 4 children: 2 boys, 2 girls in the years to come. In 1817 they moved to Sackets Harbor, Jefferson, N.Y. where they spent the rest of their lives.

The substantial Guthrie home at Sackets Harbor, Jefferson County

The eldest son Alfred, who ultimately became a mechanical engineer, was born in Sherburne, New York, on the 1st April, 1805. He died in Chicago, Illinois, on the 17th August, 1882. He came with his parents to Sacket's Harbor in 1817, and here, as was the practice of the time, he studied medicine and chemistry under his father's tutelage, being his assistant at the time of his discovery of chloroform. For ten years he practised medicine, but the money available as a country doctor was so little that he changed direction, engaging in other occupations instead.

The younger son, Edwin, was born on the 11th December, 1806. As with his elder brother he studied medicine under his father, but subsequently abandoned that profession and settled in Iowa, where he held public office. Soon after the beginning of the war with Mexico, he raised a company of Iowa volunteers, of which he became captain, and went to the war. He was wounded in the knee during the engagement at Pass La Hoya, and, after suffering two amputations, died at the Castle of Perote, Mexico on the 20th July 1847. Guthrie county, Iowa, is named in his honour. The girls were Harriet (Chamberlain) 1810 – 1864 an abolitionist and Cynthia (Burt) 1823 – 1884.

As already stated Dr Guthrie began his career as an apprentice to his father and it was only during the winter of 1810 to 1811, that he had formal studies at the College of Physicians and Surgeons of New York (which is now Columbia University), and later, following his time in the army, in January 1815, he attended lectures at the University of Pennsylvania. These short courses, over only 31 days as described in his diaries, constituted his entire formal medical education.

During the war of 1812 (1812-1815) with Great Britain he was an examining surgeon in the American army and from his experiences there afterwards directed much of his energies towards the needs of the army.

In 1817 Samuel Guthrie Jr. moved to Sackets Harbor, Jefferson County, in northern New York where he opened up practice as a rural doctor. In addition to his medical practice, Dr. Guthrie became a successful businessman, best known in his time for manufacturing chloroform, vinegar, and priming powder for firearms, which made flintlock muskets obsolete. He became the largest supplier of the powder in the United States and Canada. He also invented a process for converting potato starch into molasses, and he distilled an alcohol that was reputed to be of unequalled quality in the Jefferson County. In 1817 he had opened a vinegar manufactory for the supply of vinegar to Madison Barracks, vinegar being an antiscorbutic agent (preventing scurvy) and was also used to purify drinking water. The various business enterprises saw him withdraw from the medical side of his life.

Dr. Samuel Guthrie

His experiments with explosives, which lasted some four decades, formed the basis of his income, but were not without severe cost to himself, leaving him a virtual invalid during his final years. In one of these experiments some twenty-five pounds of half-dried powder ignited and such was the energy given off that the roof of the building was lifted and the heavy stone-work of the walls was spread out. That Guthrie survived was due to the door set to open outwards, which on bursting open lessened the effect of the explosive force.

The rifles of the time were of the flint-lock type which were time-consuming to load and to operate, at best allowing one shot per minute to be made. Here the powder and shot were loaded through the front of the barrel, primer powder was placed at the rear primer hole and ignited by a flint being struck to give a spark. In wet weather the flint often failed to spark and smouldering remains of the powder from the previous shot often led to the new powder firing spontaneously leading to damage to the handler of the weapon. This type of weapon was in use from the seventeenth century onwards and was made obsolete by the percussion cap invented by Guthrie, together with a punch lock for igniting it. This tripled or even quadrupled the rate of fire available and was naturally a great advantage in combat. Guthrie began to manufacture his powder caps in 1826. His powder was made from potassium chlorate and antimony sulphide, with shellac being used twice, once being added before the graining process and later for coating, with or without bronze, to protect the powder against dampness. The percussion cap was used extensively over the next fifty years before being replaced by the modern-day bullet.

Guthrie was involved in the 10th April 1827 establishment of the Houndsfield Library, which had, for the time, a massive 500 volumes, and he became one of the library's Trustees. He was also a shareholder in the first woollen mills established in Watertown. He did, as most non-city folk did, farm and tried out new varieties of crops, not always successfully. One of his failures was a sugar beet from French seed, planted in the hope of raising a commercial sugar crop. However, although beet of good size was obtained, the sugar content proved too little to be of use and the experiment was not repeated after the initial year. Suggestions from the *Boston Cultivator* paper saw Guthrie have his farmhands try out various new seed such as Chinese tree corn and roan potato in the years 1835 to 1840 on his land. He also produced molasses from potatoes, pure oil of turpentine and made his own potassium chlorate for his percussion powder. He was the largest supplier of the capped percussion powder to both the US and Canadian armies for many years, but the arrival of the bullet saw a steadily diminishing income.

The discovery of chloroform

The Feb.1831 issue of the Yale College *Elements of Chemistry* publication (Vol 11, pp 19-20) reported on Dutch Liquid , "chloric ether" (now known as dichloroethene $C_2H_2Cl_2$), described being made by the mixing of ethylene with chlorine. This was a dense oily liquid. In the same issue Professor Silliman pointed out that the medical aspects of this liquid had not been worked out and went on to suggest that in might well be an active diffusible stimulant.

On reading the article Guthrie immediately began experimenting using chloride of lime with alcohol. Finally, by the distillation in a clean copper still, in which three pounds of chloride of lime was placed with two gallons of alcohol of 0.844 specific gravity, he recovered one gallon of "ethereal spirit". He pointed out that the process had to be ended when the product ceased to come off highly sweet and aromatic, and then the output was closed up by corks in glass vessels. The remaining unaltered alcohol was recovered by further distillation for further use. He reported his findings in the *American Journal of Science & Arts*, Article V1, Vol. XX1, No. 2 of Sept. 12 1831. The "Dutch Liquid" that Guthrie was trying to make has the formula $C_2H_2Cl_2$ and Guthries' compound was later, 1834, named chloroform by the Frenchman Dumas (No. 9 of this series), who showed its formula to be $CHCl_3$.

His fortuitous synthesis of chloroform meant that it was later used for anaesthesia, where it replaced the current anaesthetic of choice among surgeons, which was a combination of herbal extractions and opiates. The preparations of these were not standardized and these sedatives were bitterly denounced as either being too weak to be effective or too strong, resulting sometimes in the death of the patient.

The first narcosis with chloroform was performed by James Young Simpson on himself on November 4, 1847. Chloroform was to have a widespread use in medicine, which only waned when nitrous oxide and other chemical anaesthetics were used, which although discovered before 1831, were not used in surgical applications until almost 1850. An idea of the extent of use of Chloroform can be seen from a letter from the War Department, Surgeon General's Office, Washington of May 24th 1887 to Guthrie's grandson which reads as follows: "*Mr Guthrie, Dear Sir:- the quantity of Chloroform used during the four years of the late war was* *something more than one million and a half of pounds; and since the war 8,500 pounds. Very respectfully, John Moore, Surgeon General USA."*

Guthrie did not patent his discovery and the only income derived by him from it was from the sales of chloroform in his locality.

The primacy of the discovery of chloroform was later contested by Eugène Souberian and Justus von Liebig (see *"Memoirs of Dr. Samuel Guthrie, and the history of the discovery of chloroform"*.)

Later life

Both of Guthrie's sons had moved away by 1832 and Guthrie found himself dealing with the various businesses he had set up and thus found little time for serious experimental work. For the last ten years of his life Guthrie was a virtual invalid, unable to properly oversee the businesses and unable to do any experimental work. His finances had deteriorated so much that in 1847 he sold the house in order to maintain himself, his wife having died in 1840. He died on the 19th October 1848 and was buried in the Lakeside Cemetery, Sacket's Harbor, Jefferson Co., N.Y.

The gravestone of Samuel Guthrie in Lakeside, Sacket's Harbor, N.Y.

In his leisure time he played the violin and was a keen angler and hunter. Guthrie received no honours as was the case with many of those discovering items which won their way into general usage. As a final point, historical investigation shows a distinct genealogical link between him and Sir Winston Churchill (1874-1965) of World War II fame

Some references

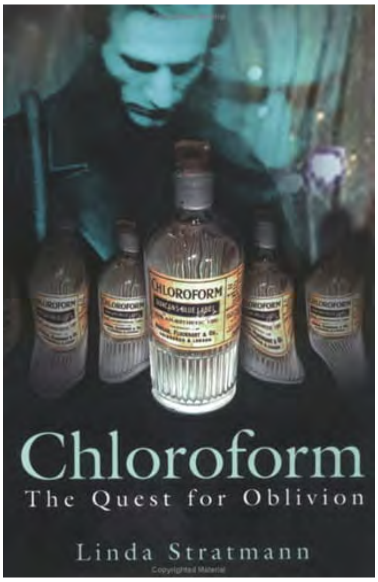
Records of the Guthrie Family by Harriet N. and Eveline Guthrie Dunn, Chicago 1898

http://www.famousamericans.net/samuelguthrie/

https://pubs.acs.org/doi/pdf/10.1021/ed017p253

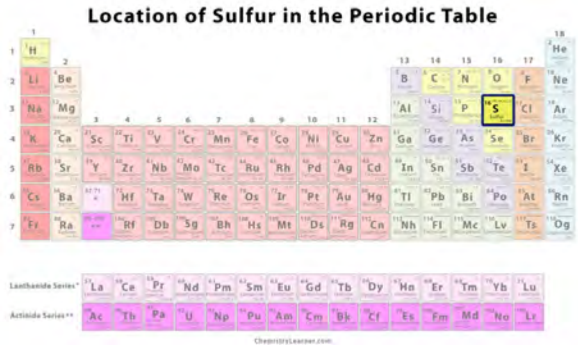
"Memoirs of Dr. Samuel Guthrie, and the history of the discovery of chloroform" O. Guthrie 1887
Full text of "Memoirs of Dr. Samuel Guthrie, and the history of the discovery of chloroform" (archive.org)

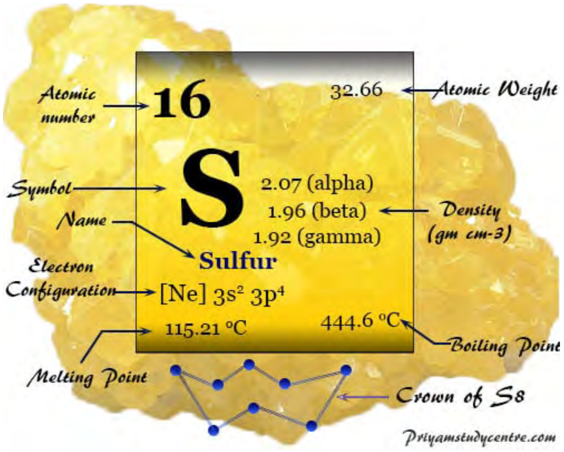
Chloroform: the quest for oblivion, L. Stratmann, 2003, Sutton Publishing



The sulfur story: devil's gold or essential element?

Sulfur (sulphur) has often had a bad press, from the fire and brimstone of the Bible (brimstone is an old name for sulfur and means burning stone), to acid rain and smelly chemicals like the mercaptans and dihydrogen sulfide. But sulfur is also an essential element in biology and in industry and has more good sides than bad. In this series we will look at some aspects of the chemistry, properties and uses of sulfur and its compounds. Sulfur is the second element in group 16, below oxygen; it is a non-metal and is widely distributed in rocks, fossil fuels and biology. See p.61 for a Chemlingo on the naming of sulphur and its compounds.





1. Sources and extraction

A recent online article on the Mining and refining of sulfur gives a good introduction to the extraction and importance of sulfur ([Mining And Refining: Sulfur | Hackaday]).

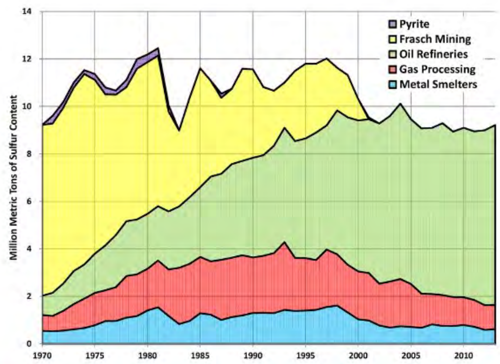
World production:
How much sulfur is produced each year and where from? World production of sulfur is ~79 million tonnes, and the top ten sources (2021) are:

Country	**/1000 t**
China	17,000
USA	8,100
Russia	7,500
Saudi Arabia	6,500
UAE	6,000
Canada	4,900
Kazakhstan	4,500
India	3,500
South Korea	3,100
Japan	3,000

[Sulfur production globally by country 2021 | Statista]

The USA was the main producer for many years but has now been overtaken by China.

World Resources: Resources of elemental sulfur in evaporite and volcanic deposits, and sulfur associated with natural gas, petroleum, tar sands, and metal sulfides, total about 5 billion tons. The sulfur in gypsum and anhydrite is almost limitless, and 600 billion tons of sulfur is contained in coal, oil shale, and shale rich in organic matter. Production from these sources would require development of low-cost methods of extraction. The sources of sulfur have changed in the last 200 years, and especially in the last 50 years, as shown in the data from the USA.



Sources of sulfur in the USA 1970-2015
By Plazak - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=43807853

Initially sulfur was found in elemental form in volcanic regions, often as surface deposits e.g. in Sicily, Indonesia (see photo below).

Menambang Belerang - Sulfur - Wikipedia
By Candra Firmansyah - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=60213157

There are a number of interesting articles online with photos and videos showing the mining of sulfur in Indonesia.

http://www.businessinsider.com/sulfur-miners-active-volcano-indonesia-dangerous-jobs-2022-1

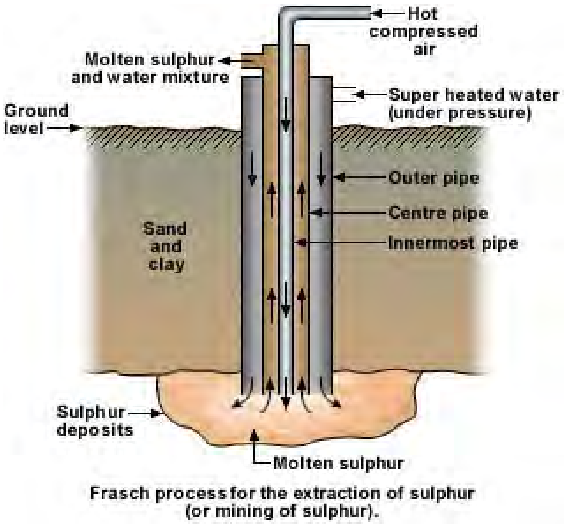
The men who mine the 'Devil's gold' - BBC Future

(483) Why Miners Risk Their Lives To Get Sulfur From An Active Volcano | Risky Business - YouTube

Solid sulfur with its familiar yellow colour.
Sulfur-sample.jpg (1925×1444) (wikimedia.org)

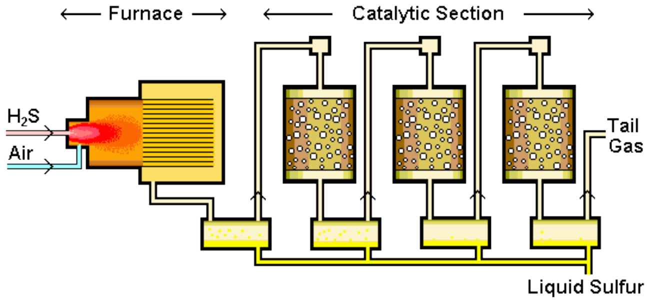
Sulfur has been known and used since antiquity, when it was obtained from volcanoes. In the late 1700s to the late 1800s most sulfur was obtained from Sicily. A trade dispute in 1840 led to the wider use of pyrites as a source of sulfur, including in Ireland where pyrite was mined in Avoca, Co. Wicklow. Metal refining from sulfide ores was and still is also a source of sulfur as sulfur dioxide, and smelters are often coupled with a sulfuric acid plant.

In 1867 sulfur was discovered in Louisiana and Texas in the USA on top of salt domes. The Frasch process for extracting pure sulfur from these deposits was invented in 1894 and led to economic sulfur production by the Frasch process from 1903 to 2000 in the USA. This is the process usually described in chemistry textbooks, but it is now obsolete.



The Frasch process for extracting sulfur from salt domes
https://www.nuroil.com/sulphur-production-and-uses.aspx

Oil and gas contain up to 6 wt% sulfur, depending on their origin, and when it is above 0.5% they are known as sour oil or gas. Removing sulfur makes them sweet. Concern in the 1970s about acid rain produced from SO_2 from burning fossil fuels, including coal, containing sulfur, led to processes for removal of sulfur as H_2S gas. This led to sulfur being produced as a by-product of fossil fuel production and it is now the dominant source of sulfur worldwide. Sulfur is converted to H_2S by partial oxidation at 1050ºC, followed by catalytic stages to complete the conversion. This is the Claus process, invented in 1883 and produces gaseous sulfur, which is condensed out to give liquid sulfur and then solid sulfur.



From sour to sweet: the Claus process for producing sulfur from H_2S
https://www.nuroil.com/sulphur-production-and-uses.aspx

Sulfur compounds in oil and gas are converted into H_2S by a process of hydrosulfurization (reaction with hydrogen gas). The H_2S is then partly oxidised in a furnace to produce SO_2, and the mixture of SO_2 and H_2S then react over a catalyst to produce sulfur.

$$2H_2S(g) + 3O_2(g) \rightarrow 2SO_2(g) + 2H_2O(g)$$

$$2H_2S(g) + SO_2(g) \rightarrow 3S(g) + 2H_2O(g)$$

At times this has produced a glut of sulfur on the market, but with the phasing out of fossil fuels in the next decades to reduce global warming, there may well be a shortage of sulfur in the face of increasing demand. The main use of sulfur is to produce sulfuric acid, over 246 Mt annually, and this is predicted to increase because of its many uses.

Sulfur recovered from hydrocarbons in Alberta, stockpiled for shipment in North Vancouver, British Columbia
AlbertaSulfurAtVancouverBC - Sulfur - Wikipedia

A recent article discusses the looming shortfall in sulfur production due to decarbonization and the decreased use of fossil fuels, and thus reduction in by-product sulfur. *The researchers estimate that this will result in a* ***shortfall in annual supply of between 100 and 320 million tonnes*** *- between 40% and 130% of current supply - depending on how quickly decarbonisation occurs.*

Mark Maslin, Livia Van Heerde, Simon Day, (2022), 'Sulfur: A potential resource crisis that could stifle green technology and threaten food security as the world decarbonises'
The Geographical Journal, 22 August 2022
The Geographical Journal - Wiley Online Library

Sulfur may be described as the devil's gold but sulfur is an essential element in industry, agriculture and biology.

In the next article we will look at the many forms of sulphur.

□

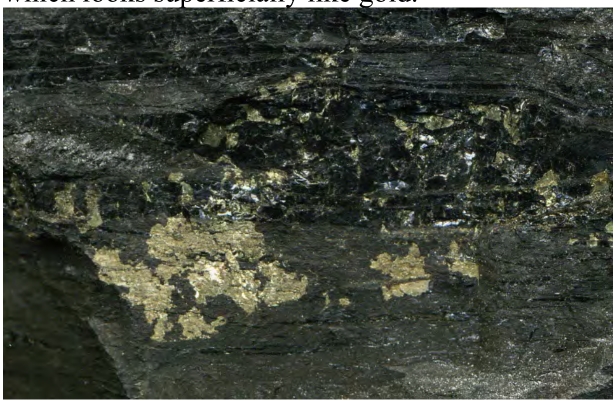
Amazing Minerals

#1 Iron pyrites, pyrite, Fool's Gold FeS_2

Cubic crystals of iron pyrites
File:2780M-pyrite1.jpg - Wikimedia Commons

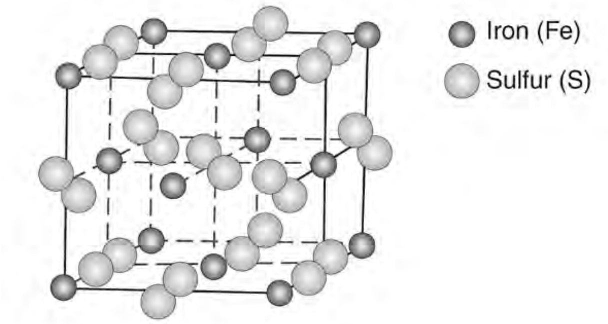
Don't be fooled by fool's gold

You may have seen specks of 'gold' in a piece of coal or quartz, and many people have been fooled into thinking this is gold, rather than fool's gold. Iron(II) disulfide, FeS_2, is a very common mineral which looks superficially like gold.



Iron pyrite in butuminous coal.
Pyrite in bituminous coal (Pennsylvanian; eastern USA) | Flickr

It is often found in coal and in rocks and its presence in concrete blocks has caused major problems with buildings in Ireland (see CinA! #118, p. 46). In the presence of air and water, FeS_2 reacts, swells and produces sulfuric acid and hydrated iron(III) oxide, rust. This leads to the cracking of the blocks and significant damage to houses. In old coal mines the presence of iron pyrites leads to the formation of acid mine water (see below). The structure of FeS_2 is given below and it contains the S_2^{2-} ion. You can see from the unit cell and the sample above, that FeS_2 forms cubic crystals.



Structure of iron pyrites, iron(II) disulfide, FeS_2
Pyrite | Indiana Geological & Water Survey

How is iron pyrites formed?

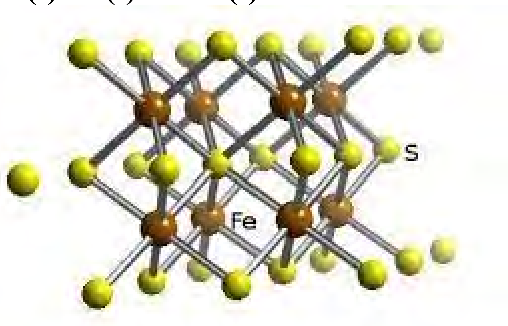
Iron pyrites is formed when iron and sulfur are present together under wet, reducing (anaerobic) conditions. It is estimated that 5 million tonnes of FeS_2 are produced each year, 90% by microbiological processes. Most organic matter contains sulfur and this is broken down by bacteria to release sulfur anions, which react with iron present to form first FeS, and then FeS_2, which is thermodynamically stable under reducing conditions.

Note that iron pyrites has a different formula and structure to the common iron(II) sulfide formed when, for example, hydrogen sulfide is bubbled into a solution containing iron(II). A black precipitate of FeS is formed, which contains the S^{2-} ion. For those chemists who did qualitative analysis at school, this was a very familiar reaction.

$Fe^{2+}(aq) + H_2S(g) \rightarrow FeS(s) + 2H^+(aq)$

A common lab experiment to illustrate the formation of a chemical compound is the reaction of iron and sulfur powders. A black, magnetic powder and a yellow powder are mixed together and heated. A reaction occurs, heat is given off and a non-magnetic black solid is formed, which reacts with acid to give dihydrogen sulfide, H_2S, with a rotten egg smell. Adding acid to the starting material liberates hydrogen gas from reaction with the iron. A new substance has been formed with very different properties. It has the formula FeS, iron(II) sulfide. Notice that this substances contains S^{2-} ions and has a different structure.

Fe(s) + S(s) → FeS(s)



Structure of iron(II) sulfide, a NiAs structure
[WebElements Periodic Table » Iron » iron sulphide]

It is called pyrite or iron pyrites from the Greek *pyrites lithos*, or stone of fire, because when struck it can cause sparks. Pyrite was used in early flint lock firearms to create the spark to ignite the gunpowder. There are other related minerals: chalcopyrite (copper iron sulfide, $CuFeS_2$), and arsenopyrite (iron arsenic sulfide, $FeAsS_2$.)

Sulfides and disulfides

Sulfur is in group 16 below oxygen and so there are similarities, and differences, in their chemistries. Sulfide is the analogue of oxide and disulphide of peroxide and each ion forms the corresponding hydride.

S^{2-}	O^{2-}	S_2^{2-}	O_2^{2-}
H_2S	H_2O	H_2S_2	H_2O_2

Reaction with acids:
Sulfide gives H_2S and the metal salt
e.g. $FeS(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2S(g)$

Oxide gives H_2O and the metal salt
These are acid-base reactions – no change in O.S.

Disulfide gives H_2S and S
$FeS_2(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + S(s) + H_2S(g)$
Peroxide gives H_2O and O_2
These are redox reactions: sulfur changes O.S. from -1 to -2 and 0 (as does oxygen in peroxide). This type of reaction is known as **disproportionation**, where one species undergoes simultaneous oxidation and reduction – an internal redox reaction.

Pyrite as a source of sulfur

In the 19th century and into the 20th century iron pyrite was used as a source of sulfur for making sulfuric acid. When heated in air (roasting) iron pyrite is converted into iron oxide and sulfur dioxide. Sulfur dioxide is then used to make sulfuric acid. Partial roasting produced elemental sulfur.

Another source of sulfur in the 19th century was volcanic sulfur from Sicily; today sulfur is obtained as a by-product of the oil industry (see p.45 for The Sulfur Story, part 1.). Ireland used to be an important source of iron pyrite from the Avoca mines for making sulfuric acid; much of it was exported but it was also used in the fertilizer and explosives industry in Arklow to make sulfuric acid. At its peak the Wicklow mines were producing 100,000 tons of pyrite per year.

[Avoca West - Mining - County Wicklow Heritage]
Ch. 6 *The Industrial Resources of Ireland* Robert Kane
[Part 6 of The Industrial Resources of Ireland (ucc.ie)]

How is iron pyrites formed?

Iron pyrites is formed when iron and sulfur are present together under wet, reducing (anaerobic) conditions. It is estimated that 5 Mt of FeS_2 are produced in nature each year and 14 Mt are mined. It is produced when sulfate and iron(II) are present in anoxic environments through the action of specialised micro-organisms (MO).

$$SO_4^{2-}(aq) \xrightarrow{MO} S^{2-}(aq) \xrightarrow{Fe^{2+}(aq)} FeS(s) \xrightarrow[H_2S]{MO} FeS_2(s)$$

Iron pyrites, FeS_2, is the thermodynamically stable form under reducing conditions.

Acid mine drainage (AMD)

Iron pyrites is widely distributed in metal ores and minerals and in coal deposits. One unwanted side-effect of both metal and coal mining is the production of acid mine water, usually after mining has stopped and the mines are allowed to fill with water. Under these conditions, helped by bacteria, iron pyrites is converted into sulfuric acid and the iron into iron(II) in solution, and then into hydrated iron(III) oxide on exposure to air, also known as ochre. Initially the pyrite dissolves to give an acid solution of iron(II) but when this meets the air, the iron(II) is oxidised to iron(III) and forms hydrated iron(III) hydroxide. The process is speeded up by the presence of micro-organisms. Acid mine drainage (AMD), as found in the Avoca River, lowers the pH of the river and turns the river orange from the hydrated iron(III) oxide, which coats the bottom of the river. The acid water also mobilises other unwanted metals and AMD is a major environmental issue for old mines.

$FeS_2 + 3.5O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$

$4Fe^{2+} + O_2 + 4H^+ \xrightarrow{MO} 4Fe^{3+} + 2H_2O$

$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$

In a final step when the AMD meets excess water and air, solid $Fe(OH)_3$ is formed as a yellow precipitate.

$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$

The pyrite problem: Pyrite and Construction Projects

The current pyrite problem in Ireland due to the presence of pyrite (and mica) in building blocks was covered in CinA! #118, Autumn 2021, p, 46, A brief summary is given below.

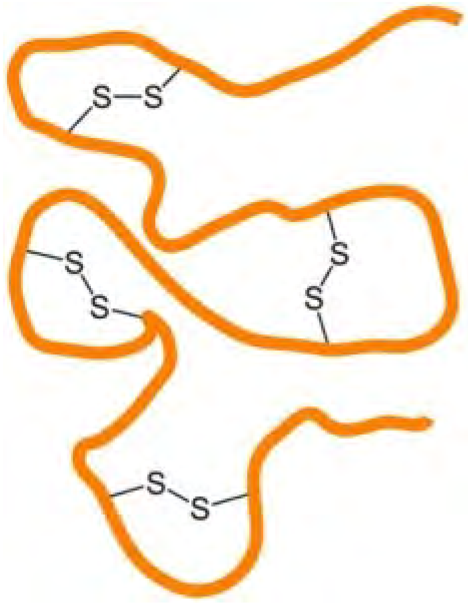
Crushed stone *used to make concrete, concrete block, and asphalt paving materials must be free of pyrite. Pyrite will oxidize when it is exposed to air and moisture. That oxidation will result in the production of acids and a volume change that will damage the concrete and reduce its strength. This damage can result in failure or maintenance problems.*

Pyrite should not be present in the base material, subsoil or bedrock under roads, parking lots, or buildings. Oxidation of pyrite can result in damage to pavement, foundations, and floors. In pArts of the country where pyrite is commonly found, construction sites should be tested to detect the presence of pyritic materials. If pyrite is detected, the site can be rejected or the problem materials can be excavated and replaced with quality fill.

Pyrite Mineral | Uses and Properties (geology.com)

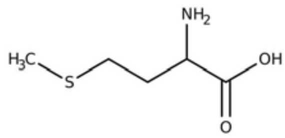
Disulphide bond in biology

Sulfur is an essential element in biology and is contained in all living things. The -S-S- linkage is quite common in many proteins, for example in linking molecules in hair, responsible for the tertiary structure of proteins.

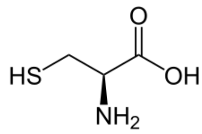


Disulfide Bond in Protein.
Image Credit : Wikimedia Commons

Sulfur is a primary constituent of two important amino acids, methionine and cysteine.



L-methionine



L-cysteine

Sulfur is present in all the cells and extracellular compartments as part of the AAs cystine, cysteine, and methionine. The covalent bonding of sulfhydryl groups between molecules forms disulfide bridges, which are responsible for the tertiary structure of proteins necessary for the function of certain enzymes, insulin, and other proteins. Sulfur is a component of heparin, chondroitin in bones and cartilage, thiamin, biotin, pantothenic acid, and S-adenosyl methionine (SAM-e). It also is a part of glutathione, an important antioxidant. Sources of sulfur include animal proteins, legumes, broccoli, and nuts.

Mary Loo *Integrative Medicine for Children*, 2009

Current uses of iron pyrites

Despite pyrite not being a major source of sulfur or sulfur dioxide nowadays, it is still an important mineral and around 14 Mt are produced each year. Since the production of sulfur from oil and gas is predicted to drop dramatically due to decarbonization, pyrite may come back into its own as a major sulfur source in the future as the demand for sulfuric acid is set to grow. But iron pyrites has other uses, some of which are listed below.

1. In the glass industry to produce amber glass, which helps to protect the contents from spoilage by UV light.
2. To make vehicle brake pads
3. To make grinding wheels.
4. Used in making PV solar cells, as it is a semiconductor.
5. Source of sulfur in making iron more malleable.
6. As a gemstone to make jewellery, often called marcasite.
7. As a source of gold as it often contains 0.25% or more of tiny gold inclusions.
8. In Li-S batteries as an electrocatalyst.

Some further reading:

Pyrite: a natural history of Fool's Gold, David Rickard, OUP, 2016

Pyrite: The Real Story Behind "Fool's Gold" (thermofisher.com)

The Many Faces of Fool's Gold | American Scientist

□

In the next issue:
Amazing Minerals #2 Quartz

The death-knell of phlogiston

About eight days ago I discovered that sulfur in burning, far from losing weight, on the contrary, gains it; it is the same with phosphorus; this increase of weight arises from a prodigious quantity of air that is fixed during combustion and combines with the vapors. This discovery, which I have established by experiments, that I regard as decisive, has led me to think that what is observed in the combustion of sulfur and phosphorus may well take place in the case of all substances that gain in weight by combustion and calcination; and I am persuaded that the increase in weight of metallic calxes is due to the same cause... This discovery seems to me one of the most interesting that has been made since Stahl and since it is difficult not to disclose something inadvertently in conversation with friends that could lead to the truth I have thought it necessary to make the present deposit to the Secretary of the Academy to await the time I make my experiments public.

Antoine-Laurent Lavoisier

Sealed note deposited with the Secretary of the French Academy 1 Nov 1772. Oeuvres de Lavoisier, Correspondance, Fasc. II. 1770-75 (1957), 389-90. Adapted from translation by A. N. Meldrum, The Eighteenth-Century Revolution in Science (1930), 3.

□

Chemical Myths Exploded!

In this series we are looking at some areas of chemistry where there are common student misconceptions/alternative conceptions. These often come from the way the chemistry is taught or represented in books. Unfortunately, misconceptions can be hard to eradicate and it is best for the teacher to recognise what they are, to uncover students' ideas about them and deliberately target them.

#5 Electrochemistry

Electrochemistry is a topic which students find difficult and one which is rife with misconceptions, at second and at third level. It is an important topic in LC chemistry and it is important that teachers are familiar with the major misconceptions in this area. Much research has been done over the years on student misconceptions in electrochemistry. This article is a revision course in electrochemistry, that goes beyond LC level, but picks up some of the most common misconceptions.

Redox reactions

Redox reactions involve an exchange of electrons between two chemical species.

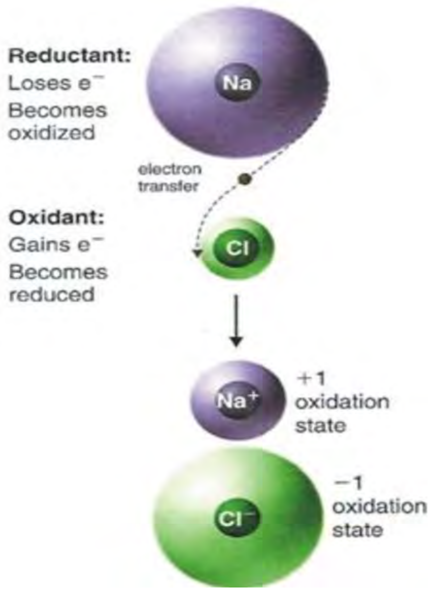
Oxidation involves a loss of electrons; reduction involves a gain of electrons. Oxidation and reduction always happen together whether in a test-tube or in an electrochemical cell.

Mnemonic: **OIL RIG**

The diagram below illustrates this process: a reductant loses electrons to the oxidant and is oxidized; an oxidant gains electrons from the reductant and is reduced.

In oxidation the oxidation state/number increases (more positive). In the reaction below sodium goes from O.S. 0 to O.S. +1 (loss); chlorine goes from O.S. 0 to O.S. -1 (gain).

In reduction the oxidation state/number decreases (more negative).



In balancing redox equations, we must first balance the electrons transferred before balancing the number of atoms or charge. The number of electrons lost and gained must be the same. N.B. acid-base reactions and complexation reactions are not redox reactions.

Electrochemical reactions always involve redox reactions, whether in an electrolytic cell or a voltaic/galvanic cell.

What is electrochemistry?

Electrochemistry is that branch of chemistry which looks at the production of electrical energy from chemical reactions (emf cells, batteries, fuel cells) and the effect of electricity on chemicals (electrolysis).

Chemical and electrical energy can be interconverted in electrochemical cells and the connection between them is the Gibb's free energy.

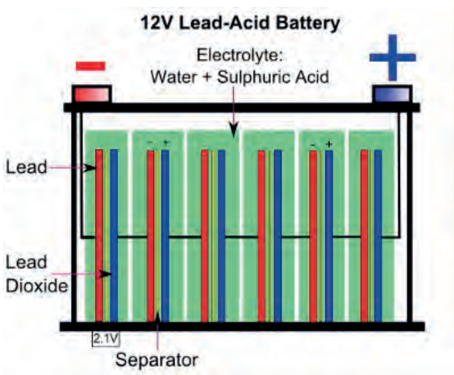
The equation below connects thermodynamics and

$$\Delta G^o = - nE^oF$$

electrochemistry.

E^o is the standard electrode potential of an electrochemical cell, in which a chemical reaction occurs for which ΔG^o is the free energy change. n is the number of electrons transferred and F, the Faraday, is the conversion factor from volts to joules. A spontaneous reaction requires a negative ΔG^o and corresponds to a positive E^o. A voltaic or galvanic cell is a free energy convertor, which converts the free energy of a chemical reaction inside the cell into electrical energy (a voltage).

We loosely talk about batteries, but a battery is correctly several electrochemical cells wired together to produce a bigger voltage. A lead-acid car battery is made of 6 2V cells. The 1.5 V AA batteries used in a torch are a single cell.



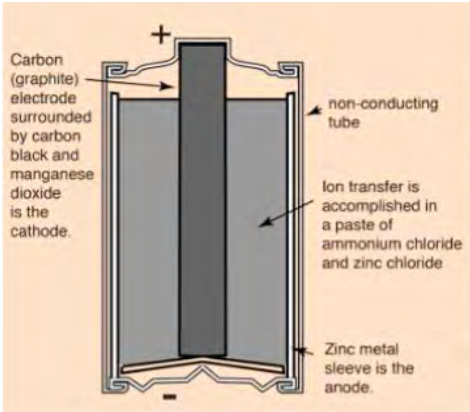


Figure 1: a) a lead-acid battery b) a single carbon-zinc cell

a) [Lead Acid Battery construction and working principle - EngineersWorld]

b) [Batteries (gsu.edu)]

Interestingly the lithium car batteries used in electric cars and battery storage modules are made up of many individual, small lithium cells wired in series, although a mix of series and parallel is also used. In series increases the voltage; in parallel increases the capacity of the battery.

In the early work on electrochemistry these were called electrochemical piles, because they used a pile (or stack) of metal plates interleaved with paper soaked with electrolyte (Figure 2.)

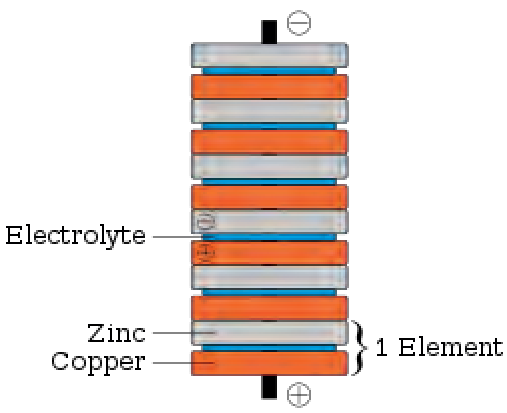


Figure 2: An electrochemical pile
[Voltaic pile - Wikipedia]

Different types of electrochemical cells

There are two types of electrochemical cell:
electrolysis (electrolytic) cells and
voltaic or galvanic cells, also known as emf cells.
This reaction takes place in an electrochemical cell, see below.

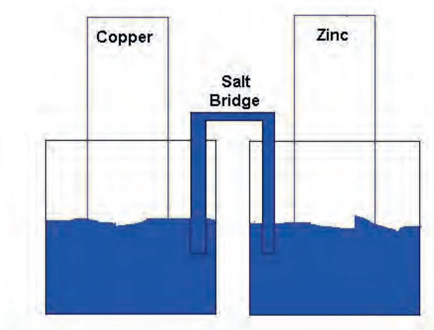


Figure 3: A typical electrochemical cell with a salt bridge (Daniell cell)

All electrochemical cells must have the following:

- **two electrodes,**
- **an electrolyte (and container),**
- **an external circuit.**

Nothing happens if any one of these is missing.

This is the reason that we can store batteries in a shop or at home for years without them losing their charge. Until the terminals are connected and a circuit completed, nothing can happen. When the electrolyte is a solid or a paste they are often called **dry batteries**, whereas the lead-acid battery is a **wet battery**, with a liquid electrolyte.

MISCONCEPTION # 1

Confusion between electrolytic cells and galvanic/voltaic cells because both have two electrodes and an electrolyte.

An electrolytic cell consumes energy (electrons) from outside which produces a chemical change at the electrodes.

A voltaic/galvanic cell produces energy (electrons) from the chemical reaction occurring at the electrodes.

An emf cell is a voltaic cell from which no current is drawn so that it has the maximum allowed potential.

A fuel cell is a voltaic cell where the chemical reactants are supplied from outside the cell, rather than being contained within the cell. Theoretically a fuel cell can run forever as long as fuel is supplied.

In an **emf cell/battery/fuel cell** (also known as galvanic or voltaic cells) the chemical reaction in the cell generates electricity, which flows through the external circuit and can be made to do work e.g. light a bulb, run a radio etc. The free energy change of the chemical reaction is converted into electrical energy in the cell. In an emf cell we measure the equilibrium cell voltage without drawing any current (energy) and this thus represents the maximum voltage attainable. In practice as we draw current from a cell, reaction happens, and the voltage drops as it discharges and eventually falls to zero – we then say the cell has gone 'flat' and needs either recharging or throwing away. An electrochemical cell is a free energy converter!

In an **electrolysis cell**, electricity is supplied from outside the cell and flows through the cell causing a chemical reaction and consuming energy, e.g. in electroplating metals, the production of aluminium, the production of chlorine.

In a **rechargeable** (**secondary**) cell, charging the cell by putting electrons back into the cell, reverses the chemical reaction, recharging the cell. The cell then produces electricity when the cell is reused, and converts it back into its uncharged state. Lithium batteries in phones and laptops are rechargeable batteries. So a rechargeable cell alternates between electrolysis (charging) and voltaic (discharging.)

A **primary** cell is a single-use cell which cannot be recharged.

N.B. although cell and battery are used interchangeably in everyday life, a battery is technically something like a car battery which contains several cells joined together.

One point of confusion and misconception between voltaic cells and electrolysis cells, which are the opposite of each other, is the labelling of the electrodes as anode and cathode. In the two different cells anode and cathode have opposite signs, but the definition is **not** in terms of their sign but in terms of the process occurring:

Oxidation occurs at the ANODE (loss of electrons)

Reduction occurs at the CATHODE (gain of electrons)

This reminds us that the process occurring in an electrochemical cell is a redox process.

Electrolysis cells:

- Energy supplied from outside the cell
- Ions move towards the electrodes and are discharged:
- Cations move to the negative electrode and anions move to the positive electrode
- Consumes energy as the cell reaction is non-spontaneous, ΔG^o is positive
- Anode is positive (oxidation) and cathode is negative (reduction)

Cell reaction:

$X^{z-}(aq) \rightarrow \frac{1}{2} X_2(g) + ze^-$ $M^{z+}(aq) + ze^- \rightarrow M(s)$

Voltaic (emf, galvanic) cells:

- Produces energy as cell reaction is spontaneous, ΔG^o is negative

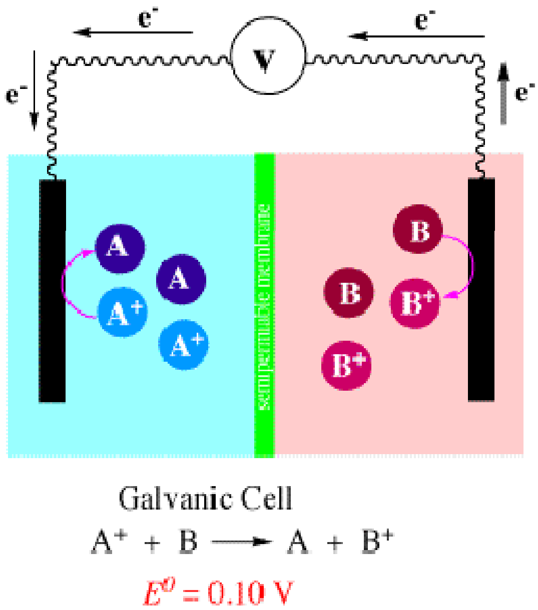
- Electrons are produced at the anode (negative) and move through the external circuit to the cathode (positive) and can do work on the way
- Chemicals in the cell react at the electrodes liberating energy

Cell reaction:

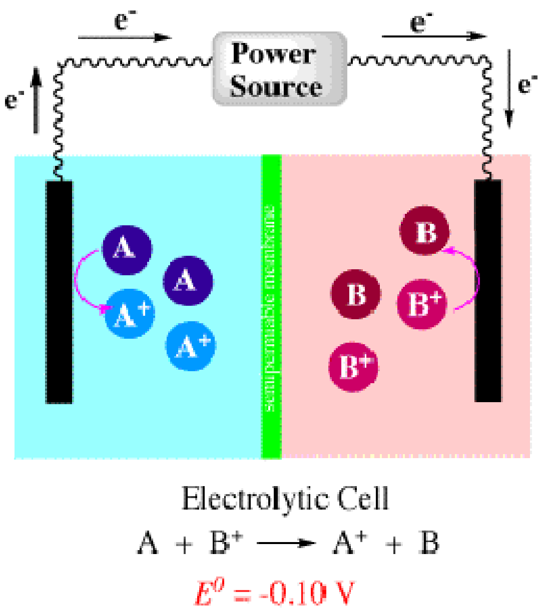
$\frac{1}{2} X_2(g) + ze^- \rightarrow X^{z-}(aq)$ $M(s) \rightarrow M^{z+}(aq) + ze^-$

N.B. the different signs of anode and cathode and the reversed reactions and the opposite flow of electrons in the external circuit.

Voltaic/emf cell



Electrolysis cell



Reduction	**Oxidation**	**Oxidation**	**Reduction**
CATHODE	**ANODE**	**ANODE**	**CATHODE**
Positive	**Negative**	**Positive**	**Negative**

A rechargeable cell switches from being a voltaic cell on discharge to an electrolysis cell on charging. It is thus a reversible cell. Single use cells are irreversible.

MISCONCEPTION # 2
The terms anode and cathode do not refer to the charges on the electrodes.

The terms anode and cathode refer to the process occurring not the charge – the anode (oxidation) is positive in electrolysis and negative in voltaic cells, and the cathode (reduction) is negative in electrolysis, positive in voltaic cells.

Types of electrical conductivity

MISCONCEPTION # 3
Current can only be carried by electrons in cells and is thus carried through the cell by electrons.
Current can be carried by electrons or by ions. In an electrochemical cell, electrons carry current in the outside circuit and ions carry current within the cell between the electrodes.

There are two types of electrical conductivity: **electronic conduction** where current is carried by electrons, e.g. in a wire. This is how current is carried between electrodes outside the cell. Current can also be carried by ions in ionic solutions or in solid ionic conductors by the movement of ions. Current is carried across the cell between electrodes by the movement of ions (NOT electrons.) This is called **ionic conduction.**

Standard electrode potentials, E°

A certain free energy change and electrode potential is associated with a given couple, e.g. Na+/Na, known as a half cell and corresponding to a half-reaction. It is called a half-reaction because it is only half of a full redox reaction. Two half-reactions must be combined to produce a redox reaction (see below).

$Na^+(aq) + 1e^- \rightarrow Na(s)$; $E^\circ = -2.71$ V ($\Delta G^\circ = +1 \times 2.71 \times 96500$J)

The positive sign for ΔG^o tells us that the spontaneous, favoured reaction, is the reverse of that written. A negative E^o means that the reverse reaction is favoured i.e. sodium metal wants to lose electrons to form sodium ions – this is the thermodynamically favoured reaction. Sodium metal is a reducing agent (reductant) and in the process is oxidized forming sodium ions.

Standard electrode potentials are reduction potentials (electrons are gained and occur on the LHS of the half-reaction) measured under standard conditions – 25ºC, 1 atm pressure and 1M concentration, relative to the standard hydrogen electrode (0.00 V)..

For a typical non-metal like fluorine:
$\frac{1}{2} F_{2}(g) + 1e^- \rightarrow F^-(aq)$; $E^o = +2.87$ V
($\Delta G^o = -1 \times 2.87 \times 96{,}500$ J)

This means that fluorine wants to gain electrons to form fluoride ions and is an oxidising agent (oxidant) and in the process is reduced to fluoride ions.

We can see that metals and non-metals are the opposite to each other – metals tend to lose electrons and non-metals tend to gain electrons. We can put these two half-equations together to make a balanced redox equation, making sure that the number of electrons in reduction equals that in oxidation. A viable cell reaction will have an overall positive E^o and negative ΔG^o.

$\frac{1}{2} F_{2}(g) + 1e^- \rightarrow F^-(aq)$; $E^o = +2.87$ V

We must reverse the Na^+/Na half-reaction, reversing the sign of E^o.

$Na(s) \rightarrow Na^+(aq) + 1e^-$; $E^o = +2.71$ V

We can now add these two equations and as 1e- is involved in each half-reaction we can also add the electrode potentials.

$\frac{1}{2} F_{2}(g) + Na(s) \rightarrow NaF(aq)$; $E^o_{cell} = +2.87+2.71 = +5.58$V

The size of E^o_{cell} tells us that this is a highly favoured reaction between a strong reducing agent and a strong oxidising agent. A table of standard electrode potentials gives us the electrochemical series (see below).

Standard cell voltages, E^o_{cell}

A spontaneous redox reaction (ΔG^o negative) can be broken into its two half-reactions and assembled in an electrochemical cell, with two half-cells joined (where necessary) by a salt bridge.

The voltage of the cell is a measure of the driving force for the reaction or spontaneity of the cell reaction and is the free energy change measured in volts.

The cell voltage depends on:

a) the nature of the cell reaction (the two half-reactions),

b) the concentration of the chemicals in the cell.

The standard cell voltage, E^o_{cell}, is measured at 1M concentrations (strictly at unit activity), gases at 1 atm pressure, relative to the hydrogen electrode (taken as zero).

An electrochemical cell is written in this way:

e.g. **$Zn|Zn^{2+}||H^+|H_2,Pt$; $E^o = +0.76$ V**

1M 1M 1atm

The single vertical line | represents a phase boundary (e.g. solid/solution) and the double vertical line represents the salt bridge || linking the two half cells (two phase boundaries).

The cell reaction, written from L to R is:

$Zn(s) + 2H^+(aq,1M) \rightarrow Zn^{2+}(aq,1M) + H_2(g,1\ atm)$

This is made up from two half-cells, one an oxidation and one a reduction.

1) $Zn(s) \rightarrow Zn^{2+}(aq,1M) + 2e^-$; E^o_{ox} $(Zn|Zn^{2+}) = +0.76$V

2) $2H^+(aq,1M) + 2e^- \rightarrow H_2(g,1\ atm)$; E^o_{red} $(2H^+|H_2) = 0.0$V

For the overall reaction: $E^o = E^o_{ox} + E^o_{red} = 0.76 + 0.0 = 0.76$ V

MISCONCEPTION # 4
Half-cell voltages can always be added when combining two half-cells to give a complete cell reaction.
When we add two half-equations with the same number of electrons their voltages add, as we are effectively adding free energy changes. In general, free energy changes are additive but electrode potentials are per electron and are not always additive. Thus doubling an equation does not affect E^o but doubles the free energy change.

MISCONCEPTION # 5

It is possible to measure the electrode potential for an individual half-cell.
We can only measure a cell voltage not the voltage of an individual electrode. In order to separate out individual half-cell voltages we must use a reference electrode and measure relative to it.

We cannot measure half-cell voltages directly only cell voltages, so they are all measured relative to the standard hydrogen electrode taken as zero.
i.e. E^o_{red} ($2H^+_{aq}$→H_{2g}) is fixed as 0.00 V.

Thus: $E^o_{ox}(Zn|Zn^{2+})$ = E^o_{cell} - $E^o_{red}(H^+|H_2)$ = 0.76 – 0.00 = +0.76 V

This is why hydrogen occurs in the middle of the electrochemical series.

The positive value tells us that zinc metal is a reducing agent and tends to lose electrons producing zinc ions. By measuring the cell voltages of different cells compared to hydrogen, we can draw up a table of standard potentials for different half-cells. These are known as **standard electrode potentials**. They are given as reduction potentials. Thus metals typically have negative electrode potentials and non-metals have positive electrode potentials. Noble metals like copper, silver and gold have positive electrode potentials. (Oxidation potentials have the opposite sign to reduction potentials.)

The standard electrode potential $E^o_{red}(Zn^{2+}|Zn)$ = - $E^o_{ox}(Zn|Zn^{2+})$ = -0.76V

N.B. reversing a half-reaction changes the sign of E° but doubling or halving the reaction does not change E° as it is the energy change/electron transferred. Energies are always additive but voltages are not.

The arrangement of standard electrode potentials in order of decreasing E^o_{red} is known as the **electrochemical serie;** metals, the most negative are usually given at the top and non-metals, the most positive, are at the bottom (see Table 1.)

As the standard electrode potential become more **negative** the metals become **more reducing,** i.e. they lose electrons more easily, as the reverse reaction is the favoured reaction.

e.g. $Na^+(aq) + e^- \rightarrow Na(s)$; E^o ($Na^+|Na$) = -2.87 V

← favoured reaction is loss of electrons

A negative E° means that the backward reaction is favoured.

As the standard electrode potential becomes more positive the non-metals become more oxidising, i.e. they gain electrons more easily and the forward reaction is the favoured reaction.

e.g. $F_2(g) + 2e^- \rightarrow 2F^-(aq)$; $E^o(F_2|F^-)$ = + 2.87 V

favoured reaction is gain of electrons →

A positive E° means that the forward reaction is favoured.

Thus metals and non-metals are at opposite ends of the electrochemical series and have opposite properties.

See the below for a table of standard electrode potentials and the electrochemical series.

Table 1: Standard electrode potentials

Oxidizing Agent	Reducing Agent	E°/V
$Li^+ + e^-$ =	Li	-3.04
$Na^+ + e^-$ =	Na	-2.71
$Mg^{+2} + 2e^-$ =	Mg	-2.38
$Al^{+3} + 3e^-$ =	Al	-1.66
$Zn^{+2} + 2e^-$ =	Zn	-0.76
$Fe^{+2} + 2e^-$ =	Fe	-0.41
$Sn^{+2} + 2e^-$ =	Sn	-0.14
$Pb^{+2} + 2e^-$ =	Pb	-0.13
$2H^+ + e^-$ =	H_2	-0.00
$Cu^{+2} + 2e^-$ =	Cu	+0.34
$I_2(s) + 2e^-$ =	$2I^-$	+0.54
$Ag^+ + e^-$ =	Ag	+0.80
$Hg^{+2} + 2e^-$ =	Hg	+0.85
$Br_2 + 2e^-$ =	$2Br^-$	+1.07
$O_2 + 4H^+ + 4e^-$ =	$2H_2O$	+1.23
$Cl_2 + 2e^-$ =	$2Cl^-$	+1.36
$F_2 + 2e^-$ =	$2F^-$	+2.87

The electrochemical and activity series

MISCONCEPTION #6:
The electrochemical series and the activity(displacement) series are not the same.
The electrochemical series ranks the elements and redox couples in order of their equilibrium voltages (i.e. reflects ideal behaviour). The activity series ranks the elements in order of reactivity and this is affected by kinetic factors, not just thermodynamics. Thus some elements are 'out of place' in the activity series.

The electrochemical series and the activity series of elements are often confused. **They are not the same, but are similar.** The electrochemical series arranges the elements in order of their electrode reduction potentials. It refers to standard conditions and only considers thermodynamics – what should happen. In

practice, in the laboratory, the elements don't always react as the electrochemical series predicts and the activity series ranks the elements according to their activity (reactivity). A metal higher up the table should displace a metal lower down the series; thus zinc will displace copper from solution. A non-metal lower down the series should displace a non-metal higher up the series; thus chlorine will displace bromine and iodine from solution. The displacement series is one version of the activity series.
The alkali metals are a good example of the difference between the electrochemical series and the activity series.

Table 2: Group 1 electrode potentials

	$E^o(M^+/M)/V$
Li	-3.24
Na	-2.90
K	-3.12
Rb	-3.08
Cs	-3.08

Their electrode potentials are very similar and lithium should be the most reactive, with little difference between the bottom three elements. In fact the activity series is:

Li<Na<K<<Rb<<Cs

(See the YouTube video [(597) Alkali metals in water - Chemical elements: properties and reactions (1/8) - YouTube]

There is a dramatic increase in reactivity down the group due to kinetic factors, which outweigh the thermodynamics.)

Concentration and cell voltage – the Nernst equation

In a chemical reaction, if the concentration of the reactant increases or that of the product decreases, then the reaction shifts to the right and E^o becomes more positive, i.e. the reaction is more favoured (Le Chatelier's principle).

If the concentration of the reactant decreases or that of the product increases, the reaction shifts to the left and E^o becomes less positive, i.e. the reaction is less favoured (Le Chatelier's principle).

This behaviour is expressed in the Nernst equation.
For a reaction: $aA + bB \rightarrow cC + dD$

$$E = E^o - \frac{0.0591}{n} \log_{10} \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

E^o is the standard cell voltage and [X] represents the concentration of the various species in the cell reaction. You can recognise in this equation the equilibrium constant for the cell reaction.

This is an important equation. It says that the measured cell voltage, E, changes as the concentration of the chemical species changes. This equation is the basis of the pH electrode used in the pH meter and ion-selective electrodes, whose voltage changes with the concentration of ions (see Figure 4.)

Figure 4: Structure of a pH electrode
[**Glass Electrode - pH Measurement (priyamstudycentre.com)**]

The equation also explains why the cell voltage falls off as a cell is discharged and the chemicals get used up.

What is a concentration cell?

All electrochemical cells must have two electrodes and an electrolyte (with ot without a salt bridge) connecting them, as well as an external circuit. **Do both electrodes have to be different in a voltaic cell?** They usually are, as in the Daniell cell above (zinc and copper electrodes), and the difference between the two electrodes produces the cell voltage (~1.1 V in a Daniell cell.)

However, a voltage can also be produced if the electrodes are the same but with two different electrolyte concentrations in the two pArts of the cell. The driving force is the free energy difference between two different concentrations, so that they try to become equal. This is a reminder that the cell voltage and the electrode potential depends on concentration. Different concentrations, mean different half-cell voltages.

In Figure 5 we have an example of a silver ion concentration cell. One side of the cell contains a low concentration of silver ions (determined by the solubility of AgCl) and the other contains 1.0 M $AgNO_3$(aq). The difference in concentration produces a voltage. If the two [Ag+] in each side was the same, the voltage would be zero.

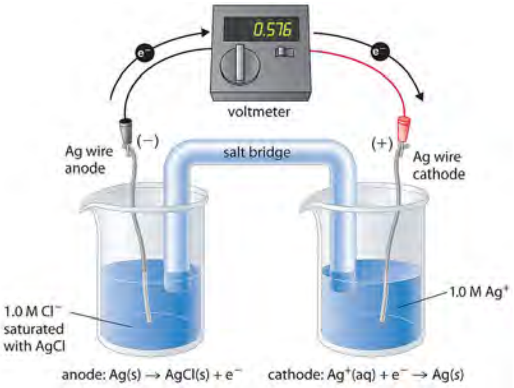


Figure 5: A silver concentration cell
[Difference Between Concentration Cell and Chemical Cell | Compare the Difference Between Similar Terms]

What is the purpose of a salt bridge?

In Figure 3 you will notice a salt bridge joining the two halves of the cell, allowing ions to move and an electrical connection to be made, but without direct physical mixing of the two compartments. In the original Daniell cell, a familiar school demonstration, a porous pot is used to separate the two halves of the cell (Figure 6).

Figure 6: Some original Daniell cells with a porous pot separating the two halves.
[NMAH-Daniell cell batteries 1836 - Daniell cell - Wikipedia]

A salt bridge can consist of a glass tube filled with an electrolyte gel, a porous plastic or ceramic separator, or a strip of filter paper soaked in a neutral electrolyte.

There are misconceptions about its purpose and function. The earliest voltaic piles had no salt bridge and it is not always needed. It serves to keep the two half cells separate and stops the chemical mixing, when this would cause problems. The salt bridge contains ions which can move and so its main function is to allow ions to move and preserve charge balance, as on discharge ions are produced and consumed at the electrodes.

MISCONCEPTION #7
The function of the salt bridge is to supply electrons to complete the circuit.

The salt bridge supplies ions not electrons, allowing charge to flow through the cell. The primary function is to complete the circuit so that charge can flow from one half-cell to the other. Without a salt bridge nothing would happen. The second is to balance the mass by allowing anions to move to the half-cell where additional cations are being produced.

Ideally, but not necessarily, the anion in the salt bridge would be the same as the anion in the half-cells. For instance, if the solutions surroundings the Zn and Cu electrodes were zinc sulfate and copper (II) sulfate, then the salt bridge would be filled with potassium sulfate. But just about any soluble salt will work in a salt bridge, as long as there are mobile but chemically inert ions. The salt used should not react directly with other cell chemicals and ideally the two ions should move at equal spends (equal transport numbers). Potassium nitrate solution is often used in salt bridges.

If any misconceptions or problems in electrochemistry are not covered in this article, or if you have questions about any other topic, please contact [peter.childs@ul.ie].

Chemlingo: Sulphur or sulfur?

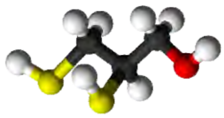
Peter E. Childs

When I was learning chemistry and for the first half of my career, sulphur was the name of element #16 and sulfur was confined to American textbooks. Since 1990 the preferred spelling by IUPAC, the body which approves chemistry's nomenclature, has been sulfur and this name was approved by the Royal Society of Chemistry in 1992. This caused a lot of controversy at the time amongst English chemists (see [Return of sulphur - MyRSC].) The name comes from the Latin *sulfur* which became in Middle English *sulphur* via Anglo-Norman s*ulfre*. The heat generated by this change has now died down and sulfur is now universally accepted as the English name. In English it replaced the old term brimstone, meaning burning stone, as in the phrase 'fire and brimstone'.

The Greek called sulfur *theion*, with the sense of the divine or divine fire, which was used for sulfur, from which we get the alternative prefix for sulfur compounds, thio-, as in thiosulphate and thiol for the -SH group. Thio- is used for compounds where S has replaced oxygen; so thiol, -SH compared to -ol, -OH. Thiosulfate has a sulfur replacing one oxygen in sulfate. A chemical reaction where oxygen is replaced by sulfur is known as thionation or thiation.

Thio- should not be confused with theo-, as found in theobromine and theophylline, although they have a common origin in Greek. The prefix *theo*- means God (as in theology) and theobromine is the food of the gods, obtained from the genus of the cacao tree, *Theobroma*, from which we get chocolate. The presence of theobromine in chocolate is why you shouldn't give it to dogs. Theophylline is an isomer of theobromine and is found in tea leaves.

What is the difference between methanethiol and methyl mercaptan? There is no difference as they are alternative names for CH_3SH, which is a sulfur analogue of CH_3OH, methanol. The name mercaptan was first used by the Danish chemist William Christopher Zeise in 1832 for compounds containing -SH, from the Latin *mercurium captans*, mercury capturer, because of their ability to bond with and capture mercury. A chelating agent containing sulfur, bimercaprol British anti-Lewisite), is used to treat mercury and heavy metal poisoning.



2,3-Dithiopropanol (dimercaptrol)

Methyl mercaptan has a disgusting smell and is responsible for bad breath and the smell of human waste and flatulence. It is added in small concentrations (<10 ppm) to natural gas to make it smell so that gas leaks can be detected. It is also used to synthesise methionine, an essential amino acid.

Thiols are found in many common foodstuffs, such as broccoli, sprouts, onions, garlic, meat and dairy products etc., and sulfur is essential in our diet. All living things contain sulfur and when organic matter dies and is transformed over millennia into fossil fuels, they always contain sulfur. Dihydrogen sulfide and mercaptans are found as impurities, in varying concentrations, in natural gas and oil and must be removed before use, as burning them produces sulfur dioxide and contributes to air pollution and acid rain. They are removed in the processing of oil and gas and are now the major source of sulfur.

Chemical Quotations:
Dorothy Hodgkin (1910-1994)

http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1964/

"I used to say the evening that I developed the first x-ray photograph I took of insulin in 1935 was the most exciting moment of my life. But the Saturday afternoon in late July 1969, when we realized that the insulin electron density map was interpretable, runs that moment very close."

Diary

2022

ChemEd-Ireland 2022
15 October
TUS Limerick
Marie.walsh@tus.ie

2023

ASE Annual Conference
5-7 Jan.
Sheffield Hallam University, UK
ASE Annual Conference 2023 at Sheffield Hallam University | www.ase.org.uk

ISTA Annual Conference
31 March/1 April
TUS Limerick
ISTA Annual Conference Branch Rota – Irish Science Teachers' Association

Chemistry Education Research and Practice
Gordon Research Conference
"Coordinating the Production and Consumption of Knowledge on Chemistry Teaching and Learning"
9 – 14 July
2023 Chemistry Education Research and Practice Conference GRC

ChemEd 2023
23-27 July, 2023
University of Guelph, Canada
ChemEd 2023 – calling all chemistry educators (uoguelph.ca)

ChemEd-Ireland 2023
'Green chemistry and the classroom'
21 October
Department of Chemistry, TCD
John.o'donoghue@tcd.ie

Information Page

Sponsors
The sponsors whose logos are featured on the outer back cover give donations of between €250 to €1,600 per year to enable the production and distribution of *Chemistry in Action*! free of charge to Irish Chemistry teachers. Some of these sponsors have been supporting the magazine since the first issue, and have helped to ensure its survival over the last 40+ years. Their help is much appreciated.

*****

Contributions wanted!
Contributions are always welcome to *Chemistry in Action!* providing the material is of interest to second-level chemistry teachers. Articles, experiments/ demonstrations, teaching tips, book and AV reviews etc. are all welcome. Send by email as a Word document when submitting material. Do not embed diagrams, photos or tables but just insert between paragraphs.

You can contact the editor by email at: peter.childs@ul.ie or one of the assistant editors.

*****

Internet version
The most recent back issues plus some TY Science modules and other resources are available at:
www.cheminaction.com
For information contact the web editor, Maria Sheehan at mariasheehan400@gmail.com

*****

Editorial correspondence
To communicate with the editor for any reason, please use the following information:
Dr. Peter E. Childs
Hon. Editor
E-mail: peter.childs@ul.ie
Communications in e-mail are preferred.
You can also send contributions to one of the assistant editors:
Marie Walsh
marie.walsh@lit,ie
Maria Sheehan (web editor)
mariasheehan400@gmail.com
Sarah Hayes sarah.hayes@ul.ie
Anne O'Dwyer
anne.odwyer@mic.ul.ie

*****

TY Science Modules
We have discontinued selling these modules in print, as postage got too expensive. At present 6 of them are available online, free of charge, at our website:
www.cheminaction.com
We hope to make more of them available in future.

Back issues
If you would like hard copies of the last few issues (from 114 onwards) please send **€5 per copy** (cheque or PO payable to P.E. Childs) to Dr. P.E. Childs, 6 Golf Links Road, Castletroy, Limerick.

In the next issue:

Proceedings, 41st ChemEd-Ireland, 2022

Amazing minerals: Quartz

The many forms of sulfur

Acknowledgements

The Editor would like to thank the President of the University of Limerick for encouraging the publication of *Chemistry in Action!* and for the use of university facilities in its production, printing and distribution. A special thanks to Marie Walsh for her invaluable assistance over many years in producing *Chemistry in Action!,* and to the other assistant editors. The financial help of the companies and bodies, whose logos are given below, is gratefully acknowledged, as they make it possible since 1980 to produce and distribute *Chemistry in Action!* free-of-charge to Irish chemistry teachers.