Chemistry In Action!

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The great telescope at Birr Castle.

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) to **peter.childs@ul.ie** together.
For subscription details etc. see inside back cover.

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Editorial #118

That was the year that was

I don't know whether you remember the TV skit show, 'That was the week that was', in the 1960s. Probably not, but it made me think that this last year was 'That was the year that was.' We didn't expect the pandemic, just as nobody expects the Spanish Inquisition (Monty Python), but we all had to live with it. Everything changed but at least the majority of students took the LC exams this year, even if JC exams were cancelled. The lockdown and working online were hard on students, parents and teachers. But I am sure everyone learned a lot of lessons and maybe blended learning and the flipped classroom, a mix of online and face-to-face learning, will be here to stay in some form. They always say that innovation and change happen faster under the pressure of wartime, and the pandemic was a sort of war. Everyone had to learn new skills and become more computer and Zoom/MS teams proficient. It is almost certain that learning suffered, especially in practical subjects. Let us hope that, given the amazing vaccination progress in the country, this academic year will be more normal both at school and at third level. The ones most affected were probably those students in 5th and 6th years, 2020/21 and let us hope it didn't affect their long-term careers. One casualty of the pandemic appears to have been academic standards, with grade inflation across the board. This has been especially bad in the UK with A levels, based on only teacher and school assessment, not examinations. Once grade inflation has happened it will be difficult to reverse and return to the old system based on externally marked examination. There have been many calls to modify or even scrap the current LC system. The main criticism has been that it favours short-term rote learning and regurgitation of set answers, over against critical thinking, real problem solving and deep understanding. I would suggest that this is not the fault of the basic system, based on external examination, but on the nature of the questions. Teachers will always teach to the examination, which often interprets the syllabus (see the article by Humphrey Jones on p. 11). It **is** possible to design a different type of examination which assesses a range of skills, including critical thinking, problem-solving and deep understanding. Once this is done, if it is clearly linked to the syllabus and learning outcomes, teachers will adapt their teaching to the new style of assessment.

A storm warning

In this issue I asked Humphrey Jones to write an article on the implementation and assessment of the new LC Agricultural Science specification. This appears on p. 11 and makes for disturbing reading. His experience and the reaction of Ag. Science teachers bears out our worst fears about the new format for subject specification, based too heavily on learning outcomes. If the experience of Ag. Science and the Junior Science course are anything to go on, the wholesale implementation of this model for the other LC sciences will be a disaster. One good outcome from the pandemic is that it has delayed the process of revising these courses. Science teachers of all subjects, based on the ISTA and IASTA surveys, are almost unanimous in their concerns about the new format based on learning outcomes (often poorly written) and the lack of depth of treatment to guide teachers, students, textbook authors, and examiners. It is almost a case of everyone does what is right in their own eyes, just because they do not have enough detailed guidance. Nobody disagrees with the idea of regular syllabus revision, maybe every 5 to 6 cycles, but this can be done by minor changes, without a major rewrite or changing the whole format of a syllabus, which has been tried and tested and found acceptable. This is akin to regular servicing of a car and minor upgrades, to keep it safe and on the road. What the NCCA is trying to push through is a complete rebuild to turn a car into a different sort of vehicle all together. Will this year be the year the NCCA and the Minister actually listen to teachers, take note of their concerns and revise their plans? Let us hope so.

Peter E. Childs, **Hon. Editor**

In this issue #118

In this issue you will find Humphrey Jones' article based on his experience teaching the new Ag. Science specification, and the results of a survey of Ag. Science teachers. It makes for disturbing reading on p. 11. Professor Áine Hyland gives us her response to Humphrey's article on p. 16. These articles are important because of their relevance to the proposed revision of LC Biology, Chemistry and Physics using the same flawed curriculum model. The experience of Ag. Science teachers is a warning bell for all LC science teachers.

The Irish teams did well in the International Chemistry Olympiad, see the report on p. 4.

Each year a report is produced on Chemical Education in Ireland for the EuCheMS Division of Chemical Education by the Irish delegate(s). You can find the report for 2020-21 on p. 8.

Encouraging girls to do STEM subjects and take up STEM careers is still a problem in many countries, and may be especially difficult for girls from ethnic minorities. My friend Silvija Markic, a professor of science education from Lugwigsburg in Germany, is interested in this problem of heterogeneity in science education, especially with regard to language. Changing girls' image of science and science careers is important if we are to utilise fully 50% of our talent pool. Silvija and co-workers describe a board game on p. 19, whose purpose is to encourage girls to change their views about science and science careers through discussion. The idea might be adaptable to the Irish classroom. If you have any good ideas or experiences in this area of providing careers advice to girls in Ireland, please share them through this magazine.

We continue our series looking at chemical myths, areas of chemistry where students (and sometimes their teachers) have misconceptions, which affect their short-term and long-term understanding of the topic. In this issue we look at intermolecular forces (p. 33.) This is something students always seem to find difficult.

The chemical elements and the Periodic Table are the basis of chemistry and the elements are fascinating in their own right. In this issue Peter Davern (p. 24) starts a series on quirky facts about the elements, which can be used to enliven your lessons. Peter Davern and the Chemistry Department at UL have commissioned a large Periodic Table with samples of the elements and you have the opportunity to adopt an element (see p. 26.)

Adrian Ryder continues his series on Chemists you should know, by looking at J.L. Gay Lussac, a French chemist (p. 28), followed by a Chemical Quotation from Gay Lussac (p. 32). We also present part 3 of Adrian's colourful series on Gemstones (p. 47). The origin of colour in gemstones often is due to transition metal ions, in different oxidation states.

We can't escape the subject of climate change and as science teachers we need to be informed about it. From pp. 36 onwards we have a number of articles relating to climate change and the role of CO_2, the Janus molecule. We need to connect what we teach to what is happening in everyday life – see p. 46 for a note about the mica and pyrites problem in housing.

What was a calotype or a daguerrotype? To find out consult the Chemlingo article on p. 56.

A few years back we had a series on Places to Visit of scientific or industrial interest. In this issue we feature Birr Castle, famous in the 19th century for the largest telescope in the world" Well worth a day out in Co. Offaly (see p. 57.)

Education News and Views

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

New President for TÚS

The new Technological University of Shannon: Midlands Midwest will be officially launched on October 1st 2021. Professor Vincent Cunnane, currently President of Limerick Institute of Technology (LIT), has been appointed as President of the new Institution, which combines LIT and Athlone Institute of Technology.

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New women university presidents

There were no women Presidents of Irish universities, but now there are Four. Professor Kerstin Mey has just been appointed President of the University of Limerick, after acting as caretaker for nearly 2 years. Professor Linda Doyle has taken over as Provost of Trinity College Dublin, Professor Eeva Leinonen as President of Maynooth University and Professor Maggie Cusack as President of Munster Technological University.

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ChemEd-Ireland online again

The 40th annual ChemEd-Ireland conference for chemistry teachers was held in DCU on October 16th, but it will be online again this year. It is being organised by Dr James Lovatt.

The conferences were started in 1982 in Thomond College of Education, Limerick, by Dr Peter Childs. The talks will be available online after the conference.

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The Proceedings will be published in the Spring 2022 issue. If you have any reminiscences or comments on past conferences please send them to peter.childs@ul.ie for the Proceedings e.g. something you learned that changed your teaching.

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ChemEd-Ireland 2022

The 41st ChemEd-Ireland conference will held in TÚS at the Moylish Campus in Limerick, organised by Marie Walsh. The date will be Saturday October 15th 2022.

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Major success for Irish Secondary students at the 53rd International Chemistry Olympiad

Team Ireland has achieved its best success to date in the International Chemistry Olympiad which was held from Saturday, July 24 to Monday, August 2, 2021, with all four competing students receiving awards for the first time. Two students, Oisín Ó Feinneadha, from St. Peter's College Secondary School, Wexford and Tong Wu, from Clongowes Wood College, Clane, Co. Kildare got silver medals, placing them in the top 10-30% of Chemistry students in the world. Oscar Despard, from Sandford Park School, Ranelagh, Dublin also received a bronze medal and Aoife Morris, from St. Aloysius' College, Carrigtwohill, Co. Cork completed the extraordinary success of Team Ireland by getting an Honourable Mention award.

The International Chemistry Olympiad (IChO) is an annual competition for the world's most talented chemistry students at secondary school level. The International Chemistry Olympiad started in the former Czechoslovakia in 1968. Ireland has participated in the competition since 1997 and has been very successful in the previous 24 years, with a previous bronze medals total of 20, four honourable mentions and two silver medals awarded in 1999 and 2006. However, the phenomenal success of Team Ireland in 2021 surpassed all previous achievements as this is the first year that all four members of the Team achieved awards and the first year that Ireland came away with two silver medals in the same

competition, doubling our overall tally from 2 to 4.

The 53rd International Chemistry Olympiad was one of the largest to take place since its inauguration, with 312 student participants from 85 countries competing in 2021. The competition was originally scheduled to take place in Japan but due to the ongoing COVID-19 global pandemic, the IChO2021 Japan Committee and the International Steering Committee decided to conduct the competition remotely to ensure the maximum safety of all student participants and international delegations. The competition involved a highly challenging five-hour theoretical examination paper run remotely consisting of nine problems, involving very complex chemistry topics.

The journey for the four students to IChO2021 Japan commenced in the Spring of 2021 where over 210 Chemistry students from across the island of Ireland participated in Round 1 of the Chemistry Olympiad Ireland competition. This was reduced down to about 50 who competed for national metals and the highly commended awards. From this group, Team Ireland was chosen after extensive training during the Easter Holidays and further assessment.

Team Ireland Award Winners at IChO2021 Japan
L – R: Aoife, Oisín, Tong and Oscar

The four members of Team Ireland received extensive training for IChO2021 from an expert team of Chemistry Academic Staff from five Irish colleges – Dr. Carl Poree, Dr. John O'Donoghue and Professor Mike Lyons (TCD), Dr. Elizabeth Gilchrist and Dr. Tim O'Sullivan (UCC), Dr. Brian Murphy (AIT), Dr. Pat O'Malley, Dr. Odilla Finlayson, Dr. Nessan Kerrigan and Dr. Hasim Ibrahim (DCU) and Dr. Cormac Quigley (GMIT).

The Irish international delegation consisted of Dr. Carl Poree (TCD), Dr. John O'Donoghue (TCD and RSC), Dr. Elizabeth Gilchrist (UCC) and Dr. Brian Murphy (AIT), who supported the four Irish students throughout the competition in July and who participated in the International Jury. They commented "We are truly delighted with the performance of Team Ireland in IChO2021 Japan and so proud of these four brilliant young chemists. They represented Ireland at the very highest level on the world stage in chemistry and all of them brought home an award! Great credit is due to these remarkable students. Their success also shows the quality of the chemistry teaching that takes place in many of our schools across the island of Ireland. Their schools and chemistry teachers deserve enormous praise also for ensuring that chemistry is offered to secondary level students and for providing such excellent preparation in the chemical sciences within the school curriculum".

Dr. Poree (TCD) and Dr. Murphy (AIT), current Co-Chairs of the Irish Chemistry Olympiad Committee stated that "The Committee acknowledges greatly the continuous support of the International Cooperation Section of the Department of Education which allows the Committee to hold an all-Ireland Chemistry Olympiad annually and which facilitates the participation of Irish students in the International Chemistry Olympiad. Without this support we would not be in a position to showcase the best of our Irish students in a core STEM subject on the international stage".

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Grade inflation in 2021 LC results

In 2021 Junior Cert exams were cancelled and school grades were awarded. This year's LC students had the option of accepting teacher's grade, sitting the exam or both. In the case of accepting both, the student would be awarded the higher grade. In 2020 only teacher's grades were possible. The majority of students opted for both (91.2%) and 8.8% for teacher's grade only, but in

the event quite a few didn't turn up for the exam, leaving lots of unused papers. When the results came out, 52.5% were based on teacher's grades, 16.1% on the exam grades and in 31.4% the two grades were the same. These %s are an indication that teachers were inflating their student's grades, as borne out by the SECs 2020 report.

In 2021 there were 57,952 LC students and 3,173 LCAP students. Average grades were up by 2.6% on 2020, which were up 4.4% on 2019 (pre-pandemic). This average increase masked greater increases in specific subjects. For example, HL Maths there were 15.1% H1s in 2021, compared to an average of 6% in 2017-19, +151%. HL Chemistry in 2021 had 23.4% H1s, compared to an average of 12.2 % 2017-19, +91.8%, and Biology had 17.4% H1s in 2021, 8.3% in 2017-19, +110%. This is grade inflation with a vengeance!

In 35 out of 40 HL subjects girls outperformed boys, following past trends, but with an increased gap. This can be considered as over-performance by girls or underperformance by boys. One result is that girls will achieve higher CAO points and will thus predominate in entry for third level courses. Last year's report by the SEC on LC grades concluded that all grades were being over-estimated, and girls benefited more than boys, and this has increased in 2021. David Quinn had a perceptive comment on this in the *Sunday Times* (12/9/21).

The [SEC] commission said that last year the calculated grades process "showed strong evidence that there was overestimation of outcomes at all points in the achievement spectrum" and "the grade distributions in the school estimates" for this year were worse. In other words, teachers were overmarking pupils by even more than 12 months ago.

The report also pointed out something that should have alarm bells ringing, namely that girls were benefiting from inflated grades more than boys because of "unconscious bias" on the part of some teachers. The 2020 analysis found the same thing. "This was not unexpected, given that research suggests that unconscious estimation bias in similar contexts to this are generally in the direction of favouring female students," this year's report states.

Boys must not be left behind in equality stakes | Ireland | The Sunday Times (thetimes.co.uk)

See 86709_aacaf08c-a32b-4e74-817b-5a3ba1e2a7e8.pdf for SECs 2020 report.

This inflation makes it impossible to compare current grades with past grades, as there is simply no standard of comparison.

In the UK all school exams were cancelled so A-level results, as in 2020, were awarded based on school assessed grades, moderated by Ofqual. Nobody was surprised when this resulted in grade inflation: in 2019 pre-pandemic there were 8% A* and 17% A grades; in 2021 there were 19% A* and 26% A grades. This means that 45% of the cohort got the top grades, an increase of 80%. Quite frankly this is ridiculous and makes a mockery of any standardised, objective assessment of student ability.

Problems with grade inflation

- It gives students an inflated idea of their ability, as teachers tend to give students (especially girls) the benefit of the doubt.
- It destroys confidence in the integrity of the assessment system for both third level access and employment.
- It disadvantages students carrying grades from previous years.
- It removes any discrimination from the results as too many get top marks.
- It puts pressure on high demand university courses so that more students are qualified than there are places. I Ireland it has meant that places are allocated by lottery sd too many students qualify on points.
- It increases the disparity between fee paying and state schools, between DEIS and non-DEIS schools, and between girls and boys.
- It creates problems for later years when grades go back to normal.

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2021 Results in the LC sciences

2021 Results in the sciences (A = HL, G = OL)

Subject	Level	1	2	3	4	5	6	7	8
PHYSICS	A	21.1	20.1	20.0	16.6	12.1	7.1	2.1	1.1
PHYSICS	G	5.3	13.4	17.6	21.3	16.3	15.3	4.4	6.4
CHEMISTRY	A	23.4	21.6	19.4	15.2	10.4	6.1	2.5	1.4
CHEMISTRY	G	5.0	10.9	17.3	20.9	15.8	17.3	5.4	7.6
PHYS & CH	A	22.0	20.2	14.9	15.7	14.9	6.8	3.9	1.6
PHYS & CH	G	5.3	1.8	10.5	21.1	12.3	22.8	10.5	15.8
AG SCIENCE	A	11.3	16.6	22.6	21.5	15.7	8.8	2.3	1.2
AG SCIENCE	G	0.8	5.7	14.2	20.8	23.5	21.0	6.6	7.5
BIOLOGY	A	17.4	18.3	19.4	18.0	13.8	8.9	3.1	1.3
BIOLOGY	G	1.7	6.8	15.1	23.0	24.7	18.8	5.2	4.6

Comparison of LC science numbers for 2020 and 2021
Total cohort: 2020, 55,598; 2021, 57,952

Subject	2020 (%)	2021 (%)
Biology	34,853 (62.7)	34,888 (60.2)
Chemistry	9,662 (17.4)	9,651 (16.6)
Physics	8,097 (14.6)	7,988 (13.8)
Ag. Science	8,501 (15.3)	8,468 (14.6)

There was a small increase in the LC cohort from 2020 to 2021, but only Biology showed a small increase, the other sciences decreased slightly. However, all the %s of the LC cohort decreased from 2020 to 2021. There is certainly no massive swing towards the sciences in school. Biology retains its dominant position and Ag. Science continues to occupy 3rd place above Physics. The new syllabus in Ag. Science does not seem to have a major effect one way or the other.

OL and HL numbers for the LC sciences

Subject	2020 OL	2020 HL	2021 HL	2021 OL
Biology	5,270	29,583	4,211	30,677
Chemistry	966	8,696	857	8,744
Physics	1,060	7,037	778	7,210
Ag. Science	1,130	7,371	915	7,553

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Annual Report to the EuCheMS Division of Chemical Education for 2019-2021

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1. Abstract

Much of face-to-face education was disrupted in March 2020 due to Covid-19, with primary and second-level schools online from March to May 2020, and again from January to mid-April 2021 (with staggered returns from early March to mid-April). Third-level education was also disrupted with all teaching (lectures and tutorials/seminars) delivered virtually from March 2020 to date. Limited laboratory work was possible for undergraduate chemistry students, with much of this carried out virtually.

The 2nd level final year state examinations were modified due to Covid restrictions over the last two years. However, all students received results marking their completion of their second level schooling. Some additional places were available in 3rd level institutions.

Despite the challenges presented by the Covid-19 pandemic the Irish chemistry education community were extremely active throughout the reporting phase (June 2019- May 2021).

2. National educational policy

New Curricula:

The Leaving Certificate specifications in Chemistry (and also Physics and Biology) are currently being reviewed and revised. The current syllabi were introduced in 2000 and while a new specification was developed in March 2014, it was not implemented due to the uncertainty re the practical coursework component. The current revisions are taking into account the changes that have taken place in the science curriculum for the first 3 years of second level and also examining the feasibility of integrating a coursework assessment component, broadening the examination from written examination only and also allowing assessment of other skills.

At 2nd level:

Much of the teaching has been online since March 2020 – at primary & second level. The National written examinations (Leaving Certificate) at the end of second level were replaced in 2020 with Accredited grades, which comprised of standardisation by the State Examinations Commission of teacher/school estimated grades for each student. In 2021, students had the option to take the national written examinations and /or the Accredited grade and were awarded the higher of the two grades between examination and accredited grade.

Due to somewhat higher grades being awarded and also an increase in places available in 3rd level courses, more students were eligible for places at Universities and colleges and this has led to greater numbers taking 3rd level courses.

At 3rd level:

Third-level has seen some significant changes in both laboratory work and student in-take numbers. Much of the teaching has been on-line at 3rd level – so it will be interesting to see the effect of this on laboratory work next year and throughout the course of the students' studies. Additionally, there are higher numbers of students in all courses, which raises questions regarding how institutions will cope with these numbers as we move back towards in-person learning in the coming months and years.

The continued merger of the Institutes of Technology has given rise to 2 additional designated Technological Universities:

Munster Technological University (MTU), and Technological University of the Shannon (TUS). Two further designations are expected in the future – as Technological University for the South-East Ireland (TUSEI), and Technological University for the West and North-West of Ireland.

3. **Events in chemical education**

Annual staples in the chemical education (and STEM education) calendar continued in a virtual format, some examples are highlighted below:

BT Young Scientist and Technology Exhibition: The BTYSTE is a national Science Fair run by BT Ireland, and is one of the largest Science Fairs globally. It took place virtually in January 2021, with over 550 projects from 213 schools qualifying to take part from an initial entry of over 1,350 projects. With over 105,000 attendees from 77 countries, the virtual event proved to be a great success for all involved. https://btyoungscientist.com/

SciFest: SciFest provides a forum for students at local/regional/national level to present and display their scientific investigations. The SciFest programme consists of a series of one-day STEM fairs for second-level student and is designed to be as inclusive and accessible as possible. Due to restrictions, the 2020 and 2021 Scifest were online, with students submitting their projects for judging. https://scifest.ie/

Irish Science Teachers Association (ISTA) Conference – The ISTA Conference 2021 was held virtually in March 2021. The theme of this year's conference was "The Big Ideas in Science Education and Hope for the Future". It was inspired by the current work on the Senior Cycle Science syllabi and rapidly changing World that we live in. A chemistry education highlight was Prof. Sir Martyn Poliakoff on Mendeleev. https://www.ista.ie/conference-brochure-2021/

Science week 2020: Science Week ran from 8-15th November in 2020 with virtual events hosted by Festivals across the country. https://www.sfi.ie/events/festivals/

Chem-Ed Ireland: ChemEd Ireland is a one-day annual conference on Chemistry Education mainly for Chemistry teachers. This annual event provides an opportunity to network and to share resources and ideas relevant to teaching chemistry in Ireland. In October 2019, it was hosted by Technological University Dublin and the theme for the conference was the International Year of the Periodic Table. In October 2020, the conference was held virtually and hosted by UCC. The virtual nature of the event gave rise to a very high attendance (over 220). While the social dimension of the conference was lacking, the event reached a wider audience due to its virtual nature and hence is a point to note for future events.

International Chemistry Olympiad: Ireland selects and sends a team to participate in the IChO each year. The Irish Chemistry Olympiad Organising Committee comprised of a group of academic staff across five higher education institutes in Ireland – DCU, TCD, AIT, GMIT and UCC. For IChO 2020, Round 1 selection was held in person pre lockdown; however, final selection, training and the event itself was conducted remotely. Given the range of uncertainties during this time, the Irish team performed very well under the circumstances.
https://icho2020.tubitak.gov.tr/storage/Guidelines%20&%20Decisions/IChO_2020_Final_Report_Turkey.pdf

For IChO 2021, all of the selection examinations, and training was carried out online and the teams completed the IChO tests in a central location in their own country. (Update July 2021 – the Irish team competed successfully at IChO 2021, and secured 2 silver medals, a bronze medal and an Honourable Mention; an outstanding achievement) https://www.icho2021.org/

4. **Activities of the National Chemical Society (Institute of Chemistry of Ireland)**

ICI Young Chemists Network (ICI-YCN): The newly formed ICI-YCN is the young division of the Institute of Chemistry of Ireland and represents the interests of all young chemists in Ireland. Its aim is to promote networking and collaboration opportunities for early stage researchers by organising conferences and networking events for young chemists. It also aims to support young chemists by providing a platform to promote upcoming positions suited for young chemists. https://www.chemistryireland.org/young-chemists-network/

Awards:

Further details are available here: https://www.chemistryireland.org/awards-events/

The Boyle Higgins Gold medal and Lecture Award was presented to Professor Suresh Pillai (IT Sligo) in 2019 and to Professor Amira P. de Silva (QUB) in 2020, in recognition of their outstanding and internationally recognised research contribution to the advancement of chemistry.

The ICI Annual Award for Chemistry - Eva Philbin Public Lecture Series was presented to Professor Declan McCormack (TUD) in 2019 and Professor Declan Gilheany (UCD) in 2020 for their significant contribution to the advancement of chemistry and raising the profile of chemistry through effective communication to a wider audience.

The ICI David Brown Award 2021 was presented to Professor Nicholas Farrell (Virginia Commonwealth University, USA)

ICI Postgraduate Award is for PhD students who have demonstrated excellence in research through publications and have shown a commitment to supporting and promoting Chemistry. The awardees were Priyanka Ganguly (Sligo IT) and Conor Crawford (UCD) in 2020 and Saoirse Dervin (Sligo IT) in 2019.

Second Level Education Award was presented to Brian Durkan, St. Muredach's College, Ballina, Co. Mayo and Óran O'Sullivan, Coláiste Choilm, Ballincollig, Co. Cork for their achievement in obtaining the highest chemistry grades in Ireland at Leaving Certificate in 2019.

Research Colloquium – the Irish Chemistry Research Colloquium was held from the 17th - 18th of June 2021 (virtually) at the University of Limerick (UL). The event was hosted by the Department of Chemical Sciences and the Bernal Institute at UL.

5. Publications

The publications of the ICI are available at **https://www.chemistryireland.org/news-publications/#chemire**, in particular ***Irish Chemical News*** From the University of Limerick: ***Chemistry in Action!*** https://www.cheminaction.com/

6. Liaison with the chemical industry

Many third-level institutions have strong links with industry reflected in both research and teaching. One such example is presented here for illustrative purposes:

SSPC PhD programme: SSPC is the Science Foundation Ireland (SFI) Research Centre for Pharmaceuticals and one of the largest national producers of chemistry PhD graduates. The aim of SSPC is to deliver industry-relevant technical solutions, which result in job growth and retention within this sector in Ireland and grow the skills base of qualified scientists and engineers. A key impact of SSPC is the creation of a unique talent pipeline with the transition rate of SSPC researchers to industry currently standing at 70%. One of the key drivers facilitating this is the SSPC PhD industry placement programme, which brings students into the industrial environment for a three-month placement aligned with their research area. During their placements, students have industry mentors, to provide guidance and to help them to expand their professional networks. Companies benefit from invaluable research expertise. The student placements in academic and industry partners are important components of the Structured PhD programme;they are carefully managed to ensure that students gain enhanced knowledge and experience, honing their ability to work in interdisciplinary teams and to undertake cross-disciplinary activities.

STEM Teacher Internship Programme: provides pre-service STEM (Science, Technology, Engineering and Maths) teachers with the opportunity to gain skills and experiences within the STEM Industry. The programme was developed together with Accenture and the 30% Club with the overall aim of providing future STEM teachers with a personal experience of STEM roles and careers in the industry. This, in turn, will empower them to inspire future generations of their own students, particularly female students, to engage in STEM subjects and careers.

7. **International and European initiatives**
EuChemS Chemistry Congress 2024 will be hosted by Institute of Chemistry of Ireland in Dublin.
Institutions in Ireland are partners in several EU-funded projects involving Chemistry education. For example:
'Diversity in Science for Social Inclusion' (DiSSI) project: (2019-2023, Erasmus+, Irish partner Dr Sarah Hayes (SSPC, UL))
Aims to address a gap in research and practice. Diversity is multidimensional in nature and the consideration of only one dimension of diversity can yield inclusive practices of only limited scope. https://dissi.org/

'Educating science teachers for all' (ESTA) project (2020-2023, Erasmus+, Irish Partner Dr Catherine Martin (UL, MLAL); Dr Sarah Hayes (SSPC, UL)
Aims to develop more responsive and inclusive science education by developing training programmes for pre- and in-service science teachers to include the issues of cultural diversity and linguistic heterogeneity. https://esta-project.eu/

8. **Other events and activities**
President of Ireland Michael D. Higgins is the patron of the Institute of Chemistry Ireland.

9. **Contact details of delegates.**
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Ploughing a Muddy Field – Reflections on the Implementation of the New Agricultural Science Specification

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Out with the old, in with the new

Over the past two years I have been ploughing a muddy field. Not literally, but figuratively as I attempted to get my head around the new Leaving Certificate Agricultural Science specification. The new specification (syllabus to you and I) was released by the National Council for Curriculum and Assessment (NCCA) in January 2019 and first taught in September of that year. It replaced an outdated syllabus that was no longer fit for purpose, written before Ireland had joined the European Union, which contained just 1000 words, spread sparsely over five pages. There was no "depth of treatment", teacher guidelines or clarity on what detail the teacher needed to go into and, in truth, it was the examinations and their marking schemes that served as the curriculum. It was a perfect example of "the assessment dog wagging the curriculum tail".

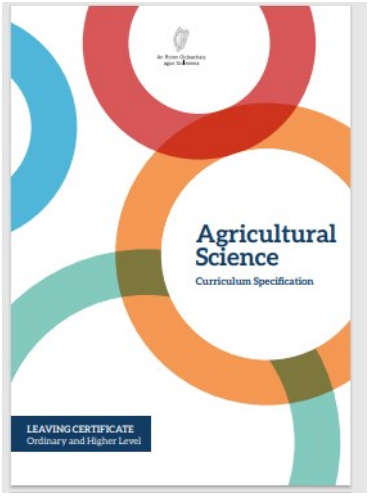

Figure 1: The new Agricultural Science Curriculum Specification (NCCA)

The syllabus needed to be replaced with something far more cutting edge, something that reflected modern agricultural and scientific practices and served to build a deeper understanding of the origins of our food, but also

the economic and environmental impact it makes. It also needed to consider the greater role digital technology, genetics and biotechnology now have on Irish agricultural practice, while positioning itself firmly as a laboratory science and providing greater opportunity to its students for investigative and experimental study.

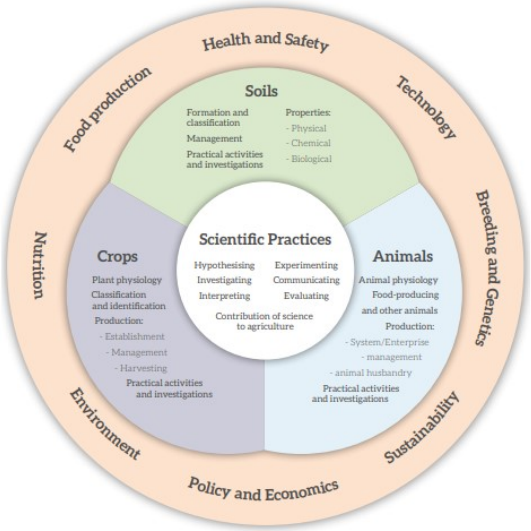

Figure 2: The structure of the specification (NCCA)

To be fair, the new specification brought the course into the 21st century and the content of the curriculum does address the shortcomings of the old course. (See [NCCA-Specification-for-Leaving-Cert-Agricultural-Science.pdf (curriculumonline.ie)]) It is now a dynamic, interesting and inviting subject (some may argue it always was), and my students enjoyed the course over the past two years. Topics like sustainability, genetics and the environmental impact of agriculture, have come to the fore while there is still a strong emphasis on farm practice and the science that underpins it. But things are not all rosy in the garden (or the field) and there are some very significant issues with the new specification that have implications for the future direction of the senior sciences in Ireland, as new specifications for Chemistry, Biology and Physics near completion.

The IASTA Survey 2021

The Irish Agricultural Science Teachers' Association (IASTA) conducted a survey of their members back in January 2021 on the implementation of the new specification. They received nearly 280 responses, almost half of their membership, and the results don't paint a pretty picture. It reveals significant issues with the implementation of the new specification, the training provided by the PDST, the assessment (both the examination and the practical component – termed the "Individual Investigative Study") and, above all else, the lack of clarity in learning outcomes within the specification.

A) The learning outcomes

We are all very familiar with the learning outcomes model of curriculum design, particularly after the implementation of the new Junior Science specification. The new subject specification for Agricultural Science follows the same model from Junior Cycle and consists of 91 learning outcomes, utilising a series of "action verbs". They fall into one of four strands, although some learning outcomes are repeated across multiple strands, with one strand (Scientific Practices) at the core. Within the strands, there are eight cross-cutting themes which interlace across the topics.

The learning outcomes are vague, poorly written and provide little clarity, for the most part, for the teacher on how much detail is required. Each individual teacher is required to ascertain for themselves the "depth of treatment" for each learning outcome, and must hope that the State Examinations Commission adjudge them similarly. A rubric of the action verbs is meant to provide clarity to the teacher but it does not. There are multiple learning outcomes which use the action verb "appreciate" (hardly an action?) and the rubric states that this means "*to recognise the meaning of, have a practical understanding of*". Hmm, which is it?

In the IASTA survey, respondents were asked to gauge the clarity of the learning outcomes from 1 (Very Clear) to 5 (Not Very Clear) – the average response was 4.23 with just one single person choosing 1 on the scale (see Figure 3 below). This is damning.

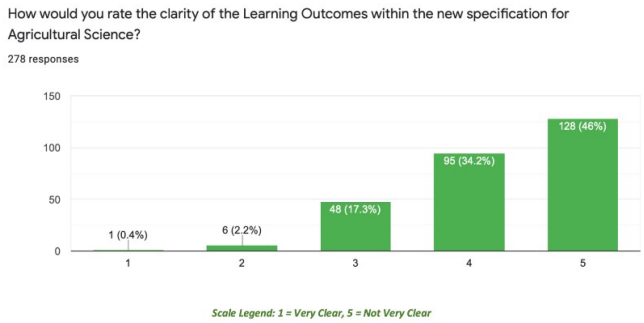

Figure 3: IASTA Survey, 2021

This lack of clarity has a direct effect on the teachers' confidence in judging the depth of treatment required within each learning outcome. A staggering 71% of teachers adjudged their confidence as 'Not Very Confident' (5 on the scale) when asked, while only 0.4% were 'Very Confident' (1 on the scale) in their ability to judge the depth required (Figure 4).

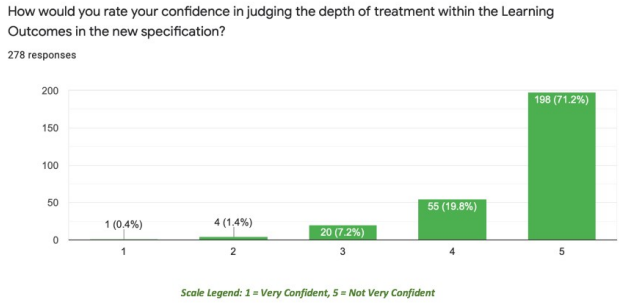

Figure 4: IASTA Survey, 2021

At the IASTA annual conference in 2020, just before the pandemic hit, one delegate said during an open discussion: *"I am teaching a topic on the Ag. Science specification at the moment and I don't know if I should be spending two months on the topic, two weeks, two days or two hours on it"* **This is hardly ideal!**

In summary, the learning outcomes in the Agricultural Science specification are, in my opinion, poorly written, vague, overly long, lacking clarity, far too broad and, crucially, confusing. They need to be urgently reviewed and greater clarity provided on the knowledge and skills supposedly contained within them. They are the root of all that is wrong with the new specification. The training, carried out by the Professional Development Service for Teachers (PDST), provided little clarity on the learning outcomes and how they can be interpreted. To be fair, the PDST were not adequately resourced nor given adequate time to provide the necessary training. Instead, the IASTA have been instrumental in provided opportunities for teachers to share resources, unpack learning outcomes, design units of learning and discuss the mandatory practical investigations (a positive change to the new specification, although not without their flaws).

B) The Individual Investigative Study (IIS)

The IASTA Survey also highlighted issues with the training on the new practical component – the Individual Investigative Study (IIS) – while also highlighting significant stress, anxiety and frustration amongst teachers of the subject. The IIS is a complex project which involves a mixture of research and scientific investigation on a specific theme within agriculture (in 2021 this was sustainability). The brief for this was meant to be released at the beginning of the school year in 2019, instead it was released at the end of the first term. Training didn't begin until February 2020, but many teachers didn't get a chance to complete their training due to the Covid pandemic. The State Examinations Commission (SEC) made minor concessions to the guidelines but ultimately students were expected to complete their scientific investigations and submit a full report. Many students didn't have access to school laboratories, even when they did return to school, and the vast majority of teachers reported that the pandemic had significant impact on the IIS in their classrooms. In a separate IASTA survey at the end of the school, the majority of teachers reported high stress levels amongst their students during the IIS process, a lack of clarity from the DES on the completion of the report, and even reported significant difficulties with the online document format issued by the DES. It was an unmitigated disaster for the vast majority.

I'm probably one of only a few teachers of Agricultural Science who see the current IIS model, as a practical assessment tool, in a positive light. I think it assesses a different set of skills than the examination does but it should not have been a requirement to complete it last academic year, due to the enormous challenges the pandemic presented. Unfortunately, that experience will live long in the minds of teachers of Agricultural Science. It has been tainted.

C) Sample examination papers

The State Examinations Commission (SEC) published a single sample paper, for both Higher and Ordinary Levels, in November 2020. The new

paper is a significant improvement on the old-style paper, with full colour and space for answers on the exam paper itself. However, the vague learning outcomes have affected the examinations too.

In the first IASTA survey, the majority of teachers believed that the sample papers did not reflect the knowledge and skills within the strands and cross-cutting themes, or the learning outcomes. It seemed that the SEC were also finding it difficult to judge the depth of knowledge required from the vague learning outcomes. There were multiple examples of questions, which clearly have nothing to do with the learning outcomes but were more reflective of the old course. The new paper was also extremely long, at 36 pages, and weaker pupils would really struggle to maintain focus and motivation when tasked with reading and completing it. Why was there only one sample paper published and why was it published so late? Perhaps this has been the precedent to date but, in the realm of Leaving Certificate and curriculum reform, everything should be open to change, no?

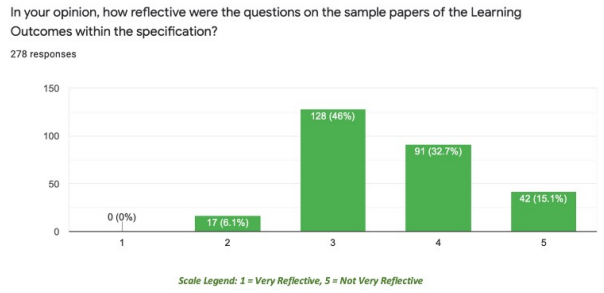

Figure 5: IASTA Survey, 2021

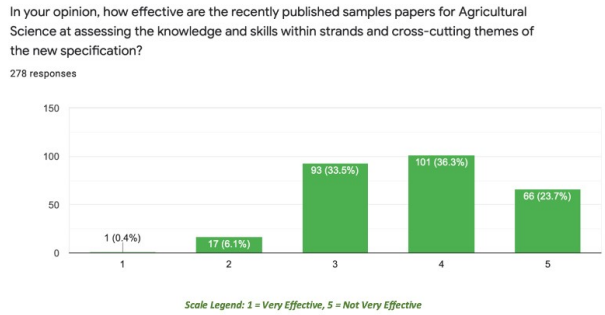

Figure 6: IASTA Survey, 2021

The 2021 Leaving Certificate examination papers were even longer, with additional questions and choice available to the students who chose to sit the paper. The Higher Level paper was a staggering 52 pages long. Even with the additional time available to students, even reading through the paper must have been mindboggling. In my opinion, the Higher Level paper was also significantly more difficult than the sample paper that it was based upon.

Again, there were multiple examples of the vague nature of the learning outcomes affecting the examination paper. There were several questions on topics not mentioned in the specification, or outside the realm of the learning outcome. One such example was in Question 18, part (c). The question presented the lactation curve, a diagram all teachers of Agricultural Science would be familiar with, and some detail on the energy requirements of the dairy animal at various stages in various stages of lactation (milk production). (Figure 7) Most of the questions refer to "negative energy balance". However, there is no mention of the lactation curve in any learning outcome on the specification nor is there mention of the term 'negative energy balance'. 'Energy' is mentioned in just one learning outcome in the 'Animal' strand (*discuss the importance of nutrition and ration formulation to meet the protein, energy and performance requirements at different growth/development stages of cattle …*). Is the lactation curve a growth or development stage in cattle? Possibly, but it is not definitely mentioned in the specification (the term lactation doesn't appear in the specification by the way). Is it clear that this learning outcome required pupils to know the term "negative energy balance"? No. This is a term I have not used specifically in teaching Agricultural Science over the past 20 years, and it doesn't appear in any of the textbooks. I'm sure many teachers of Agricultural Science do use the term, or adjudged the term essential when "unpacking" the above learning outcome, but I bet a considerable majority did not. Instead, I would have used the term "milking off the cow's back" and I'm sure most of my colleagues would have too.

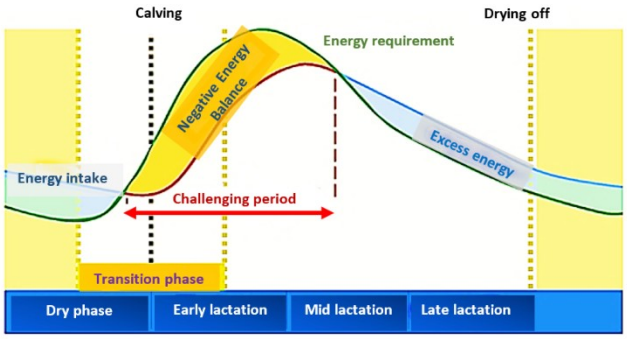

Figure 7: Diagram from State Examinations Commission, 2021

This question was unfair and not reflective of the learning outcomes within the specification. But crucially, this question has shifted the goal posts. I will in future use the term, not because of the specification but because of the examination. The examination, in just its first year, has altered my interpretation of the specification. *Again, we see the assessment dog wagging the curriculum tail and this undoubtedly will continue.* Over the coming years, the depth of treatment will come from the examination questions and acceptable answers in the marking scheme and every year our interpretation will have to change, depending on how the SEC has interpreted the learning outcomes in that year. This will be a never-ending process with each examination providing new interpretations. It's a grossly unfair process, on both students and teachers. This is just one of multiple examples of how the SEC has interpreted the learning outcomes differently to me. I have no doubt other teachers have interpreted differently again.

Conclusions

It is abundantly clear to everyone teaching Agricultural Science that the learning outcomes, in their current form, are not fit for purpose and the National Council for Curriculum and Assessment (NCCA) needs to provide far greater clarity on their meaning and the depth of knowledge required by the students to satisfy the State Examinations Commission. As mentioned previously, they are the root of all that is wrong with the specification.

This isn't a new revelation. Similar problems were evident in the Junior Cycle Science specification and in the new specifications for Leaving Certificate Computer Science and Economics. Internationally, learning outcomes-based specifications are never used for high stakes examinations, like the Leaving Certificate, which have such an impact on the lives of our students. Their shortcomings were also highlighted comprehensively in 2014 by Áine Hyland in the 'Hyland Report', commissioned by the Irish Science Teachers' Association.

> *"While learning outcomes are a very valuable tool for identifying what learners should know and be able to do at the end of a course or programme, it is not appropriate to use learning outcomes alone to define a syllabus and its assessment."*

The problem is that the NCCA are fully committed to the learning outcome model for new subject specifications and equally committed to not provided any sort of clarity on the depth of treatment required within them. The problems faced by teachers and students of Agricultural Science over the past two years will be echoed in Biology, Chemistry and Physics in the coming years. The current syllabi for these subjects are highly regarded amongst teachers and, while there is a need to update them – to reflect new knowledge in the realm of science - their current model should be maintained as much as possible.

Draft specifications for the new Senior Cycle sciences will likely be published over the course of the next academic year. It is imperative that teachers engage constructively but firmly with the consultation process and make it abundantly clear that the flawed model used in Agricultural Science does not form the foundation for Chemistry, Biology and Physics. In the meantime, it is my hope that sense prevails and the NCCA will listen to teachers of Agricultural Science and, if you pardon the expression, put the specific back in the specification.

The field is muddy now and the plough is dragging behind me, expelling energy, but I'm praying for a dry spell and a smoother run next time.

Humphrey Jones is a Guidance Counsellor and a teacher of Agricultural Science and Biology in St. Columba's College in Dublin. He is a member of IASTA and the Vice Chairperson of the Irish Science Teachers' Association.

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A response

Professor Áine Hyland

This an impressive and timely article, in which Humphrey Jones, a teacher of Agricultural Science, discusses and analyses the new syllabus/specification for Leaving Certificate which was examined by the State Examinations Commission (SEC) for the first time in June 2021. Agricultural Science has been a Leaving Certificate subject for many years and there was general agreement that the old syllabus, dating from the 1960s, was outdated and needed to be revised and brought into the 21st century. The old syllabus pre-dated the setting up of the National Council for Curriculum and Assessment (NCCA) in 1988. It pre-dated the Curriculum and Examinations Board which had existed from 1984 to 1988. It had been written in the 1960s when the inspectorate in the Department of Education had responsibility for setting, marking and providing certification for the Leaving Certificate. As the old Agricultural Science syllabus was so sparse, textbooks (informed by examination papers) were effectively regarded by students and teachers as "the syllabus". As Jones so rightly states in his article, *"assessment was the tail that wagged the curriculum dog".*

Since the setting up of the NCCA, the practice had been to provide greater clarity in curriculum and syllabus documentation. In the most recent revision of Leaving Certificate Physics, Chemistry and Biology between 2002 and 2004, the syllabi were laid out under four headings: Content; Depth of Treatment; Activities and Social and Applied Aspects. These syllabi were relatively detailed (between 45 and 75 pages each) and were accompanied by Guidelines for Teachers – one for each subject (~ 100 pages each). The syllabi were developed following widespread consultation – with teachers, higher education institutions, scientists and employers. Those syllabi were widely welcomed throughout the country and resulted in an increased take-up of science subjects at Leaving Cert. level.
Shortly after the new science syllabi were introduced, the NCCA came up with radical plans to reform senior cycle and to provide a new curriculum framework for teaching and learning for students in their final two or three years of second level education. These plans did not find favour with the then Minister for Education, Mary Hanafin T.D., who described them as a "Rolls Royce model" of curriculum. In 2009, following further extensive consultation with stakeholders, the NCCA issued a document entitled *Towards Learning: An Overview of Senior Cycle Education*[1] – a document which was to inform all subsequent syllabus design. This document set out a curriculum framework which emphasised the following five key skills: Information Processing: Being Personally Effective; Communicating; Critical and Creative Thinking and Working with Others. The framework also stated that to ensure coherence and consistency across all subjects, the syllabus for each subject would follow the same structure.

It might be useful at this stage to explain the roles of the various national bodies in curriculum and syllabus reform. The NCCA, which was set up in 1988, became a statutory body under Section 38 of the Education Act in 2001. Its role is *"to advise the Minister (for Education) on matters relating to (a) the curriculum for early childhood education, primary and post-primary schools and (b) the assessment procedures employed in schools and examinations on subjects which are part of the curriculum".* For a number of years after the setting up of the NCCA, the inspectorate of the Department of Education continued to set and administer the public examinations and it was not until March 2003 that the SEC was established by statutory order. The SEC assumed responsibility for the operation of the state certificate examinations from 2003 onwards. The SEC is described on its website as *"a non-departmental public body under the aegis of the Department of Education and Skills. It is responsible for the development, assessment, accreditation and certification of the second-level examinations of the Irish State – the Junior Certificate and the Leaving Certificate".* In relation to second level education, Ireland now has two separate bodies with different but perhaps slightly overlapping roles relating to assessment and examinations – the NCCA and the SEC. The NCCA advises on assessment and examinations and the role of the SEC has been limited to administering, marking and certifying the national examinations i.e. the Junior and Leaving Cert. Both bodies report to the Minister for Education,

who under the terms of the 1998 Education Act has ultimate responsibility for curriculum and assessment.

In other countries which have two such bodies, and which have a nationally assessed examination or examinations, the curriculum body (in Scotland, it's *Education Scotland)* sets out the overall philosophy underpinning the curriculum and provides a broad curriculum framework, which can be interpreted and implemented in various ways by local education authorities and / or schools. Where external assessment and certification of students exists, there is usually a second body (in Scotland it's the *Scottish Qualifications Authority*) which sets out the details of the individual syllabi for assessment purposes. These syllabi (or specification as they are sometimes referred to) are always quite detailed and follow good practice in syllabus design. They start with Learning Outcomes, which are then expanded to include depth of treatment (i.e. the level or extent to which a topic should be taught), examples of content and pedagogy and assessment guidelines. Such a design ensures that the syllabus is coherent, that it is interpreted in the same way by all those who prepare their students for the examination, and that the content, pedagogy and assessment are constructively aligned with the learning outcomes. When the NCCA began to review Leaving Certificate syllabi towards the end of the first decade of the 21st century, they were influenced by curriculum developments in other parts of the English-speaking world. Among the countries and jurisdictions which were referenced by the NCCA (2014) as countries which were exemplary as far as curriculum design was concerned were Scotland, Victoria (Australia) and Ontario (Canada). The International Baccalaureate was also referenced. The OECD had a noticeable influence on educational policy in the jurisdictions mentioned in the NCCA reports. The OECD Programme for International Student Assessment (PISA)[2] had provided comparative information over the previous two decades about the overall performance of students in different education systems. PISA studies are designed to evaluate systems – not to assess individual students - and can be a useful tool for policy-makers when analysing the effectiveness of their education systems.

In all the jurisdictions referenced by the NCCA, a starting point for designing the curriculum and syllabi is a statement of the Learning Outcomes, which students are expected to achieve by the completion of the programme or course. A Learning Outcomes approach to curriculum design became popular across the English-speaking world in the 1990s. Prior to that it was more common for curriculum design to start by stating the aims and objectives of the curriculum. Learning Outcomes are articulated in terms of what a student is expected to know and be able to do, whereas Aims and Objectives were focused on what the teacher was expected to teach. The new emphasis was student-centred rather than teacher or subject-centred. It was a welcome development and has proved to be successful in emphasising student needs and placing the learner at the centre of the teaching and learning process. However, while clearly-articulated learning outcomes are a very valuable tool, it is not appropriate to use learning outcomes **alone** to define a syllabus and its assessment. Learning outcomes are statements of essential learning, and as such they are written at minimum / threshold, i.e. pass/fail standard [3]. It is recognised in the literature that it would be very difficult (if not impossible) to write learning outcomes in such a way as to enable student achievements to be graded.

Unlike other jurisdictions, the NCCA decided around 2010 that its curriculum **and syllabus design** template, for both junior and senior cycle syllabi, would consist ONLY of Learning Outcomes. The Subject Development Groups were informed that the design template, which had been used since the 1990s, would no longer be used. The new template would refer only to Learning Outcomes and would provide no other details. There would be no explanation of depth of treatment, nor would teacher guidelines be provided, nor any detail in relation to how the syllabi would be assessed. Concerns were expressed by teachers, academics, scientists and some employer organisations about such an approach - a concern that was recognised by the NCCA in a *Report on the Consultation*[4] issued in 2012. A report written by this author at that time highlighted the shortcomings of such an approach [5].

Later that year, in a report entitled *The Development of new Leaving Certificate science*

courses: background and process [6], the NCCA's Board of Studies for Science agreed to make changes to the proposed syllabus/specification design to include, *inter alia*, guidelines for teachers in the form of samples of teaching and learning material and sample assessment material that would clearly illustrate how differentiation happens at the point of assessment. An appendix to that report gave detailed examples of the type of material that would be available for teachers to explicate the new syllabi – material that mirrored that of other high-quality syllabi internationally. However, these recommendations were apparently not accepted by the NCCA Council and when the new Agricultural Science syllabus was released in January 2019, it consisted only of Learning Outcomes. To quote Jones: *"There was no depth of treatment, teacher guidelines or clarity on what detail the teacher needed to go into",* nor at that stage was any information provided on how the syllabus would be assessed. The frustration of teachers with this vague and unclear syllabus is documented and discussed very clearly in Jones's article.

The article by Jones refers to the challenges which faced teachers when confronted with the skeletal Leaving Cert. Agricultural Science syllabus, which was introduced in 2019 and was examined for the first time in June 2021. The learning outcomes of the syllabi/specification were (in Jones's words) *"poorly written, vague, overly long, lacking clarity, far too broad and (crucially) confusing".* They provided little clarity for the teacher on how much detail was required. Each individual teacher was required to ascertain for themselves the depth of treatment for each learning outcome and they could just hope that the SEC would interpret them in a similar way. The results of a survey (which had 280 responses) carried out by the Irish Agricultural Science Teachers Association (IASTA) in January 2021, indicated that the training which was provided by the Professional Development Service for Teachers (PDST) provided little clarity of the learning outcomes and how they were to be interpreted. When asked to rate the clarity of the learning outcomes in the syllabus on a scale of 1 (Very clear) to 5 (Not very clear) the vast majority of teachers were of the view that they were not very clear. (The average response was 4.23 with only one person choosing 1 on the scale). The survey showed that the lack of clarity had a direct effect on the teachers' confidence in judging the depth of treatment for each learning outcome. More than 70% of teachers replied that they were not very confident about what depth of treatment was required, while fewer than 1% were very confident.

The article goes on to compare the Leaving Certificate 2021 examination paper to the syllabus. Predictably, given the vagueness of the syllabus, there were multiple examples of how this vagueness affected the examination questions. According to Jones, there were several questions on topics not mentioned in the syllabus/specification or were outside the realm of the learning outcomes. Some examples of the mismatch between the syllabus and the examination questions are given with distressing consequences for students and teachers. A major question facing teachers of Agricultural Science in the coming years is whether they will base their teaching on the syllabus/specification or on the examination! Will it be a case (yet again) of *assessment wagging the tail of the curriculum dog??*

This author agrees unreservedly with the conclusions in Jones's article. The learning outcomes for Agricultural Science in their present form – and indeed any externally examined Leaving Certificate syllabus/specification that is defined **SOLELY** in terms of learning outcomes – are not fit for purpose. The NCCA should adopt international best practice and develop syllabi/specifications based on clearly stated learning outcomes with information about depth of treatment, guidelines for teachers about content, pedagogy, and application as well as assessment guidelines. This full information must be made available to teachers well in advance of the introduction of the new syllabi to enable them to familiarise themselves and, if necessary, update their own knowledge and skills prior to the introduction of the new syllabi.

The NCCA should reconsider the format which they have adopted in recent years to define Leaving Cert subject syllabi. To date, the only subjects which have been introduced using the new template are Computer Science; Politics and Society; Physical Education and Agricultural

Science – all of which are (in relative terms) subjects taken at Leaving Cert level by a minority of students. In 2021 for example, out of a possible 65,000+ Leaving Cert candidates, only 640 sat Computer Science; 1,992 sat Politics and Society; 1,501 sat Physical Education and 7,553 sat Agricultural Science. In terms of numbers, one cannot draw any valid conclusions from such a small sample in terms of student satisfaction or confidence. In relation to other subjects where the numbers of students taking the subject will be considerably greater, we can anticipate a national outcry in the future if there is such uncertainty about how subjects will be assessed and, in particular, if there is a lack of congruence between the syllabus/specification and the assessment/examination. Already teachers of other subjects, in particular Physics, Chemistry and Biology, as well as Gaeilge,[1] have registered their dismay at the proposed draft syllabi/specifications that are beginning to come to public notice. The NCCA and the Minister for Education are committed to consulting widely before they finalise and introduce the new syllabi/specification. Let's hope that the voices of the teachers are listened to and that and their views and concerns will be treated with the respect and dignity which they deserve. Ireland is fortunate in the very high calibre and professionality of its teachers. This article by Humphrey Jones is testament to that high standard.

□

1. [1] NCCA, *Towards Learning: An Overview of Senior Cycle Education,* 2009.
2. [1] PISA measures 16-year old students' ability to use their reading, mathematics and science knowledge and skills to meet real-life challenges.
3. [1] Jenny Moon, *Linking Levels, Learning Outcomes and Assessment Criteria.*
4. [1] NCCA, *Report on the Consultation on Leaving Certificate Science,* 2012.
5. [1] Áine Hyland, *The design of Leaving Certificate science syllabi in Ireland: an international comparison.* Irish Science Teacher' Association, April 2014.
6. [1] NCCA *The Development of new Leaving Certificate science courses: background and process,* (unpublished paper) May 2014.

Is science for me? A card game for vocational orientation in science

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Abstract

This article presents a card game for vocational orientation in science. The aim of the card game is to engage students in conversations on working in science-related fields, in order to activate or to create science-related social capital. The game exists in two versions: version (1) can be played by a female student and a parent or significant other, version (2) can be played by two students.

Challenges for vocational orientation in science

Helping young people choose a profession or a direction for further education after secondary school is a vital function of schools. Teachers play an important role in this career guidance since they (i) possess valuable knowledge on their subject areas and career opportunities in these fields and (ii) know some of their students' strengths and preferences.

However, the field of science and technology is particularly challenging for teachers who seek to guide their students in their career choices. Considerable inequalities exist in this field: the career aspirations of young people concerning science are strongly influenced by gender, social class, and ethnicity. Young women tend to show lower science aspirations than young men (Archer *et al.,* 2010), a trend that is reflected in the underrepresentation of women in science-related professions in many countries (OECD, 2009). Moreover, young people from lower social classes and from ethnic minorities tend to show lower science aspirations than young people from the middle-class and of dominant ethnicity (Archer *et al*., 2015; Carlone *et al.,* 2015).

One mechanism through which the existing inequalities in science and technology are perpetuated seems to be the reproduction within families. Parents have a major influence on their children's career orientation (Esch & Grosche, 2011). This means that, for instance, knowledge about career options in the field of science can be transmitted in families – but only in those families that possess this type of knowledge. It has been shown that in families of lower social status, knowledge about science-related careers tends to be limited (Archer *et al.,* 2015). This unequal distribution of knowledge in families could contribute to the reproduction of inequalities over generations. For chemistry, research has shown that students' home environments have a powerful influence on their chemistry knowledge and their identification with and attitudes towards chemistry (Rüschenpöhler & Markic, 2020). This is especially true of girls of non-dominant ethnicity who wish for more professional career guidance in science (Rüschenpöhler *et al*., 2020).

Science-related resources at home (science knowledge, positive attitudes towards science, etc.) are part of a student's science capital (Archer *et al.,* 2015), or in the case of chemistry, they are part of this person's chemistry capital (Rüschenpöhler & Markic, 2020). Science capital can be defined as the entirety of resources a person possesses that have value in the field of science. Analogously, chemistry capital is all resources that have value in the field of chemistry.

The card game

The project DiSenSu ("Diversity Sensitive Support: vocational orientation in STEM for female adolescents with migration background in cooperation with parents") provides interventions for vocational orientation that seek to contribute to a greater diversification within the field of science. It focuses on the support of young women of non-dominant ethnicity in their vocational orientation in science. This is done using the concepts of science and chemistry capital because these can help to identify mechanisms through which the acquisition of resources could be supported (Rüschenpöhler & Markic, 2020).

As part of this project, a card game was developed which seeks to engage girls and young women with migration background and their relatives (e.g., parents, aunts, uncles) in conversations about science professions. The goal is to initiate discussions between the players that could be continued at home, and also to encourage the questioning of internalised stereotypes. The game is thus based on the concept of science capital (Archer *et al.,* 2015) and seeks to engage the players in conversations for:

- sharing emotions towards the choice of a profession,
- exchanging knowledge, experiences with or attitudes towards science-related jobs,
- initiating next steps in career orientation.

This article presents contexts in which the game can be used, as well as the game itself (playing cards and rules of the game). The complete game is available in German language (Hönig *et al*., 2021).

Contexts in which the game can be used

The game exists in two versions. Version (1) can be played between a young woman and a parent or some significant other. This version can be employed in a number of contexts in which a parent is present with a young woman. For instance, it can be employed at a parent's evening in school, during vocational orientation days, at school festivals, and at home (e.g., as homework). Version (2) is designed for two young women to play together. It can be played during chemistry or science lessons or in some other context inside and outside school in which young women are present.

Playing cards and rules of the game

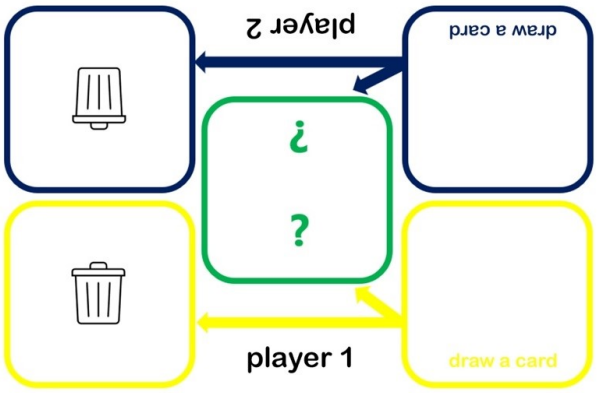

Figure 1: Board for game version 1 (a young woman plays with a parent).

The game requires a board (Figure 1) and a set of playing cards (for examples see Figure 2). The cards are based on four types of content:

(1) *Reflecting on careers in science.* These cards provide information on selected professions in science and technology, combined with a question. This type of card seeks to encourage the players to reflect on their attitude towards this profession and to exchange knowledge and experiences regarding this profession.
(2) *Getting feedback.* With these cards, the player can get feedback about e.g., how the other player perceives the young woman's potential regarding science professions.
(3) *Reflecting on the process of vocational orientation.* Some of these cards contain questions on the process of vocational orientation in science, while others seek to initiate a reflection on the process of vocational orientation in general.
(4) *Imagining working in a job in science.* These cards encourage taking over a new perspective. The players are asked to imagine working in a specific science-related job or being in a typical situation (some of them gender-related).

During the game, each player has 5 cards on the hand, and they play their cards alternately. At each round, the player decides on one card he or she wants to play and one card that goes to the bin. After each round, the players draw two additional cards. The game ends when either all cards are played or when time is over. It is thus

not a conventional game because the players cannot win or lose the game.

<table>
<tr>
<td>(1)
Imagine working in this job.
What would that be like for you?
 
© Portra/DigitalVision
Angelina, lab technician specialised in lacquers
I develop new lacquers and monitor their quality. I work both in the lab and on the production site where we test the lacquers.
Tasks. Developing lacquers, testing, and optimizing the formulae, monitoring their quality.</td>
<td>(2)
In which field can you imagine me working later?
 
© colourbox.com</td>
</tr>
<tr>
<td>(3)
What fears do you have regarding your career choice?
 
© colourbox.com</td>
<td>(4)
Imagine you work in a job that you don't like at all. What does this job look like? What don't you like about this job?
 
© colourbox.com</td>
</tr>
</table>

Figure 2: Examples for the four categories of cards (Hönig et al., 2021).

Experiences with the game

To obtain feedback on the game, version (1) (a young woman playing with a parent) was tested with 13 pairs of players (26 people). Due to the COVID-19 pandemic, this research was done with an online version of the game. Version (2) (two young women playing together) was tested with 27 secondary school students (Küsel *et al.,* submitted).

The results of this evaluation show that the game can initiate conversations on vocational orientation in science without the intervention of a third party (teacher, professional counsellor). The game allows significant others (e.g., parents, friends) to take an active role in the vocational orientation process of young women. This engagement can strengthen the young women's science capital because talking about science professions, about one's fears and doubts regarding this field, can be a first step towards a deeper reflection on science careers. This is especially important for those students who do not have a partner with whom they have established this kind of conversation in the home environment. The game fosters particularly

emotional support for the young women in their reflection on science careers.

In order to employ the game successfully, all players need an understanding of what science is and which types of professions could be science-related. It could thus be fruitful to prepare the students in class for the game, allowing them to discover professions in science and the aspects that qualify these professions as science related.

Acknowledgments

This research was funded by the Federal Ministry of Education and Research as part of the project "Diversity Sensitive Support: vocational orientation in STEM for female adolescents with migration background in cooperation with parents (DiSenSu)". Funding reference numbers 01FP1725 and 01FP1726.

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Biographies

Julian Küsel studied Chemistry and History at the University of Bremen for teaching in secondary school. Currently, he is a PhD student at Ludwigsburg University of Education and has been working for seven years in the production of digital media for educational purposes. His thesis focuses on digital media use in science teacher education at primary and secondary levels.

Marina Hönig has been teaching chemistry, mathematics, and biology in secondary school for 10 years and worked at Ludwigsburg University of Education between 2018 and 2021 in the project DiSenSu.

Lilith Rüschenpöhler obtained her PhD in chemistry education in 2020 at Ludwigsburg University of Education. Since then, she has been working both in school and at university. Her research interests include chemistry self-concept research, social inequalities in science, chemistry capital, and culture-sensitive chemistry teaching.

Silvija Markic is a professor for science education (major: chemistry education) at Ludwigsburg University of Education in Germany. Her research focuses on linguistic heterogeneity and cultural diversity in chemistry and science education, science teachers' continuous professional development based on their beliefs, pedagogical content knowledge, pedagogical scientific language knowledge, and alternative teaching approaches.

□

Elementary Chemistry

Engage your students with elemental facts

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I was once the proud owner of a pair of rectangular white cufflinks decorated in crisp black print with the names, symbols, atomic numbers, and atomic weights of beryllium and erbium. They occasionally proved a great conversation starter when out socially because with my wrists held together they spelled the word 'BeEr'. Sadly, I must concede that the conversations often fizzled out as I was unable to follow up my initial flourish with any memorable quirky facts or trivia about either element. At the time this was a slightly disconcerting realisation – I was supposed to be a chemist, after all; and what's more, an educator! I therefore committed to learning more about the chemical elements, and in no time, I was hooked.

Be, Beryllium

It turns out that beryllium played a central role in the discovery of the neutron because when English physicist James Chadwick bombarded a sample of beryllium with alpha particles in 1932, the metal responded by emitting some previously unobserved particles. Chadwick noted that these particles possessed about the same mass as the proton but were electrically neutral. From this he correctly deduced the existence of a new subatomic particle, the neutron, and earned himself a Nobel Prize in Physics for his efforts.

Er, Erbium

And as for erbium, well it really does deserve to be a better-known element because it helps make possible the high-speed global transmission of internet and telecommunications data. The data are transmitted via light signals that scatter and thus deteriorate in intensity as they travel through fibre optic cables. Thankfully, the cables are doped every 20 to 50 km with erbium, which works (with some help from laser diodes) to effectively restore the light signals' intensity, thus ensuring our YouTube clips don't stall mid-streaming.

Quirky elemental facts

Over about five years, I compiled a sizeable stock of interesting and quirky facts about all

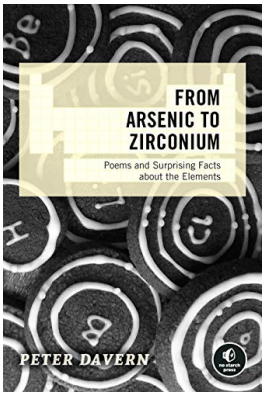
of the naturally-occurring chemical elements. Not only was this an enjoyable pastime, but I believe it also improved the quality of my teaching, as follows. Perhaps like many educators, I am all too familiar with the tell-tale signs of disengagement and drift among my students midway through a class – that slightly vacant distance gaze, the sagging shoulders, the fatigued, slouched posture, and the (sometimes not so) furtive glance at a mobile phone. This is my cue to call upon one or two of my quirky chemical element facts that are either directly or loosely related (or sometimes, just for the hell of it, completely unrelated) to the topic I am teaching.

For example, when explaining electronegativity trends on the periodic table, I might pause and highlight the metalloid antimony; not because its electronegativity is particularly noteworthy, but rather to describe how its toxicity was put to good use to treat constipation during the Middle Ages. Back then, a person would swallow a pea-sized antimony pill, which irritated the intestines to cause a relieving, laxative purge! The offending (yet medicinally invaluable) pill would then be retrieved from the projectile-esque faeces, hopefully cleaned, and retained for future use. Another type of purging effect could be produced using wine left standing overnight in an antimony goblet. Enough antimony dissolved in the wine to make the resulting potion a powerful emetic (a vomit inducer). Indeed, antimony tartrate (the metalloid's salt with tartaric acid) was widely prescribed by 17th and 18th century physicians as an emetic. It has even been suggested that the composer Mozart's untimely death in 1791 at the age of 35 was due to excessive self-administration of the antimony tartrate prescribed for him to treat an illness. Imparting quirky facts like these in a fairly spontaneous and light-hearted manner usually has the desired effect of re-engaging my students for a few more minutes, at least; and if somehow associating electronegativity with the mental image of cleaning a soiled antimony pill helps to embed the concept of electronegativity in their minds, then all the better.

Another example of an interesting nugget of quirky elemental trivia has to do with how metallic tin transforms to a powdery, grey solid when cooled below 13°C. This transformation has been observed during prolonged periods of cold, wintery weather. For example, the majestic tin organ pipes in some churches have developed some unsightly grey patches (known as tin plague or tin pest) that crumble to dust when touched. Perhaps more interestingly, though, the phenomenon was also implicated – admittedly, 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.

Make no mistake, there is a quirky story or two to tell about each and every naturally-occurring chemical element, and I have found it to be no burden to have a handful on standby to lift my students' flagging spirits, when needed. As for my 'BeEr' cufflinks, sadly I lost 'Be', and therefore switched to a similarly styled pair depicting oxygen and magnesium instead. So now when out socially I can hold my wrists aloft whenever my friends come out with something truly startling – 'OMg' (OMG, Oh my God, that's amazing!). And now, at least, I can back up my display of amazement with details of how ozone is generated by lightning storms and photocopiers alike, and how magnesium, once ignited, burns relentlessly with a 'camera flash' brightness that is extremely difficult to extinguish.

Peter Davern (peter.davern@ul.ie) is a lecturer in the Department of Chemical Sciences at the University of Limerick, and author of *"From Arsenic to Zirconium: Poems and Surprising Facts about the Elements"*, No Starch Press (San Francisco), 2020, which contains many quirky facts about the elements.



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Editor: I hope Peter will search out some more quirky elemental facts for future issues of *Chemistry in Action!*

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For more information contact Dr Peter Davern at peter.davern@ul.ie and to sponsor an element go to https://csperiodic.myshopify.com/

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Chemists you should know: 9

Joseph Louis Gay-Lussac:

(6 December 1778 – 9 May 1850)

Adrian J. Ryder
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Figure 1: Louis Joseph Gay-Lussac

The subject of this essay, Joseph Louis Gay-Lussac, was born at Saint-Léonard-de-Noblat in the present-day department of Haute-Vienne, 21 Km from Limoges, in France.

His father, Anthony Gay, (1744-1819), son of Louis Gay, a doctor, and Marguerite de Lonoailhe de Soumagne (1719-1750), was a lawyer and prosecutor and worked as a judge in Noblat Bridge. The father of two sons and three daughters, he owned much of the Lussac village and usually added the name of this hamlet of the Haute-Vienne to his name. This followed a custom of the time whereby a family added the name of their town to distinguish themselves from others of the same surname. About 1803, following the French revolution, father and son finally adopted the name Gay-Lussac permanently.

Anthony married Léonarde Bouriquet on the 19th January 1770. Anthony was a king's attorney but fell foul of Robespierre's reign of terror and was imprisoned in Saint Leonard Prison in 1793. He was fortunate to escape the guillotine and following the execution of Robespierre on July 28th 1794, was released but had lost much of his sources of income.

The children of Anthony Gay were Fanchette, Marguerite, Mariette, Joseph Louis and Pierre-François. Although not the eldest child, Joseph Louis was the elder of the two boys by a year.

Pierre-François, the second boy, was born 24th December 1779 and went on to study medicine and was an army doctor in Italy, after which he returned to St Léonard where he practised and became Mayor and Justice of the Peace. He married Marianne Eustachie Texier-Descobes on the 23rd of September 1812, with one daughter, Joséphine Rose (1818-1875) recorded to the couple. Joséphine married François Émile Massoulard and the couple had one child, Antoine 1843-1882. Pierre-François died on 28th July 1854.

Education and early career

Joseph Louis received an irregular early education which omitted any science or mathematics at the hands of various teachers, including members of the Catholic Abbey of Bourdeix, though later in life he became an atheist. Sent to the care of the Abbot of Dumonteil in 1794, he began his education in Paris, meeting with the sciences and mathematics for the first time and finally entered the École Polytechnique on the 27/12/1797, having been fortunate to narrowly avoid conscription. Here he found he had a special gift for chemistry, which stood to him for the rest of his life. He was given a post in the École teaching mathematics for which he received the small sum of 60 fr per month. The usual scholarships available were 30 fr, and these payments he received were sufficient to allow him to cease being a burden on the family finances, which had diminished greatly during the revolutionary times.

Three years later, 22/11/1800, Gay Lussac graduated in the highest group of his class and

transferred to the École des Ponts et Chaussées, and shortly afterward was assigned to C. L. Berthollet (1768 – 1822), a well-known chemist, as his assistant, spending time with him in his home in Arcueil in the southern suburbs of Paris. Here he was able to experiment freely and put together for himself a rich collection of physics and chemical instruments. In 1802 he was appointed demonstrator to A. F. Fourcroy at the École Polytechnique, wherein (1809) he became the professor of chemistry. From 1808 to 1832, he was also the professor of physics at the Sorbonne, a post which he only resigned for the chair of chemistry at the Jardin des Plantes in 1832. In 1821, he was elected a foreign member of the Royal Swedish Academy of Sciences.

Scientific work

As part of his experimental work with C. L. Berthollet, Gay Lussac took up the investigation of gases and examined Charles's results, of 1787, in much stricter detail. His experimental results confirmed Charles's findings, that volume divided by absolute temperature is a constant. These results were published in 1802, Gay-Lussac unselfishly giving the credit to Charles. Further encouraged by the Hydrogen balloon flights of Charles, on August 23rd 1804 he and Jean-Baptiste Biot ascended by balloon from the garden of the Conservatory in Paris to some 4000 metres (Figure 2), investigating the magnetic field at different altitudes. In a solo flight three weeks later on the 16th September, Gay Lussac ascended to over 7,000 metres, taking samples of the air at different heights using evacuated jars. These samples were examined by himself and his collaborator Alexander Von Humboldt, finding that the composition ratio of gases remained the same at different altitudes. The pair went on to discover that water is composed of two parts hydrogen to one part oxygen by volume. This led to Gay Lussac's "Law of Combining Volumes", which states that when different gases react they always do so in small whole number ratios by volume. In 1809 he formulated his law which states that when the mass and volume of a gas are kept constant, pressure varies directly with absolute temperature.

Figure 2: Gay-Lussac and Biot on their balloon flight
Early flight 02561u (5) - File:Early flight 02561u (2).jpg - Wikipedia

Joseph Louis married Geneviève-Marie-Joséphine Rojot on the 1st June 1809. He had first met her when she worked as a linen draper's shop assistant and was studying a chemistry textbook under the counter. He fathered five children, of whom the eldest boy, (Jules 1810-1877), became assistant to Justus Liebig in Giessen. Some publications by Jules are mistaken as his father's today since they share the same first initial (J. Gay-Lussac). The other children were Virginie Henriette Antonine (born about 1809), who married Barham Cole-Mergez and had a son Paul Cole-Mergez (1830-1855); Joséphine Éléonore (1811-1891), who married on the 25th January 1834 Adrien Charles Calley Saint-Paul de Sinçay (1808-1873) with no recorded children; Louis Frédéric (1813-1903),who married on the 16th December 1839 Adelma Trudeau (1822-1908) and had one child Henri Rene Joseph (1840-1904); and Gabriel (1819-1883) who appears not to have married.

In 1816 the prestigious journal *Annales de Chimie et de Physique* was first published.

Gay-Lussac and François Arago (1786-1853) were the first editors. The partnership continued through some 134 editions over the rest of his life.

In 1818 he was appointed to the Commission of Powder and Saltpetre, where he developed methods for the analysis of the purity of the gunpowder for the army, conducting the experiments himself regularly over the following years. Gay-Lussac was largely responsible for the development of the science of volumetric analysis and an 1824 paper is notable for the first use of the terms pipette and burette for those pieces of apparatus that have since become standard equipment in chemistry. His apparatus was an improvement on items used earlier by Descroizilles and Welter. Gay-Lussac's pipette has essentially the form of its modern counterpart, but his burette was more like a graduated cylinder with a connecting side arm. A later paper of 1828 shows the use of a one-litre volumetric flask. During his lifetime he published more than 180 memoirs on pure and applied science, his last being one on Aqua-Regia and its uses in 1848.

In 1831, 1834 and 1837 he was elected to represent Haute-Vienne in the chamber of deputies, and in 1839, having previously refused a title from Charles X, he was honoured by Louis Philippe with a nomination to the house of peers.. He was elected a Foreign Honorary Member of the American Academy of Arts and Sciences in 1832. He was also a Member of the Royal Prussian Academy, the Royal Society of London, the Imperial Academy of Russia and many other Scientific Societies.

In 1848 (the year of revolutions) Gay-Lussac stepped down from his various appointments and retired to a country house in his childhood neighbourhood of Lussac, which held his extensive library and a private laboratory, where he began his day between four and five am. In the early part of 1850, realising that he was dying, he told his son to burn his unfinished work *"Philosophie Chimique"* as he was not satisfied it was fit for printing.

Gay-Lussac died in Paris on the ninth of May 1850 and his grave is there at plot 26, Père Lachaise Cemetery (near the Alexandre Dumas Metro Station).

Figure 3: Gay-Lussac's grave (2008)

Figure 4: Close-up of the inscription

JOSEPH LOUIS GAY-LUSSAC MEMBRE DE
L'ACADEMIE DES SCIENCES ET DE TOUTES
LES SOCIETIES SAVANTES D'EUROPE GRAND
OFFICER DE LA LEGION D'HONNAUR ANCIEN
PAIR DE FRANCE, NE A ST. LEONARD (HVIENNE)
NE 6 DE 1778 MORT A PARIS LE 9 MAI 1850

His name is one of the 72 eminent scientists' names, 13 of whom are chemists, inscribed on the Eiffel Tower in Paris just below the first platform shown in the photograph below. His name is the second on the left of the south-west side in between those of Jules Jamien and Hippolyte Fizeau, both physicists. Streets in Paris, Grenoble, Évreux, Vannes and Poitiers have been named in his honour.

Figure 5: First and second platforms of the Eiffel Tower

Figure 6: 10f + 3f postage stamp issued to commemorate 100 years since the death of Gay-Lussac, issued on the 4th of June 1951.

Achievements (Joseph Louis Gay-Lussac - Achievements (liquisearch.com)

- 1802 – Gay-Lussac first formulated the law, Gay-Lussac's Law, stating that if the mass and pressure of a gas are held constant then gas volume increases linearly as the temperature rises. This is sometimes written as V = k T, where k is a constant dependent on the type, mass, and pressure of the gas and T is temperature on an absolute scale (in terms of the ideal gas law, k = n·R/P).
- 1804 – He and Jean-Baptiste Biot made a hot-air balloon ascent to a height of 7016 metres (23,000 feet) in an early investigation of the Earth's atmosphere. He wanted to collect samples of the air at different heights to record differences in temperature and moisture.
- 1805 – Together with his friend and scientific collaborator Alexander von Humboldt, he discovered that the composition of the atmosphere does not change with decreasing pressure (increasing altitude). They also discovered that water is formed by two parts of hydrogen and one part of oxygen (by volume).
- 1808 – He was the co-discoverer of boron with Louis Thenard.
- 1810 – In collaboration with Louis Thenard, he developed a method for quantitative elemental analysis by measuring the CO_2 and O_2 evolved by reaction with potassium chlorate.
- 1811 – He recognized iodine as a new element, described its properties, and suggested the name *iode* (in English iodine, from the colour of its vapour).
- 1824 – He developed an improved version of the burette that included a side arm, and coined the terms "pipette" and "burette" in an 1824 paper about the standardization of indigo solutions.

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Chemical Quotations:
Joseph Louis Gay-Lussac (1778-1850)

File:Portrait of Louis-Joseph Gay-Lussac (1778 - 1850) chemist Wellcome V0002196.jpg - Wikimedia Commons

"In order to draw any conclusion... it is prudent to wait until more numerous and exact observations have provided a solid foundation on which we may build a rigorous theory."

Joseph Louis Gay-Lussac

Chemical Myths Exploded! #3

Intermolecular forces and bonds

Intermolecular forces (bonds) is a topic that students often fund difficult and an area rife with misconceptions.

Misconception: Covalent compounds have low melting points (mpts) and boiling points (bpts) and are usually soft, so covalent bonding must be weak (also when compared with ionic bonding.)

This is a misconception because the bonds which are broken when covalent compounds melt or boil are **not** the strong covalent bonds that hold the atoms together **within** a molecule (**intra**molecular), but the much weaker **inter**molecular forces **between** molecules. A molecular substance (like water, methane, sugar, urea etc.) consists of enormous numbers (Avogadro's numbers!) of identical molecules, with 2 or more atoms joined together by strong covalent bonds. When a molecular substance melts or boils the molecules are unchanged; they merely move around faster and separate from each other. Thus the same molecules exist in the solid, the liquid and the gas. Breaking covalent bonds to form atoms or smaller fragments takes much higher temperatures and is very difficult. This is why chemical reactions involving bond breaking requires a catalyst or higher temperatures.

The mpt and bpt of any substance reflects the strength of bonding between the component particles – which may be molecules (covalent molecular compounds), atoms (metals or alloys, covalent networks or noble gases), or ions (ionic compounds). When we supply heat to a substance, the energy makes the particles move faster and faster, until first the bonding that makes it a solid breaks down (at the mpt). As more heat is added, the particles move faster in the liquid until the vapour pressure equals atmospheric pressure, and then the substance boils producing a gas. The stronger the bonds between the particles, the higher the mpt and bpt will be, as more energy is needed to overcome the attractive forces holding particles together.

One problem in this topic is a confusion over terms.

Covalent bonds holding molecules together are i**ntra**molecular bonds – the bonds **within** a molecule which hold the atoms together, and are responsible for chemical properties. They are usually strong.
Van der Waals bonds (another generic term) are **inter**molecular bonds – the bonds **between** molecules, responsible for physical properties. They are usually weak.

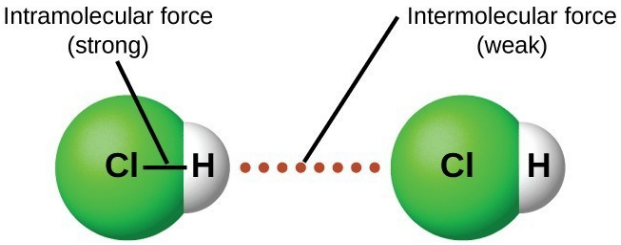

Figure 1: Intramolecular and intermolecular forces compared
(see https://courses.lumenlearning.com/chemistryformajorsxmaster/chapter/intermolecular-forces/)

In water it takes 415 kJ/mol to break the O-H bond (an **intra**molecular bond) and only 41 kJ/mol to break the hydrogen bonding (a strong **inter**molecular bond) between molecules. Covalent molecular compounds thus involve two sorts of bonding: within (strong) and between (weak) molecules.

Covalent network solids like diamond, silicon and silicon dioxide have giant structures, **with no molecules**, and all the atoms are joined to each other in a network by strong covalent bonds. These substances thus have high mpts and bpts, because to melt and boil the substances means breaking strong covalent bonds.

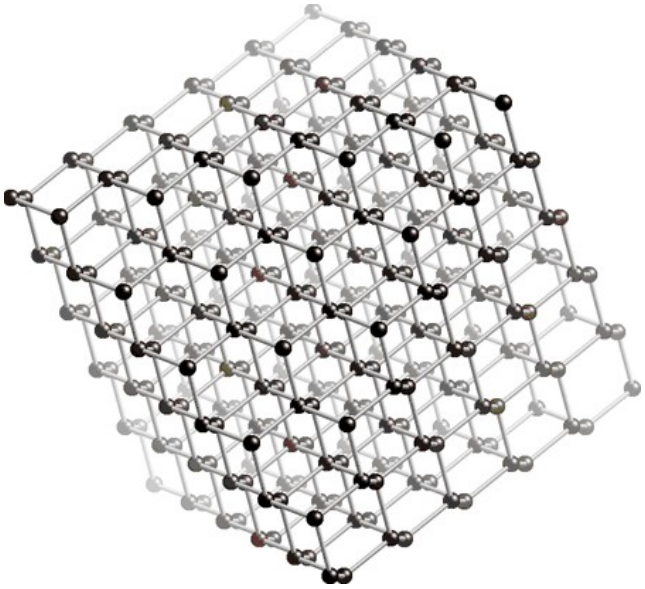

Figure 2: A representation of the diamond structure, a giant network structure, covalently bonded – it goes on forever in 3 dimensions; there are no isolated molecules.
http://sci-culture.com/advancedpoll/GCSE/diamond.htm

Dihydrogen, H_2, is the smallest molecule and has weak intermolecular bonds, but a strong H-H covalent bond. Its mpt is –259.2°C and its bpt is –252.9°C , so it is a gas at room temperature and has a very small liquid range. Only a small fraction of hydrogen molecules are dissociated into atoms even at very high temperatures, because the H-H covalent bond is very strong (436 kJ/mol).

Another confusion of terms

Misconception: A hydrogen bond is formed when hydrogen is bonded directly to an electronegative element like O, N or F, e.g. O-H.

We often talk about hydrogen when we mean hydrogen gas, H_2 or more correctly, dihydrogen gas. When we break the strong covalent H-H bond we get hydrogen atoms. But when we talk about the 'hydrogen bond' we mean the weak bond between a hydrogen atom strongly bonded to a highly electronegative atom (O, N, F) **and** weakly to the same electronegative atom on another molecule, e.g. H-O-H---OH_2 (Figure 3). We do not mean the strong covalent bond hydrogen makes directly to the other non-metal atom.

The hydrogen bond is one of the strongest intermolecular bonds but is still only ~41 kJ/mol compared to 436 kJ/mol for the covalent H-H bond. It's a pity that another term isn't used for the intermolecular hydrogen bond, as it often confuses students. It is the hydrogen bond which is responsible for the relatively high mpt and bpt of water, which are much higher than the molecular mass would suggest.

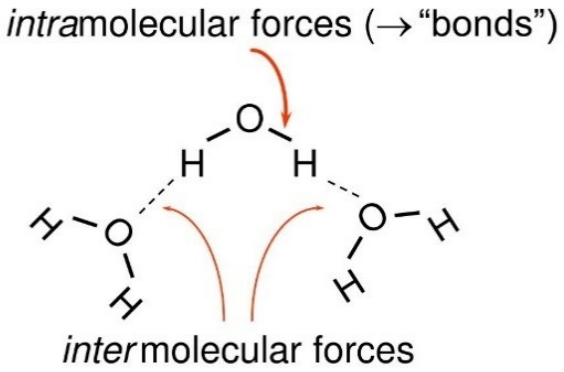

Figure 3: Intra- and intermolecular forces in water; the hydrogen bond is an intermolecular bond

Intermolecular bonds determine the physical properties of molecular substances: mpt, bpt, viscosity, hardness (in solids), vapour pressure etc. In all these processes the molecules are unchanged and only weak intermolecular bonds are broken and formed.
Intramolecular bonds determine chemical properties of molecules, such as rates of reaction, dissociation energies, heats of reaction etc. as chemical changes involve breaking and making strong covalent bonds. This is why we nearly always need heat and/or a catalyst for organic reactions to proceed at a reasonable rate. Compare, for example, the reaction of $KMnO_4$(aq) with ethanedioic (oxalic) acid and with iron(II) compounds; the first requires heat to start the reaction, the second does not.

Forces or bonds?

Sometimes books talk about forces and sometimes about bonds, e.g. intermolecular forces and intermolecular bonds. **What's the difference between a force and a bond?**
In an atom and in a molecule, we have attractive forces (between opposite charges – electrons and the positive nucleus) and repulsive forces (between like charges, between nuclei or between electrons).

All types of chemical bonding are a balance between attractive and repulsive forces.

Attractive forces pull atoms together, lowering the energy; repulsive forces force atom apart, raising the energy. If attractive and repulsive forces behaved in the same ways, atoms would not stick together. Fortunately, attractive forces increase as $1/r^2$ so they operate at relatively large distances (in atomic terms), whereas repulsive forces increase as $1/r^6$ so they only become important at short distances. The overall energy is a balance of attraction and repulsion – atoms are pulled together until the attractive and repulsive forces balance and then an equilibrium is achieved at a potential energy (PE) minimum. This is usually shown in a PE diagram (Figure 4 below), which can be drawn for **any** type of bonding. (All types of bond involve a balance between attractive and repulsive forces.) A strong covalent bond will have a deep minimum and a short bond; a weak intermolecular bond will have a shallow minimum and a long bond.

We will focus on forming a covalent molecule from atoms for simplicity. The minimum of the curve corresponds to equilibrium and the average bond length (r_o). The energy is lower at the minimum than in the starting atoms, and this energy is given out during the process as the atoms come together. When there is a minimum in the PE curve, we say a chemical bond has formed and the resultant molecule is more stable than its component atoms. If we supply energy to the molecule, it starts to vibrate and if we supply enough energy (equal to the minimum, the bond energy), the atoms will fly apart again. Attraction lowers the energy; repulsion raises the energy. The balance of forces produces a lowering of energy, which we call a bond.

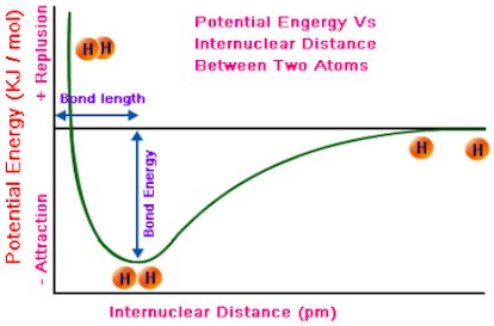

Figure 3: The PE curve for a molecule, e..g. H_2

The **deeper** the minimum the **stronger** the bond and the **more** energy is required to break it. The distance between the atoms at the minimum corresponds to the bond length. A weaker bond will have a longer bond and a lower minimum. The minimum also corresponds to the bond energy – energy given out when a bond forms (exothermic) or taken in when it is broken (endothermic). The bond is 'elastic' like a spring: if we stretch it will spring back and if we squeeze it, it will spring back. Thus a good model of a chemical bond is a spring connecting two balls (Figure 5). It can be stretched or compressed, but will return to its original position when released.

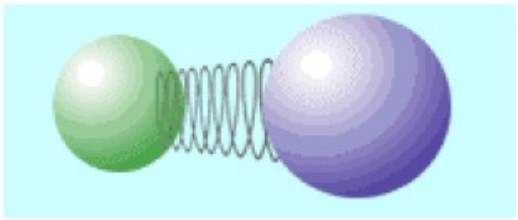

Figure 5: The chemical bond envisaged as a spring.

Another useful model of bonding involves placing two ring magnets on a vertical wire (or pencil) with same poles facing each other. The magnets will fall under gravity (attraction) but when they get close, they are held apart by magnetic repulsion (Figure 6). If we compress them together, they will spring back to an equilibrium position. If the magnets are glued to two polystyrene balls, this makes a nice model of a chemical bond in a molecule.

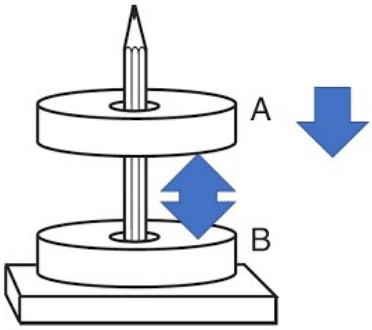

Figure 6: A simple model of chemical bonding – a balance of gravitational and magnetic forces

In the next Chemical Myths # 4 we will look in more detail at intermolecular forces and the bonds they produce.

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If you have any questions about bonding and intermolecular forces that haven't been answered, or on any other chemical 'mythconceptions', send your queries to peter.childs@ul.ie and the answer may appear in a later issue.

The climate change crisis and conundrum

You can't escape the topic of climate change and the threat it poses to the world, as a result of our unbridled appetite for fossil fuels since the industrial revolution. I have been aware of this since the 1980s and taught about it for many years in a course on Environmental Chemistry. In this article I want to present some of the current data on this topic to inform our teaching. However, although CO_2 is targeted as the main culprit in climate change, we must not forget that it also has beneficial aspects (See CO_2 – the Janus molecule below).

It is often pointed out that Ireland has one of the highest per capita greenhouse emissions, but this is somewhat misleading. What really matters is the total emissions, which contribute to global emissions. When we look at this Ireland is a very minor player. Our total annual emissions are offset in one year by the **increase** in emissions from China. The annual emission of CO_{2eq} in 2020 for Ireland was 59.78 Mt (EPA). Note that CO_2 isn't the only greenhouse gas and CO_{2eq} includes the effect of other gases such as CH_4 and N_2O. Some figures quote only CO_2 but this is about 75% of the total greenhouse emissions. Figure 1 shows annual emissions by country – Ireland is probably lost within the Rest of the World. It is a minor player even in the EU. (Note: 1 Gt = 1,000 Mt)

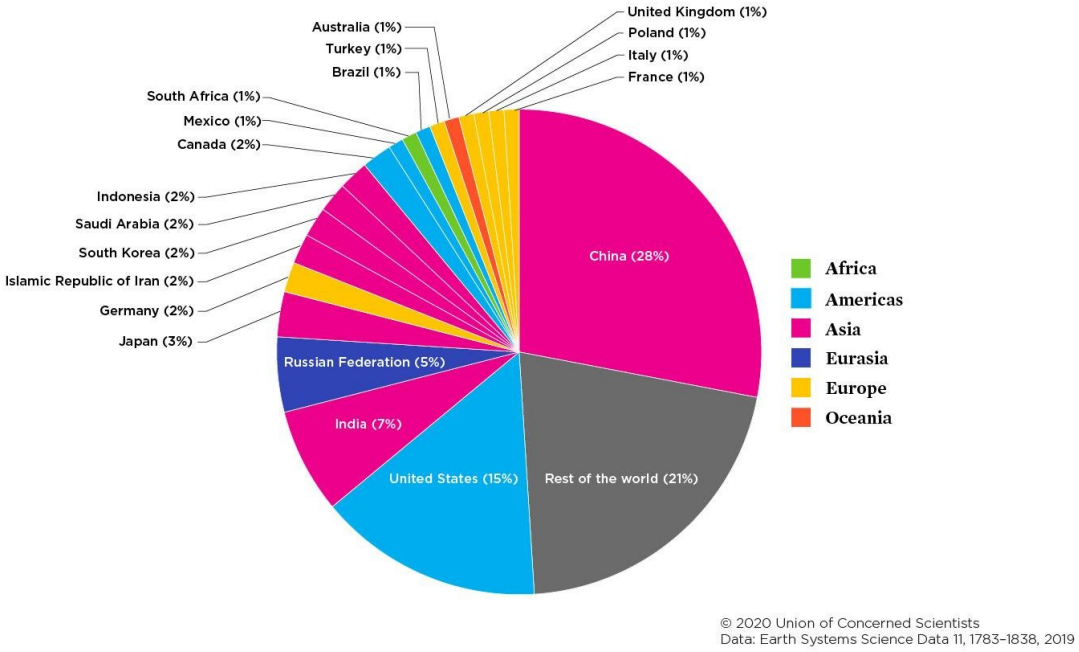


Figure 1: Global CO_2 emissions by country

In 2019 the world emissions were 36.4 Gt, going down to 34.0 Gt in 2020 (-6.4%). This drop was due to the economic effect of Covid - a rather drastic way to reduce global emissions. Ireland's contribution in 2020 was 59.78 Mt (down 5.9% on 2019), making it 0.176% of global emissions. From the chart above you can see the UK is 1%. China emits 28%, the USA 15%, India 7% and Russia 5% These are the big beasts of global emissions. These data mean that Ireland emits only 0.63 % of China's emissions. This means that if Ireland reduced its emissions to zero (an almost impossible target) it would have **no** significant effect on global emissions. Indeed the annual increases from China alone would greatly outweigh it. The same would be true of the UK, which is also a relatively small player. We should still reduce our energy use and switch, where

possible, to renewables, but we shouldn't fool ourselves that it would have any global effect. We might end up crippling our economy for no real gain. We could think of the global economy as a supertanker: very difficult to slow down and our contribution in Ireland would be like throwing a lifeboat overboard to slow it down. Figure 2 shows the rise in emissions by region since 1751.

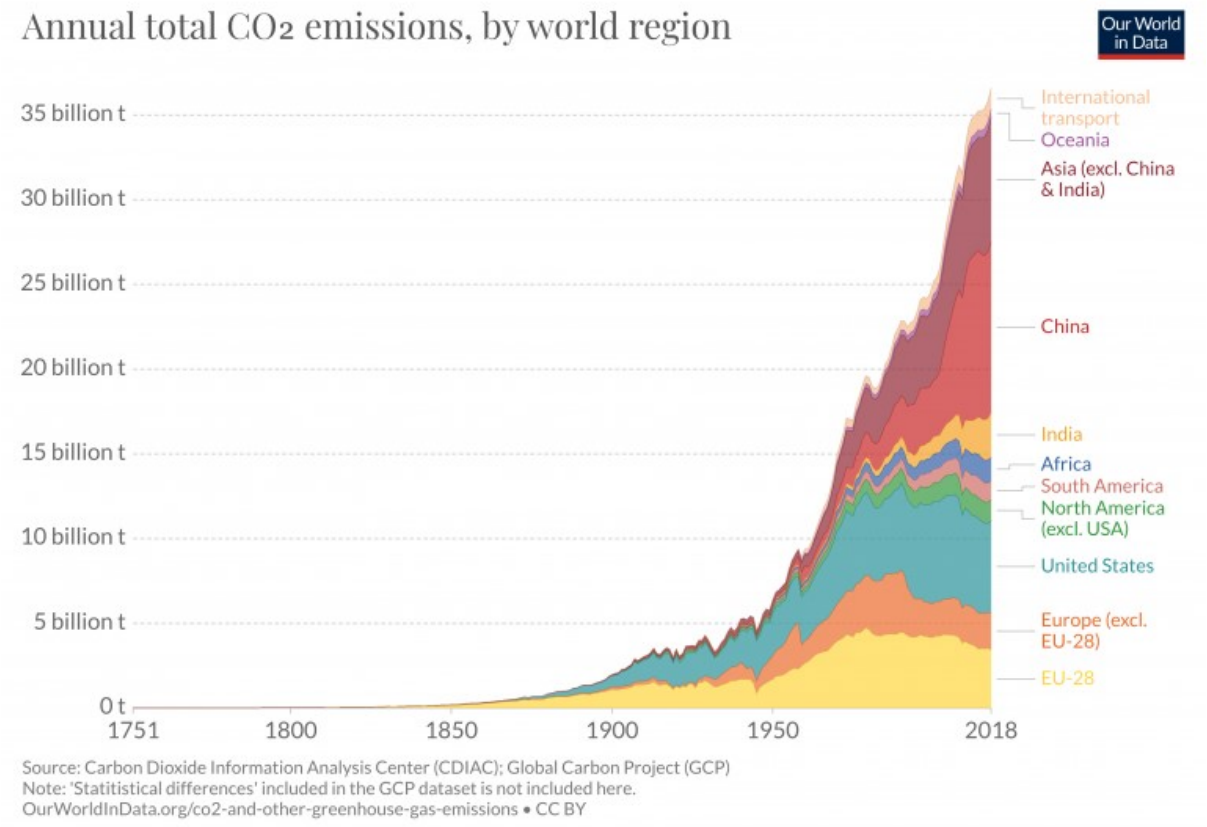


Figure 2: Global emissions by region
Source: [CO2 emissions - Our World in Data]

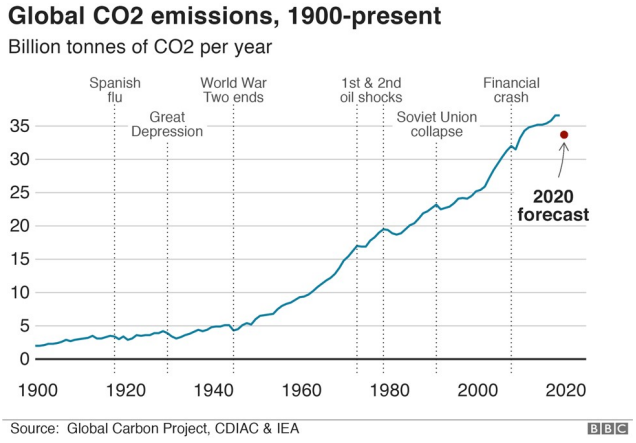


Figure 3: Total global CO_2 emissions 1900-2020
Source: [Climate change and coronavirus: Five charts about the biggest carbon crash - BBC News]

Since the late 1700s and particularly post WW2, CO_2 emissions have risen inexorably and this has resulted in an increase in CO_2 levels in the atmosphere (now 418 ppm) and rising global temperatures.

The rise in global atmospheric CO_2 levels is shown in Figure 4.

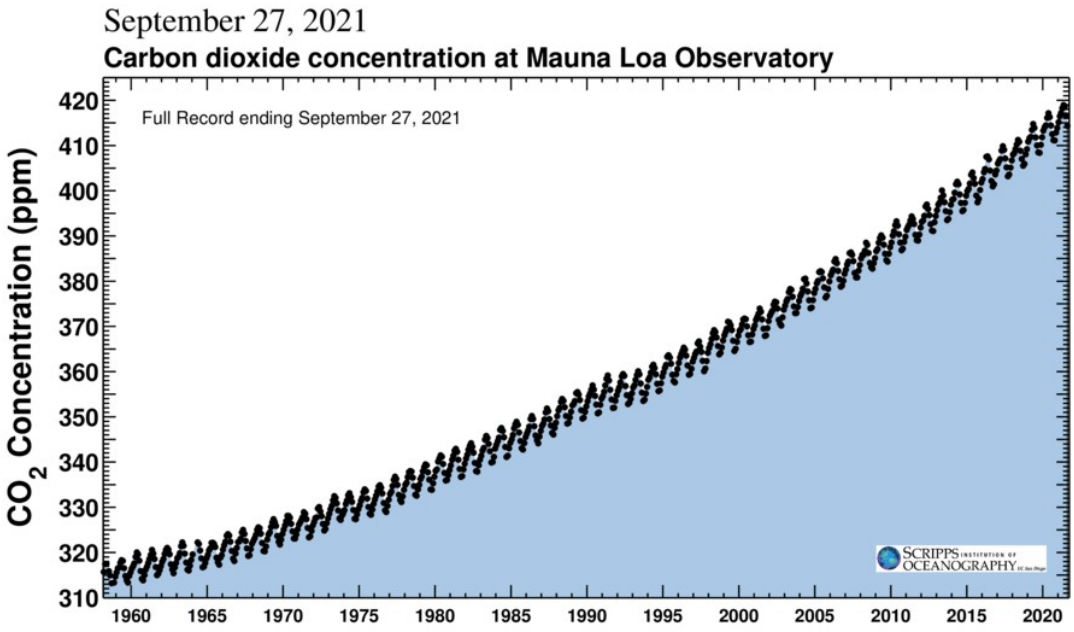


Figure 4: The rise in global CO_2 levels since 1960 (the Keeling Curve). (keelingcurve.ucsd.edu)

This rise in CO_2 levels is reflected in the average global temperature rise (Figure 5).

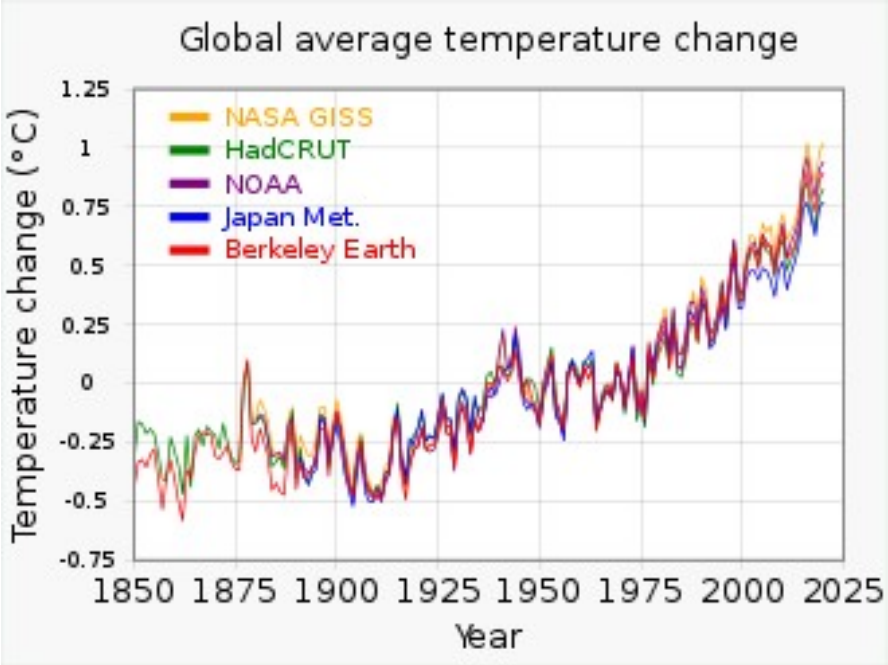


Figure 5: Global average temperature change (1850-2020) (Global temperature record - Wikipedia)

Ireland's greenhouse gas emissions

(Greenhouse Gases and Climate Change - CSO - Central Statistics Office)

Overall agriculture is the largest source of greenhouse gases in Ireland (35.3%), due mainly to methane emissions from our large national herd. Reducing this would need major changes in

agriculture and food production in Ireland, and is a reflection of our rural economy, and small population, resulting in a high per capita greenhouse emissions (3rd highest in the EU, see Greenhouse Gases and Climate Change - CSO - Central Statistics Office). Figure 6 shows the breakdown of Ireland's emissions by sector.

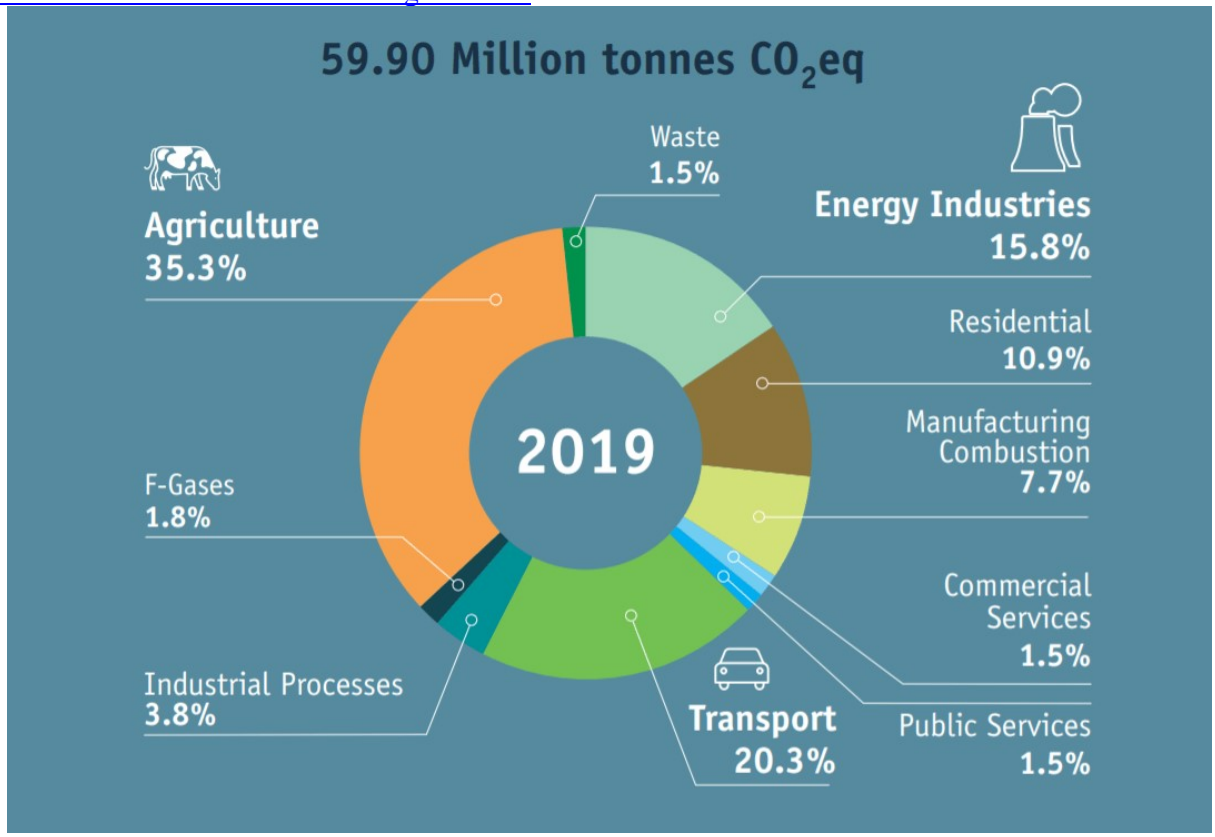


Figure 6: Emissions of CO_{2eq} by sector in Ireland (CIE - Climate Action)

Keeping the lights on

The gas supply problems in September 2021 were a foretaste of things to come. It reminds us that renewables alone cannot consistently supply our electricity needs, because when the wind doesn't blow and the sun doesn't shine in Ireland, the output of renewables disappears. A power station rated at 100 MW fuelled by gas or coal will deliver that output, but a windfarm of the same capacity would be lucky to give one third of the output over a year and in some months it would be zero. That means Ireland must have alternative electricity supplies and there are two main sources: coal or gas-fired plants (peat energy has now gone) or importation using the interconnectors with UK or Europe. Coal is bring phased out and Moneypoint is due to stop burning coal in 2025. Our gas supplies come mainly from the Corrib Gas Field, and the rest from Scotland via pipeline, and the government has ruled out further gas exploration. They have also refused permission for an LNG terminal on the Shannon and fracking for gas has been banned. That means we will depend for gas on supplies coming through Europe, ultimately from Russia. We are on the end of a very long pipeline and a long cable. Electricity from France is 70% generated by nuclear power and from UK 20%. We have a strategic reserve of oil at Whitegate but no reserve of gas, apart from what we produce ourselves.

The current energy mix in Ireland at present is (2019 figures):

Oil	49%
Natural gas	31%

Coal	2.6%
Peat	4.3%
Renewables	11.2% (86% wind)

Oil is no longer used for electricity generation and the peat plants were closed in 2020. In 2018 the source of production of electricity was:

Gas	54%
Coal & peat	21%
Renewables	22%

The Kinsale Gas field stopped production in 2020 and the Corrib Gas Field produces about 2/3rd of Ireland's gas, and is due to close ~2030. The remaining gas supplies are supplied through the gas interconnectors to Scotland.

The demand for electricity is increasing, especially with the growth of energy-intensive data centres and power cuts are likely in the future. The lack of gas storage is a key weakness and the proposed LNG terminal on the Shannon would have provided an important buffer. Our current energy situation may well discourage inward investment, if Ireland cannot guarantee to keep the lights on. Battery farms have started to be built to store surplus renewable energy and other forms of energy storage may have to be built e.g. more pumped water storage. Switching to electric cars is only green if the electricity for charging comes from renewables. Gas is the least polluting fossil fuel wrt CO2 and we will have to depend on gas-fired powered stations for many years to come, assuming we can get the gas.

Useful data sources:

Our world in data.

CO_2 and Greenhouse Gas Emissions - Our World in Data

Global temperature record - Wikipedia

Irish data:

Greenhouse Gases and Climate Change - CSO - Central Statistics Office

Energy in Ireland 2020 Report (seai.ie)

□

CO_2 – the Janus molecule

Janus was the two-faced Roman god and CO_2 is a molecule that we can't live without and increasingly we can't live with. It has a benign and a malign face. At the moment, all the attention is on CO_2 as a greenhouse gas, mainly responsible for climate change and global warming. But if there were no CO_2 in our atmosphere, the earth would be too cold for life to exist. The atmospheric warming due to CO_2 and other gases is responsible for a habitable earth, so that the sun's energy is trapped, warming the earth. Without the greenhouse effect, earth would be a snowball. However, too much of a good thing is warming the earth and this warming brings with it the risk of climate change. In addition, increased CO_2 levels result in ocean acidification, disrupting the aqueous acid-base chemistry in the oceans. This is the negative side of CO_2. But increased CO_2 levels also encourage the growth of some, but not all, crops thus fixing carbon. It would seem that CO_2 is a mix of contradictions – truly a Janus molecule.

We have also learnt from the recent CO_2 shortages (and an earlier one in 2018) that the gas is indispensable in many areas of everyday life. Waste CO_2 from industrial processes, especially fertiliser production from natural gas, is used in many industries before being released back into

the atmosphere. Thus this CO_2 does many useful services before contributing to global warming. Here are some of the areas where we have learnt CO_2 is needed:

- Cooling nuclear reactors
- Source of dry ice for the food and agriculture industries
- Putting the fizz into soft drinks
- Packing foodstuffs in an inert atmosphere to present spoilage
- Industrial refrigerant
- Stunning animals before slaughter
- Atmosphere enrichment in greenhouses
- Welding and cutting in inert atmosphere
- Enhanced oil recovery

(See Liquid Carbon Dioxide | BOConline Ireland)

In the UK 600,000 t/yr are used, 20% imported. 60% of CO_2 is a by-product of ammonia synthesis and 20% as a by-product of ethanol production, from fermentation. The shortage in the UK was due to fertiliser plants closing due to increased gas prices. It reminds us again that the world is an interconnected system.

□

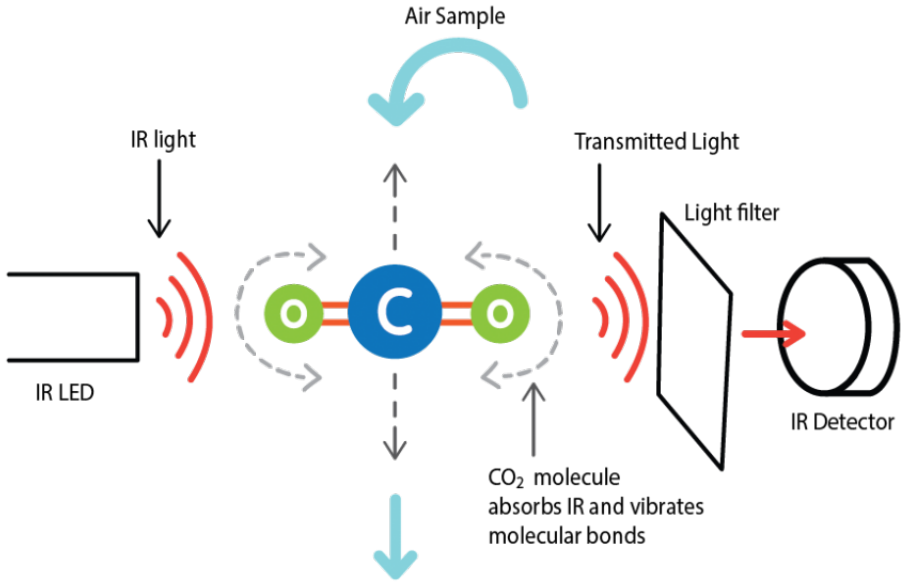
Monitoring CO_2 levels

Due to Covid there has been an increased awareness of the importance of ventilation in enclosed spaces, as good ventilation helps prevent transmission of the virus. One way of measuring ventilation in occupied spaces, like classrooms, is to measure CO_2 levels, which are largely due to respiration. Schools have been issued with CO_2 monitors, although not enough for every classroom. Apart from Covid, increased CO_2 levels also produce drowsiness. So having good ventilation might also keep your students more awake!

It raises the question of how do the monitors work. There are several types available and they can be used as useful examples in teaching LC Chemistry (or Physics), but the most sommon seem to use IR absorption.

IR monitors

CO_2 is an IR absorber, which is the reason why it traps eenergy in the atmosphere by absorbing IR emitetd from the earth's surface and converting it into heat. This IR absorption can be used to monitor CO_2 levels by using an IR source or a filter tuned to a CO_2 absorption frequency (see diagram blow). When CO_2 is present in the air, the IR intensity at the detector is reduced and can be converted into a % of CO_2 in the air. This is nice illustration of the use of IR spectroscopy.



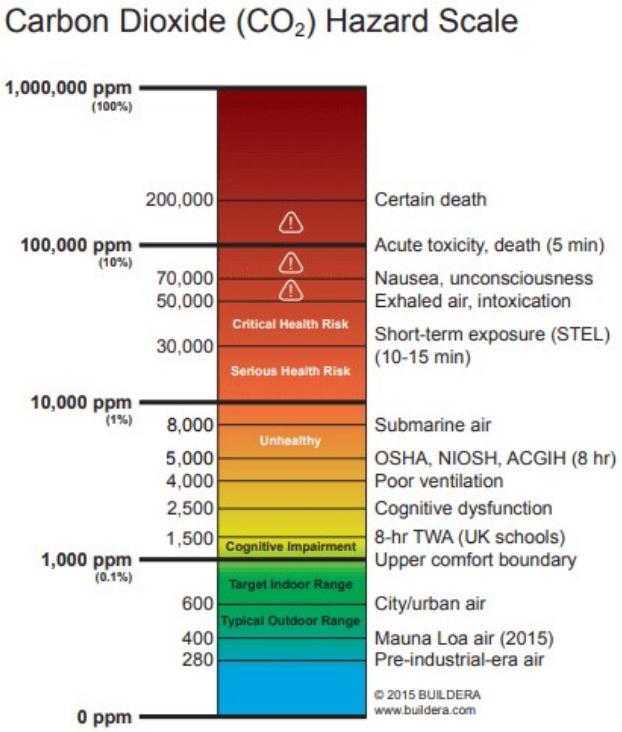
A schematic of an IR-based CO_2 monitor (PocketLab Air: Measuring Carbon Dioxide | PocketLab (thepocketlab.com))

A commercial model is shown below, which monitors from 400 (background) to 2000 ppm.

CO_2 and air quality

Air now has ~ 400 ppm CO_2 and this is normal. Poorly ventilated rooms may have higher CO_2 levels, as will areas where CO_2 is produced e.g. slurry tanks, breweries. Low levels of CO_2 can make you feel drowsy and impairs cognitive function, but higher levels can kill. CO_2 is dangerous because it is tasteless and colourless and heavier than air. (Carbon dioxide poisoning: a literature review of an often forgotten cause of intoxication in the emergency department (d-nb.info))

The disaster at L. Nyos in the Cameroon in 1986 was due to dissolved CO_2 in a deep lake, suddenly coming to the surface and killing thousands of people and animals in the surrounding area. (Lake Nyos disaster - Wikipedia) Scientists fear the same thing might happen in L. Kivu in the Congo, where millions of people would be affected. CO_2 is not to be taken lightly.



CO_2 kills by asphyxiation by replacing oxygen. Its chemical cousin, carbon monoxide, CO, is much more toxic as it replaces oxygen molecules on haemoglobin and kills at much lower concentrations. Thus there are far more deaths each year due to CO than to CO_2. However, CO_2 shouldn't be taken lightly.

□

Cement and steel: the two big CO_2 producers

Our world is literally built of concrete and steel: they are the two main materials used to make the modern world. Each year the world produces 4.1 Gt cement (2019) and 1.87 Gt steel (2019). Each tonne of cement produces 0.9 t CO_2 so that the annual production of CO_2 from cement manufacture is 3.69 Gt. Each tonne of steel uses 0.75 t coal and produces 1.9 t CO_2. This amounts to an annual production of 3.55 Gt CO_2 from steel production. Cement and steel are thus about equal in their CO_2 emissions. In 2019 global CO2 emissions were 36.4 GT so that cement makes up 9.7% and steel 9.7% of global emissions. If these industries were countries, they would jointly take #3 spot behind China and the USA. China produces 53% of world steel and 20% of world cement production and is the world's largest CO_2 producer and thus has a disproportionate impact on climate change.

For comparison with cement and steel, transport emitted ~8 Gt CO2 (2018): 74.5% road transport, 11.6% air, 10.6% shipping, rail 1%.

There is a drive in both the cement and steel industries to reduce CO_2 emissions, and to make the industries more sustainable. We will look at

each of the industries in turn. Ireland no longer has any steel production, but does produce cement in Drogheda and Limerick (CRH), in Kinnegad (Lagan Cement) and Derrylin, Co. Fermanagh (Mannok, formerly Quinn Cement), Cookstown (LeFarge Cement), with a small low-carbon cement producer in Dublin (Ecocem).

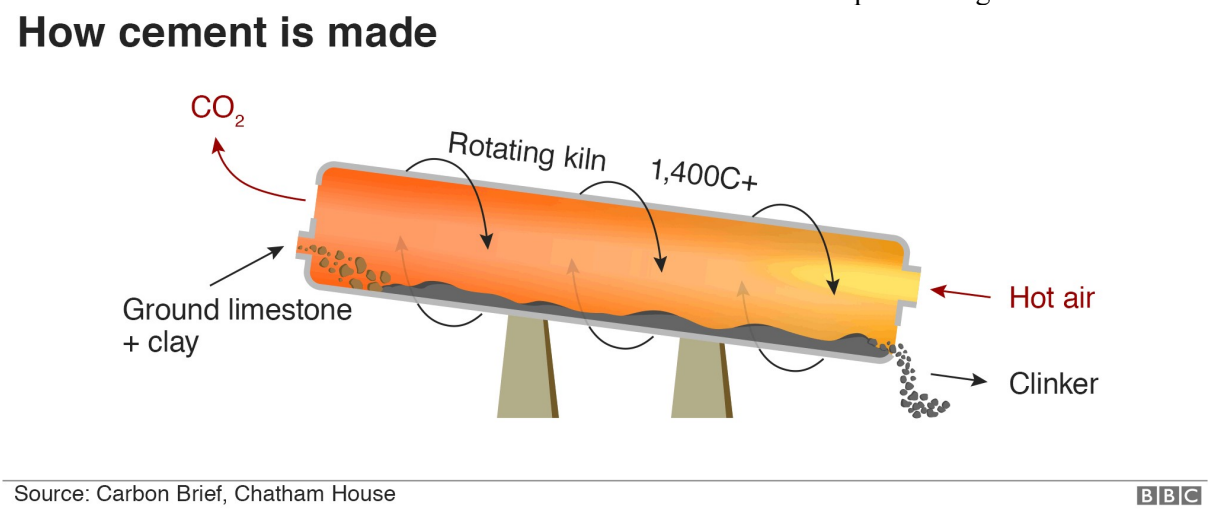
Cement production

The production of cement by the dry process (the dominant process) uses a lot of energy as it involves producing cement clinker at high temperatures (1450ºC). The high temperatures have been produced by burning fossil fuels, with consequent high CO_2 emissions. The process also involves heating limestone ($CaCO_3$) to produce lime (CaO), with the release of CO_2 (see equation below).

$$\mathbf{CaCO_3(s) \rightarrow CaO(s) + CO_2(g)}$$
$$\mathbf{100\ g \qquad 46\ g \qquad 44\ g}$$

Thus for every tonne of limestone burnt there is the production of 440 kg CO_2 into the atmosphere.

The diagram below shows the process by which the raw materials (limestone, clay and marl), finely ground together, are converted into clinker in a rotary kiln. The clinker is ground into a fine powder, together with various additives e.g. gypsum, when it is called cement. Mixed with water, sand and aggregate it produces the self-setting material known as Portland cement, which sets by hydration of the cement particles, gluing the other components together.

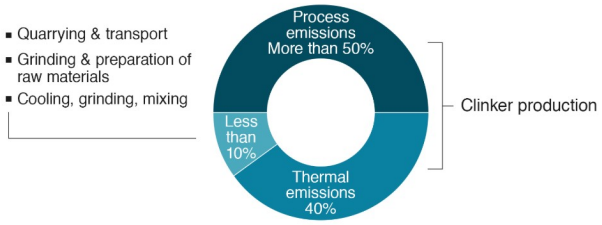


Source: Carbon Brief, Chatham House BBC

The heart of the cement process – the rotary kiln

(See How Cement Is Made | HeidelbergCement Group)

Over 50% of the CO_2 emissions are due to decomposition of limestone (itself ~95% of the raw materials). Producing the high temperatures produces 40% and the remaining emissions are due the energy used in other processes (see below).



CO_2 emissions from cement production

How can we reduce CO_2 emissions from cement manufacture, assuming we continue to use this versatile material to build our world?

Ways of decarbonising cement production:

1. Use less concrete by replacing with alternative materials.
2. Using novel cements.
3. Reduce energy use by improving efficiency and energy waste.
4. Use less CO_2 intensive fossil fuels by replacing coal with oil and then with gas.
5. Replace fossil fuels with waste materials and renewable resources (biomass).
6. Using less cement in concrete by replacing some clinker in concrete (e.g. Ecocem uses blast furnace slag).
7. Carbon capture and storage (CCS) – the most expensive option.

Several companies are producing blocks which use CO_2 in their curing rather than water as in

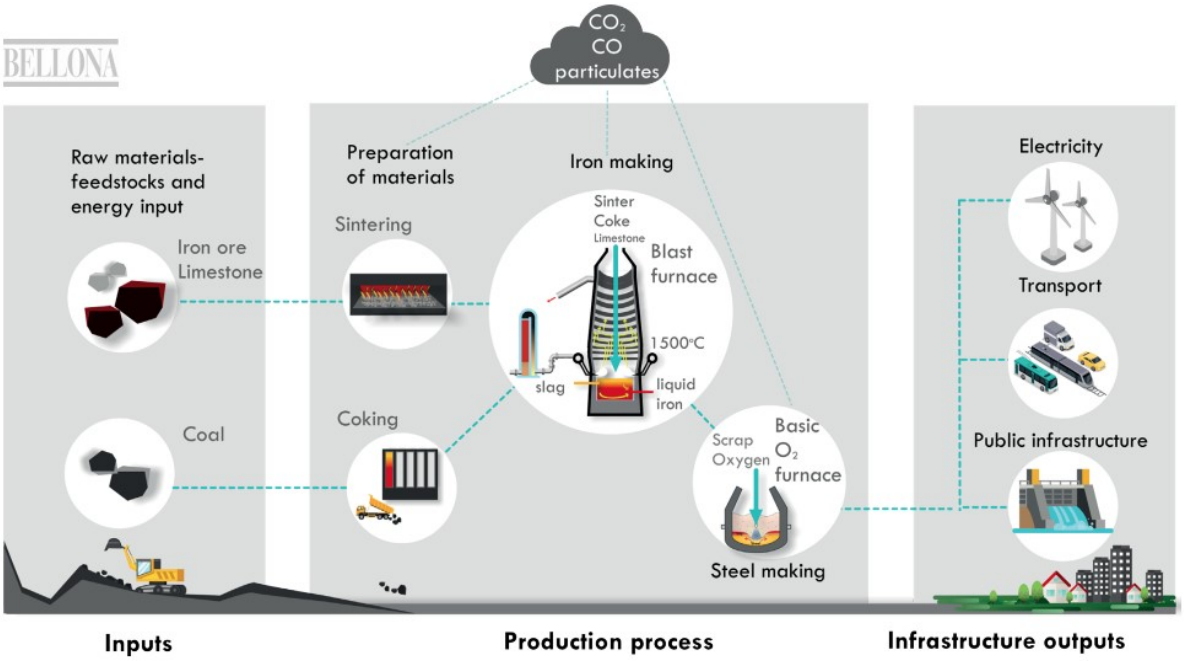
conventional concrete blocks. Carbicrete (https://carbicrete.com);
CarbonBuilt (https://www.carbonbuilt.com);
CarbonCure (CarbonCure's Concrete Solution - Concrete Technology Reducing Carbon Impact)

Useful Sources:

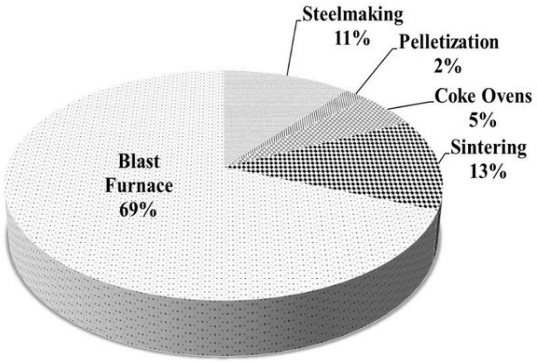
Climate change: The massive CO2 emitter you may not know about - BBC News
Making Concrete Change: Innovation in Low-carbon Cement and Concrete | Chatham House – International Affairs Think Tank
Q&A: Why cement emissions matter for climate change - Carbon Brief
History of Irish Cement: Celebrating 75 years 1938-2013
Irish-Cement-Celebrating-75-Years.pdf (irishcement.ie)

Steel production

The production of iron and then steel from iron ore is an energy-intensive process. The key stage in a blast furnace involves the reduction of iron ore using coke (from coal) and limestone, where carbon monoxide is the reducing agent. CO_2 is a major product of the blast furnace. Each tonne of iron produced emits 1.85 tonnes of CO_2. Steel is produced from iron in a separate step using a basic oxygen furnace (BOF). Steel can also be produced from scrap using an electric arc furnace (EAF), as was done in Irish Steel in Cork, but this also consumes a lot of electrical energy. It can be decarbonised if the electricity used comes from renewable resources.



The steelmaking process – CO2 emissions occur at all stages
Source: Steel and emissions: How can we break the link? - Bellona.org



The CO_2 emissions in primary steelmaking (BF-BOF), (total = 2227 kg CO_2/ton steel) (Orth et al. 2007). Source: (16) (PDF) Greenhouse Gas Emissions and Energy Consumption of Ironmaking Processes (researchgate.net)

Ways of decarbonising steel production:

1. Use less iron and steel by using alternative materials.
2. Use more scrap and the EAF process.
3. Energy efficiency e.g. using waste heat to heat incoming materials.
4. Carbon capture and storage or reuse.
5. Using alternative reductants e.g. green hydrogen.
6. Electrochemical reduction.

Steel production using green hydrogen
In July 2021 the first fossil-free steel was produced in Sweden as part of the HYBRIT pilot project and delivered to a customer. Full commercial production is scheduled for 2026. (A fossil-free future - Hybrit (hybritdevelopment.se))

Also in July ArcelorMittal today announced that its Sestao plant in Spain will become the world's first full-scale zero carbon-emissions steel plant, to be in production by 2025. Central to this development will be the construction of a 2.3 million-tonne green hydrogen DRI unit in Gijón. Around 1 million tonnes of DRI will be transported to Sestao to be used a feedstock for its two EAFs.

Useful sources:
Decarbonization in steel | McKinsey
EUROFER-Low-Carbon-Roadmap-Pathways-to-a-CO2-neutral-European-Steel-Industry.pdf

Diary

2022
60th ISTA conference
April 8-9
University College, Cork
dkennedy@ucc.ie
www.ista.ie

ECRICE 2022
July 11-13
Chemistry Teaching and Learning in a Global Unified World
Ron.blonder@wiezmann.ac.il

ICCE 2022 Cape Town, South Africa 18-22 July 2022
www.ICCE2022.org.za

ICCE 2022
18-22 July
ICCE 2022

Biennial Conference on Chemical Education 2022
new approaches to modern challenges

27th BCCE 2022
This conference has been postponed to 2022 at Purdue University, summer 2022, dates to be announced.

www.bcce2022.org

EuChemS Chemistry Congress
28 August to 1 September 2022 · LISBON.PT

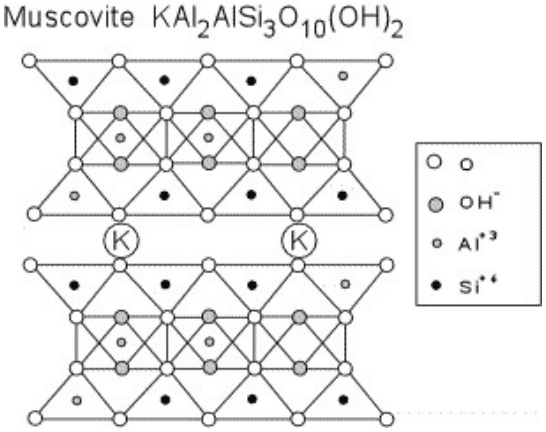
41st ChemEd-Ireland
October 15
TÚS, Moylish
Marie.walsh@tus.ie

The mica and pyrite problem with Irish concrete blocks

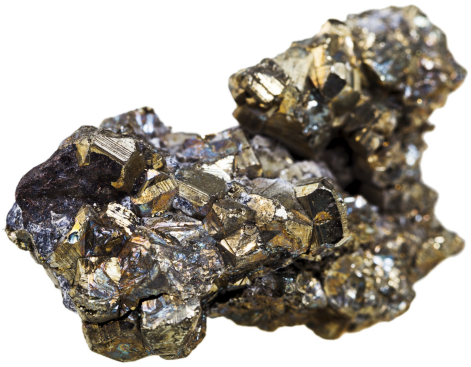
Concrete block as are supposed to stay strong and solid once they have been cured. In recent years Irish householders have faced a major problem with blocks cracking – first due to pyrite contamination and now due to muscovite mica, particularly in Donegal and Mayo. These were impurities included in the concrete mix as sand or aggregate, not in the cement. The cement powder when mixed with water, hydrates and swells gluing the particles of sand and aggregate together and setting into a rigid, strong solid. The houses were built and bought in good faith that the blocks were up to specification. Water has penetrated the blocks and reacted with the mica (which absorbs water and swells) and with the pyrite, FeS_2, in foundations which reacts and swells, converting into iron sulfates and sulfuric acid, which can react further to form calcium sulfate (gypsum). This is the same chemistry that produces acid mine water in old mines.

Mica and pyrite are commonly found in rocks and up to 1% is allowed in blocks. The defective blocks had much higher concentrations. Some blocks contained 17% mica.

Mica has a layered structure and is able to intercalate small molecules like water between the layers, causing it to swell.



The swelling produces cracks, so more water can get in and then in cold weather you have a freeze/thaw process which produces more cracking. More than 6,000 houses may be affected by mica, which was first reported in 2008, but came to public notice after 2014. It was used in minimal strength blocks, covered with a porous smooth cladding, and then lashed by the storms and cold. Water got through the cladding and into the blocks due to bad weather, which weren't strong enough to resist the swelling. Blocks of higher cement content and greater strength would have been more resistant to the presence of impurities.



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

Previously the problem was pyrite (FeS_2, also known as fool's gold) used in hardcore in foundations in Leinster, not in blocks, which was first identified in 2007 leading to the government Pyrite Remediation Scheme in 2014. Pyrite problems have also been reported in Limerick and Mayo. More than 20,000 homes have been affected by pyrite, and it may be as high as 60,000. (The PYRITE guide - Surveyors Journal)

Report of The Expert Panel on Concrete Blocks 2017
100218_78fd81fe-ab44-441b-ba10-6a9df4434c48.pdf

Investigating the causes of deterioration in concrete blocks in Southern Ireland Eden and Sandberg, 2019
33.pdf (utoronto.ca)

□

The Colourful World of Gemstones: Part 3

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The previous two essays in this series dealt particularly with six groups of the popular gemstones: the Peridots, Beryls, Diamonds, Corundums, Spinels and Tourmalines. In this third part we deal with the final three groups of gemstones being considered: the Garnets, Quartz and Topaz.

Garnets

Garnets belong to the Nesosilicate family, in which independent silicate tetrahedrons (each consisting of a central silicon atom surrounded by four oxygen atoms at the corners of a tetrahedron) are present, and have a cubic crystalline structure except for one variety, Hydrogrossular, (commonly known as Transvaal Jade), which is amorphous i.e. has no crystal form. They have the general formula $A_3B_2(SiO_4)_3$, where A is a metal ion of +2 valency & B is a metal ion of +3 valency. The Garnets are Ideo-Chromatic.

The element choices found for A are Iron (Fe), Magnesium (Mg), Calcium (Ca), and Manganese (Mn), while the choices for B are Aluminium (Al), Ferric Iron (Fe^{3+}) and Chromium (Cr), leading to the possible formation of some twelve species, however, six of these are not cut as gemstones. The twelve species are:

$Fe_3Al_2(SiO_4)_3$	$Fe_3Fe_2(SiO_4)_3$	$Fe_3Cr_2(SiO_4)_3$
$Mg_3Al_2(SiO_4)_3$	$Mg_3Fe_2(SiO_4)_3$	$Mg_3Cr_2(SiO_4)_3$
$Ca_3Al_2(SiO_4)_3$	**$Ca_3Fe_2(SiO_4)_3$**	**$Ca_3Cr_2(SiO_4)_3$**
$Mn_3Al_2(SiO_4)_3$	$Mn_3Fe_2(SiO_4)_3$	$Mn_3Cr_2(SiO_4)_3$

With the gem varieties shown in bold text.

The six gem garnet species form two isomorphous series with three members in each. An isomorphous series is a series of chemicals with one of the constituents being replaced by another element of similar valency and near equal ionic radius.

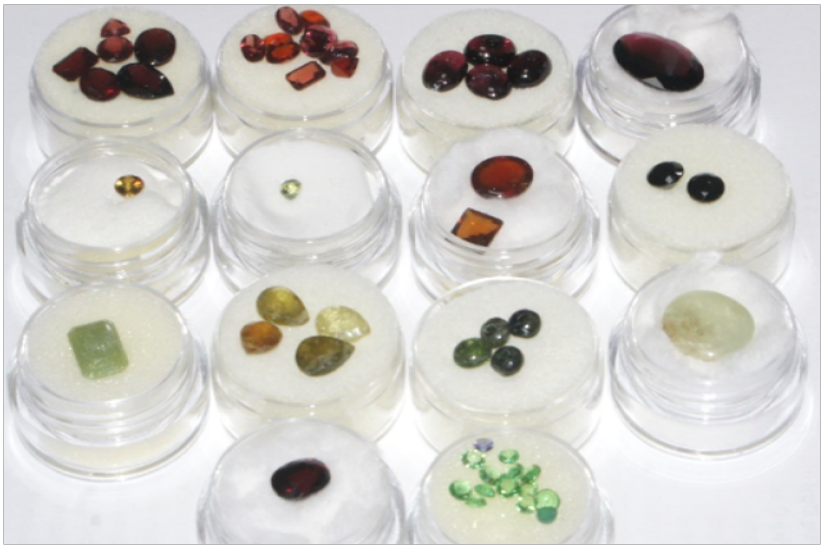


Figure 3.1: (Author): Top to Bottom, L to R: Pyrope, Rhodolite, Rhodolite, Almandite, Demantoid, Demantoid, Hessionite, Melanite, Demantoid, Grossular, Uvarovite, Mali Garnet, Spessartite, Topazolite.

The two series found are named from the initial letters of the garnet name with 'ite' tagged on at the end. Thus the two series are the Pyralspite series, using the 'Pyr' of Pyrope, the 'al' of Almandite and the 'Sp' of Spessartite; and the Ugrandite series, using the 'U' of Uvarovite, the 'gr' of Grossular and the 'and' of Andradite. The two series are shown below in Table 3.1.

Table 3.1: Members of the Pyralspite and Ugrandite Series of Garnets

Pyralspite Series		**Ugrandite Series**	
Pyrope	$Mg_3Al_2(SiO_4)_3$	Uvarovite	$Ca_3Cr_2(SiO_4)_3$
Almandite	$Fe_3Al_2(SiO_4)_3$	Grossular	$Ca_3Al_2(SiO_4)_3$
Spessartite	$Mn_3Al_2(SiO_4)_3$	Andradite	$Ca_3Fe_2(SiO_4)_3$

The garnets form continuous graduated series between the 'End-Members' expressed in the formulae above. Thus an infinite series of 'in-between' stones is found. Taking as an example Pyrope and Almandite where the difference is a magnesium or an iron component, and pure examples of each are rare. Generally the stone is composed of the two groups shown and has in-between properties. Rhodolite has the Pyrope and the Almandite groups in the ratio of about 2 to 3. Thus the physical properties of the 'in-between' Rhodolite lie between those of Pyrope and Almandite. The average specific gravity and refractive index of the three stones are shown in Table 3.2 below. It should be noted, however, that in combinations where there is more of one of the components the properties of the resultant stone will lie towards those of the one.

Table 3.2: Average values for Pyrope, Rhodolite and Almandite

Property	**Pyrope**	**Rhodolite**	**Almandite**
Specific Gravity	3.78	3.84	4.04
Refractive Index	1.740	1.760	1.790

The specific gravity of the Garnets gives the easiest method of determining to which variety a particular colour stone belongs:

Pyralspite Series		**Ugrandite Series**	
Pyrope	S.G. 3.62-3.87	Uvarovite	S.G. 3.41-3.52
Almandite	S.G. 3.93-4.30	Grossular	S.G. 3.56-3.73
Spessartite	S.G. 4.12-4.18	Andradite	S.G. 3.70-4.10

All the Garnets in the collection tested positive for magnetic effect, (method shown in Part 1 of this series), so much so that they are ideal gems to float and drag with a magnet. This magnetic effect is caused principally by the amount of iron present. The effect can be so strong as to have the magnet pick up smaller stones completely.

Apart from the garnet types previously mentioned, other garnet combinations are Malaia, (Pyrope-Spessartite), (sometimes written Malaya), Mali (Grossular-Andradite) and Maralambo (Spessartite-Almandite).

Figure 3.2: (Evan Ryder): YAG (left) & GGG (right), good diamond imitators.

Garnets have not been synthesised to any great extent and the two principal man-made materials to bear the name garnet, Yttrium Aluminium Garnet (YAG) and Gadolinium Gallium Garnet (GAG) bear the formula $Y_3Al_5O_{12}$ and $Gd_3Ga_3O_{12}$ respectively and are oxides, not silicates as the true garnets are (Figure 3.2).

Since any di-positive metal ion of suitable size can replace the four di-positive garnet metal ions above, and likewise any tri-positive metal ions the three tri-positive garnet ions above, the number of possible permutations is large. However, those that exist have not entered the gemstone market at this time and so are ignored in this essay. It should be noted that the tri-positive ions of Vanadium and Titanium may be found replacing the 'B' in the Garnet formula.

Even as late as 2009, it was common to meet statements in the publications like the following: *"The only colour that garnet has not been found in is the colour blue. In the past 40 years spectacular garnet discoveries have been made of new fabulous colours, mainly in Africa. Garnets can occur in all colours except for blue" and Max Bauer in his renowned "Precious Stones" says "Blue is a colour conspicuous by its absence."*

However, in the late 1990's colour change garnets of a blue to red colour appeared on the market and came from the Bekily mine in southern Madagascar. Since then others have been found in Tanzania. This author acquired a number of samples of this gemstone of 0.25 carat each.

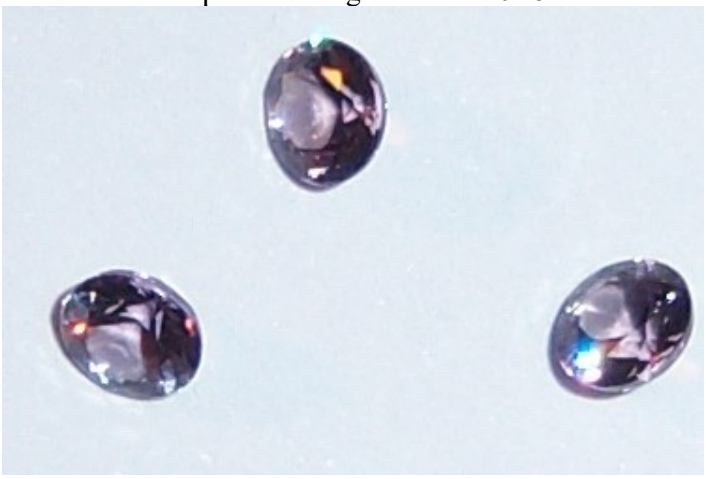


Figure: 3.3 (Author): 3 blue Garnets with some red appearing due to the colour-change effect under artificial light. (Stones from the Author's donation to the James Mitchell Museum in NUI Galway in 2013. The Museum is open from 10 am to 4 pm. Monday to Friday and admission is free.)

On testing the stone for magnetic attraction, (see part 1 of this series) it was found that the stone was attracted by a magnet, the reading showing a decrease of 0.01 g (0.05 carat, 20% of the weight of the stone). This author proceeded to experiment with these stones in the course of presenting a thesis on it to the Geology Department of the National University Of Ireland, Galway (NUIG) and determined that the Blue Colour-Change Garnet was a Spessartite – Pyrope mid-member with a Manganese – Iron ratio of about 9 to 1, and general formula $(Mn,Mg)_3Al_2(SiO_4)_3$.

The Garnet colours are primarily due to the Iron content and to a lesser extent to Manganese and Chromium, the Iron being responsible for the reds, yellowish greens and the browns found. Pyrope is red frequently with a brown tint. Its deep blood-red colour is due to traces of Iron. Manganese and Chromium are found in the crystal. Rhodolite is a Purplish red or rose coloured mid member of the Pyrope Almandite end members. Almandite Red is with violet tint. The colour is due to the ferrous Iron (Fe^{2+}), content tempered with traces of ferric Iron (Fe^{3+}) and Manganese.

Figure 3.4: (Evan Ryder): Carved single crystal Almandite Indian Elephant God.

Spessartite is orange to red-brown. The colour is due to the Manganese and deepening with Iron traces. Grossular is colourless, green, brown. The colours are due to small amounts of Ferric Iron, Chromium and Vanadium replacing Aluminium in the crystal. Andradite is black, brown, yellow-brown. The Demantoid (Green-emerald green) variety and the Topazolite, yellow to lemon-yellow, variety command the highest prices in the Garnet world. The black Melanite variety was used for mourning jewellery. The basic coloration is due to ferric Iron. Uvarovite is emerald green due to the chromium, as in the emeralds.

Quartz

We now move on to the second group being considered, the Quartz gemstone. Quartz is the crystalline variety of Silicon Dioxide (SiO_2), the main component of beach sand. Quartz is the second-most abundant mineral in the Earth's Continental crust, behind Feldspar. The Feldspar species, $KAlSi_3O_8$ – $NaAlSi_3O_8$ – $CaAl_2SiO_8$, comprise between them about 41% of the Earth's Continental Crust by weight. The Granites comprise from 20 to 60 % Quartz and at least 35% Feldspar.

Figure 3.5: (Author) A selection of various coloured Quartz gemstones.

Quartz may be divided into two groups: Macrocrystalline Quartz which exists as crystals visible to the naked eye and Cryptocrystalline Quartz, which is composed of microscopically small crystals. The Cryptocrystalline Quartz is generally known as Chalcedony and is cut as cabochons or carved into ornaments. The varieties include the Agates, Petrified Wood, Bloodstone, Jasper, Carnelian, Sard and Chrysoprase.

The Cryptocrystalline Quartz varieties are ignored here as they really are ornamental stones rather than gem-stones, which by definition are faceted.

Figure 3.6 (Author): A selection of carved Quartz Elephants. Back Row L to R: Aventurine 247 ct; Amethyst 128 ct; Rose Quartz 231 ct; Dalmation Jasper 263 ct. Front row L to R: Green Jasper 359 ct; Tiger's Eye 525 ct; Hematite/Red Jasper 354 ct. All except the Amethyst and Rose Quartz are Cryptocrystalline.

The Macrocrystalline Quartzes are Allo-Chromatic and the principal varieties are: Rock Crystal, Smoky Quartz, Amethyst, Citrine, Prasiolite, and Rose Quartz, all of which are common and can be faceted in large sizes dwarfing the other gemstone varieties. These Quartzes are readily manufactured in the laboratory and one can never be sure that what you find is natural. As gemstones go, Quartzes do not command big prices, but good quality Amethyst and Citrine are the dearest to buy.

Rock Crystal, the colourless variety of quartz, can come in massive sizes weighing many tons but many samples have other minerals, such as Gold, Pyrite, Rutile and Tourmaline embedded in the crystal and clearly visible.

Figure 3.7: (Evan Ryder): Left: Green Rutile (TiO_2) in Rock Crystal (1 inch wide)

Figure 3.8 (Author): Right: Rock Crystal pyramid with clearly defined black Tourmaline inclusions.

A large totally clear Rock Crystal sample makes for a striking pendant. (See Figure 3.13 below.) Smokey Quartz, which is Brown to Black or smokey-grey coloured, owes its colouration to natural gamma-ray rays altering the crystal structure.

Amethyst, with its colours purple, violet and pale rose-violet, is the most expensive of the Quartz gemstones. Iron replacement of the Silicon is the cause of the colouration. If Amethyst is heated to between 450 and 759 ^{o}C its colour is changed to light yellow, red-brown, green and even colourless. A few Amethysts can lose some of their colour in sunlight. The colour can be restored by X-ray radiation.

Figure 3.9: (Author); Amethyst (3.75 ct), Citrine (1.95 ct), Smokey Quartz (6.1 ct)

Citrine, whose colours run from light to dark yellow and gold-brown, is coloured by Iron. Natural Citrines are rare, the usual commercial ones being heat treated Amethyst or Smokey Quartz.

Brazilian Amethysts are heated to 470 ^{o}C to give light yellow results, while increasing the heat to 550-560 ^{o}C gives dark yellow to red-brown results. While natural Citrines are generally light yellow, the heat treated ones will have a reddish tint.

Prasiolite, the leek-green coloured Quartz, is not found in nature but is produced by heating violet Amethyst or yellowish Quartz to about 500 ^{o}C. The green colour tends to fade in sunlight.

Figure 3.10: (Author): Top Left. 12.5 ct Lemon Quartz; Top Right 17 ct Rose Quartz: Bottom Left 21.65 ct Prasiolite; Bottom right 30 ct Rock Crystal

Rose Quartz. This pretty Quartz is coloured by Titanium and the colour can fade in sunlight. The included stones are not faceted but may be used as cabochons for brooches, pendants, necklaces and bracelets.

Topaz

The final gem-stone variety being considered is the Topaz. The general formula for this Allo-Chromatic stone is $Al_2SiO_4(F,OH)_2$ (Fluorine-containing aluminium silicate). The common colour of the natural stone is a yellow to yellow-red, but light blue stones have been found. However, since the vast majority of stones found are clouded and opaque, one can take it that there is no natural untreated stone available in the gem trade. All the jewellers' topazes, while originating in nature, have been treated to give the various colours seen. Topaz has the unfortunate property of perfect cleavage parallel to the basal plane, i.e. at right angles to the striated longitudinal crystal. This means that if the stone gets a sudden shock, e.g. from a fall or knock against a hard surface, it easily splits in two. This author tested all his Topaz stones using a reflection spectrometer. The results, in all cases, showed clearly that the stones had been 'got at'!

Figure 3.11: (Evan Ryder): White Topaz (24 ct)

The colourless Topaz, the only one round-faceted Topaz gem-stone, has a specific gravity (3.49-3.57), practically equal to Diamond (3.50-3.53), for which it is a common simulant. This means that the use of the Diamond gauge described in the first of these essays cannot be used to differentiate between the colourless Diamond and the corresponding Topaz. However, since Topaz is doubly refracting and Diamond a singly refracting stone, and also that the common refractometer can register a reading for Topaz and not for Diamond, this is not a major problem.

Topaz reacts like Tourmaline to pressure and heat, generating an electric charge (piezolectricity) that can persist for up to thirty hours. This phenomenon may be used to distinguish the Topaz from many other gemstones. On heating, using a blowpipe flame, Topaz does not melt but becomes cloudy and opaque due to the loss of Fluorine and water.

The colouring agent in all the Topaz varieties is either Iron or Chromium or a combination. None of the stones in the author's collection reacted to a magnet (see part 1 of this series), indicating very low levels of Iron or Chromium substitution.

Figure 3.12: (Evan Ryder): Blue Topaz

The very popular Blue Topaz has invariably been irradiated by gamma-radiation and then heat treated to fix the colour, the colour being due to Iron substitution in the basic formula.

Figure 3.13: (Evan Ryder): Pink Topaz 1.6 ct & 0.85 ct

The yellow, pink and red varieties own their colour to Chromium substitution of the Aluminium of the basic formula. Many of these may fade in sunlight.

Rose-Topaz, sometimes known as burnt Topaz, which is extremely rare in nature, is produced artificially by gradually heating yellow or brown Topaz.

Green Topaz is not found in nature, but a greenish-blue example has been seen. Any green Topaz on the market has resulted from human interference.

Figure 3.14: (Evan Ryder): Mystic Topazes showing different effects to light. (L. 1.2 ct, R. 1.5 ct)

A shimmering multi-colour Topaz, known as Northern Lights or Mystic, was prepared in 1998 by the deposition of a very fine film of metal, often Titanium or Gold, onto the surface of a colourless Topaz. It has become a very popular Topaz gemstone and the deposition is hard wearing.
I hope you have enjoyed the series and perhaps, in time, you might indulge yourself and investigate some of the less popular stones as you meet with them.

References

Precious Stones, Max Bauer, in two Volumes, Dover Publications Inc., New York and Charles Griffin & Co. Ltd., London, 1968

https://en.wikipedia.org/wiki/Feldspar

Gemstones of the World, Walter Schumann, 4th ed., Sterling, New York/London

Gemstone & Mineral Data Book, John Sinkankas, Van Nostrand Reinhold Company, New York etc. 1981

In 2013 Adrian donated a collection of gemstones to the James Mitchell Museum, sited in the Quadrangle of NUIG, who have displayed the gems. Admission to the Museum is free and is well worth a visit.
His online practical book on gemstones can be accessed without cost at the following
http://evanryder.com/downloads/practical-gemmology.pdf

□

Chemlingo: the right type of image

Peter E. Childs

For many people photography based on silver emulsions, films and prints, is an ancient and almost forgotten technology. The development of photography in the mid-19th century was a triumph of serendipitous chemical discovery and dogged and persistent experimentation. Many different processes were developed in a great explosion of creativity from the 1840s onwards, with their own names which passed into the lexicon. Most of these are now forgotten but they changed our view of the world and enabled the first photographers to document the second half of the 19th century in a way never seen before. In my archives I came across an article which remined me of many of these obsolete processes. (Ware, 2007) Ware says *"The history of photographic science is studded with chemical triumphs."*

The first successful photographic processes were based on silver salts, which decomposed in light to give black silver particles. In 1839 Sir John Hershel discovered that sodium thiosulfate (hypo) could fix the silver image by dissolving out the unexposed silver halide. The different photographic (light writing) processes were given the suffix – type, from the Greek *typos* = impression.

Henry Talbot made his first pictures in 1835 using silver halide sensitised paper and called them *calotypes*. More familiar is the *daguerreotype* developed commercially in the 1840s and 50s by Louis Daguerre but first revealed to the world in 1839. It used silver-plated copper sheets and was expensive and by 1860 had been displaced by *ambrotypes* (ambro- from the Greek *ambrotos* = immortal), also known as the collodion process, which used a collodion layer containing silver salts on glass plates. A dichromate-based process was developed by Mungo Ponton in 1839, which were called *autotypes*, whose image was based on carbon pigments. Sir John Herschel again discovered that iron salts could be used to produce an image, when light reduced iron(III) to iron(II) salts and he called the images *siderotypes* (Greek *sideros* = iron), using silver salts (argentotypes), gold salts (chrysotypes) or mercury salts (*celaenotypes*) to fix the images. The most successful variant used Prussian blue to produce blueprints (*cyanotypes*), which survived well into the late 20th century for architectural drawings. The different metals gave prints with quite different appearances. Later a *platinotype* process was developed by William Willis in the 1870s. Silver-based photographs had a habit of fading in sunlight or in polluted air (which contained sulfur compounds), whereas platinotypes were permanent. In WWI platinum was needed for chemical catalysts and its use in photography was banned in 1916, so Willis developed *palladotypes* based on palladium. Later still organic dyes were used in combination with silver salts to produce colour photographs.

One can only admire the chemical ingenuity and commercial acumen of these early pioneers in developing a totally new technology from scratch. They had to have good chemical skills as well as an artistic eye. They had the right stuff to produce the right type.

Ware, M., (2007), 'The enduring image', *Chemistry World*, August 2007, 62-65

Places to visit: Birr Castle, Birr, Co. Offaly

In this occasional series we look at interesting places to visit in Ireland of scientific or technological interest. Birr Castle in Birr is of interest on both counts. The Parsons family who have lived in Birr Castle since, has a long tradition of scientific endeavour and technical innovation. The 7th Earl and Countess of Ross have turned to buildings and grounds of the Castle into a science theme park. This is well worth a day out or a school visit, as there are several things to see.

Location

Birr Castle is located at the edge and close to the centre of Birr, and almost in the centre of Ireland (Figure 1) and is easily accessible from all parts of Ireland.

Figure 1: Location of Birr

The Birr Castle demesne consists of the castle (Figure 2), stables and extensive grounds.

Figure 2 Birr Castle (P.E. Childs)

Opening hours

It has been open since the 26th April 2021 and is open 09:00-18:00 daily, last entry 17:00. Further details are given on the website. Tickets must be booked in advance and Covid restrictions apply indoors. However, most of the attractions are outside.

Visitor Information at Birr Castle | Birr Castle, Gardens & Science Centre | Ireland

There is a gift shop and café in the visitor centre and you can download a visitor guide. 42654-Birr-Castle-A3-Visitor-Guide-2018-GDF-OK.pdf (birrcastle.com)

Discover Primary Science and Maths tours are offered for 3rd to 6th classes. education@birrcastle.com

The astronomical connection

Figure 3: William Parsons, 3rd Earl of Rosse (William Parsons, 3rd Earl | Birr Castle, Gardens & Science Centre | Ireland)

(See William Parsons, 3rd Earl of Rosse - Wikipedia) The Parsons family have lived in Birr for 400 years since 1620 and the Castle and Demesne are at the heart of the town. In the 19th century Birr Castle was the location for the largest telescope in the world! It was constructed by the 3rd Earl William Parsons (1800-1867), a keen astronomer, who cast and ground his own mirror (now in the Science Museum in London.) The mounting for the large telescope tube has been restored and forms the centrepiece of the demesne (Figure 4). Using the telescope Parsons observed and drew the spiral nebulae. A successor devised the equipment and measured the temperature of

the moon. (This work and original equipment are displayed in the Science Centre.)

Figure 4: The great telescope at Birr (P.E. Childs)

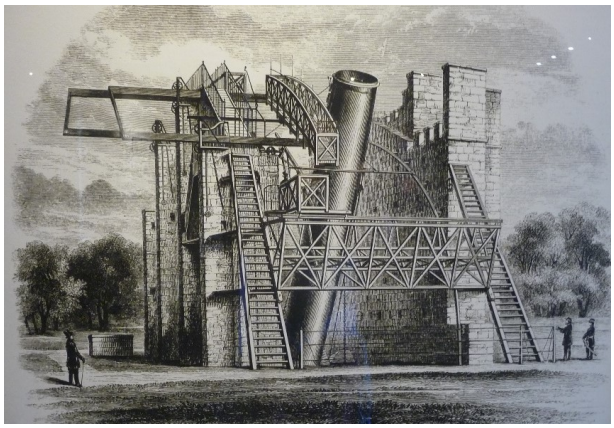


Figure 5: The Leviathan in its heyday

Astronomy moved on and the great telescope, known as 'The Leviathan', was superseded by bigger telescopes in better locations. However, Birr can still claim to be the astronomical centre of Ireland as it contains a radio telescope array, part of a Europe wide radio telescope (Figure 6).

Figure 6: The radio telescope array at Birr, I-LOFAR (P.E. Childs)

Engineering innovation

The Parsons family are better known outside Ireland for technological innovation as Charles Parsons invented the turbine, used to generate electricity (an early example was built at Birr Castle on the river) and for ship propulsion. The story of the turbine is told in the Science Centre. The grounds also contain one of the earliest suspension bridges. See Charles Algernon Parsons - Wikipedia for more information. He was an inventor who could reasonably be said to have changed the world. He featured on an Irish stamp in 1984 (Figure 7).

Figure 7: Centenary of the turbine

The Science Centre

The old Stables block has been converted into a visitor centre, and within this there are 8 galleries telling the story of science and Technology at Birr. This is a conventional science museum with cases of exhibits, posters and explanations. It is not an interactive science centre.

*The science centre reveals the wonders of early **photography**, engineering and astronomy with a special emphasis on the brilliant design and assembly of the world-famous Great Telescope.*

Discover astronomical instruments, cameras, photographs and photographic equipment used by the Third and Fourth Earls and Mary, Countess of Rosse, in the middle and late 1800s. Also on display is electrical and engineering equipment

originally belonging to Charles Parsons and used in his experiments as well as a large area devoted to the botanical work carried out in the Demesne.

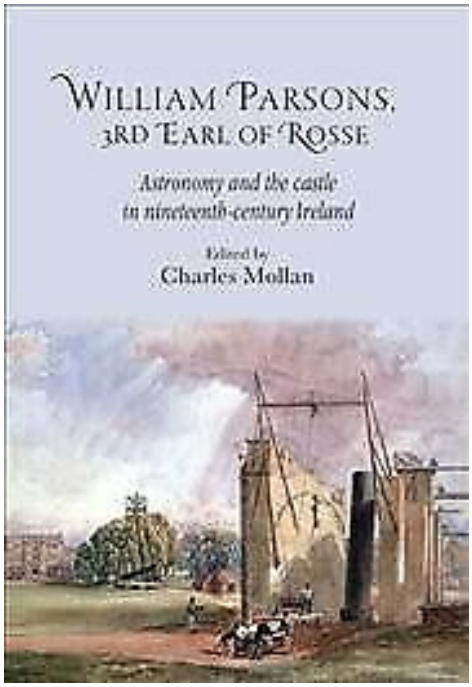
Figure 8: Mary Rosse (Mary, Countess of Rosse - Mary Rosse - Wikipedia)

Mary, Countess of Rosse (1813-1885), wife of the 3rd Earl, (Figure 8), was a keen amateur photographer, with her own dark room. (For more see Mary Rosse - Wikipedia) In those days a photographer had to prepare their own plates and develop and print the photos. It required a good knowledge of chemistry. Her original darkroom was locked up and forgotten and was rediscovered. It has been reconstructed in the Science Centre (Figure 9). Charles Parsons was her son. She was also a keen botanist and the grounds of the Castle are full of rare plants.

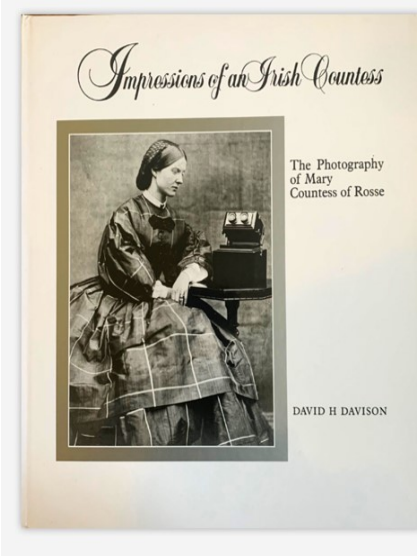
Figure 9: Part of Mary Rosse's dark room in the Science Centre (P.E. Childs)

I hope this quick tour has whetted your appetite for a visit to one of Ireland's premier scientific destinations. The Parsons family was a pioneering family in science and technology and have left their mark on the world of science and technology.

□



William Parsons 3rd Earl of Rosse by Charles Mollan published in 2015 tells the story of William Parsons, 3rd Earl of Rosse (Manchester University Press).



Impressions of a Countess by David Davison tells the story of Mary, Countess of Rosse and her photography.

Metal mirrors – chemical reflections

One of the most spectacular demonstrations or experiments in LC chemistry (or for Open Days) is the production of a silver mirror on glass. This process for silvering mirrors was invented in 1835 by Justus von Liebig, the 19th century German chemist. The production of a silver mirror has to be one of the experiments with the most wow factor on the chemistry course. It works because silver ions are easily reduced to silver metal, as silver is a noble metal. We would expect something to be possible with the other noble metals, copper and gold. In this article we describe how to make a silver mirror and a copper mirror.

N.B. You are responsible for checking and implementing the necessary safety precautions.

Making a silver mirror

Aldehyde and Ketone 2 (blogfa.com)

Tollen's reagent is used to distinguish an aldehyde (reducing) from a ketone, although they both test positive with DNP, dinitrophenylhydrazine. When warmed with an aldehyde, Tollen's reagent liberates metallic silver, which forms silver mirror on the walls of the test-tube or flask (see above).

Tollen's reagent

This must be made up freshly and disposed off after use, by acidifying and washing away with plenty of water.

Step 1: Aqueous dilute (0.1 M) silver nitrate is mixed with aqueous (1 M) sodium hydroxide (or potassium hydroxide). A brown precipitate is formed, which is silver(I) oxide.

$AgNO_3(aq) + NaOH(aq) \rightarrow AgOH(s) + NaNO_3(aq)$

$2AgOH(s) \rightarrow Ag_2O(s) + H_2O$

Step 2: Aqueous conc. ammonia (0.880) is added drop-wise (CAUTION! – in a fume cupboard) until the precipitated silver oxide completely dissolves.

$Ag_2O(s) + 4NH_3(aq) + H_2O \rightarrow 2[Ag[NH_3]_2]^+(aq) + 2OH^-(aq)$

Ammonia forms a soluble, linear complex ion with silver, $[Ag[NH_3]_2]^+(aq)$. The solution should now be strongly alkaline, as the reduction reaction proceeds faster at high pH.

The silver mirror test

The reducing agent – either an aldehyde (alkanal), a reducing sugar e.g. glucose, or glycerol, is now added and warmed, swirling the container to coat the sides. The silver(I) complex is reduced to metallic silver, which coats the glass surface. The glass must be clean to get a good mirror which sticks.

e.g. For ethanal.

$CH_3CHO(aq) + [Ag[NH_3]_2]^{+2}(aq) + 2OH^-(aq) \rightarrow CH_3COOH(aq) + Ag(s) + 2NH_3(aq) + H_2O$

Industrially in the wet process (as above) for silvering mirrors, tin(II) chloride is used to coat the glass surface first, to improve adhesion of the silver layer. The silver is deposited on the back of the mirror and then coated to prevent attack from the atmosphere. When the coating breaks down the coating often turns black (after reacting with sulfur in the air), as seen on antique mirrors. The coating can be stripped off and the mirror resilvered.

Videos showing the silver mirror experiment

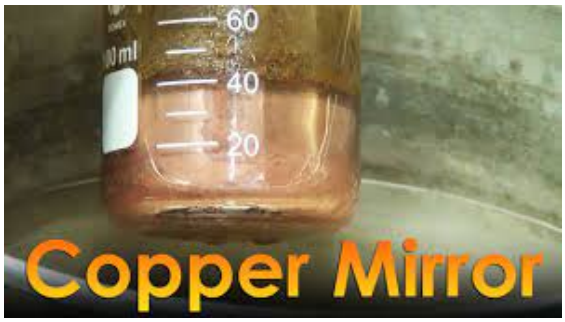
(149) Chemistry experiment 16 - Silver mirror - YouTube

(149) Silver Mirrors - YouTube

For a nice graphic see Making silver mirrors using chemistry – Compound Interest (compoundchem.com).

This basic process was discovered by Justus von Liebig, the German chemist, in 1835 and became the basis of a successful industry producing silvered mirrors, and the process is still used today.

Making a copper mirror



Silver is more noble than copper and thus easier to reduce; a stronger reducing agent is needed to make a copper mirror. A suitable candidate is hydrazine, N_2H_4, although this is not usually available in a school lab. In addition, it is poisonous and possibly carcinogenic and should thus be handled with care and full PPE.

Transfer 5 mL 1M copper(II) sulfate solution to a clean large test-tube or tall-form beaker and carefully add, with a dropper, 1 mL of 85% hydrazine hydrate solution (CAUTION! – full PPE, do in a fume cupboard). There is a vigorous reaction. Swirl and warm the test-tube/beaker in hot water and a copper mirror should coat the glass surface.

An alternative method involves the decomposition of copper(II) methanoate (formate), as the methanoate anion is a reducing agent. ~3 g of copper(II) methanoate-4-water is heated in a clean round-bottomed flask, swirling as it is heated over a flame. The salt decomposes releasing metallic copper and carbon dioxide and carbon monoxide gas. It should be done in a fume cupboard with full PPE. Copper(II) methanoate-4-water can be made by dissolving basic copper(II) carbonate in excess methanoic acid, and evaporating to crystallise out the salt.

$Cu(HCO_2)_2.4H_2O(s) \rightarrow Cu(s) + 5H_2O(g) + CO_2(g) + CO(g)$

Robert D. Pike, (2010), 'Metals in Metal Salts: A Copper Mirror Demonstration', *J. Chem. Educ.* 87(10), 1062–1063 See also Metals in Metal Salts: A Copper Mirror Demonstration (core.ac.uk)

Video showing a copper mirror

(149) Make elemental Copper - Copper mirror chemical reaction! - YouTube

Gold mirrors?

Gold is more noble than silver and should be even easier to reduce. Gold mirrors have been made by decomposing gold(III) chloride and was first tried by Liebig. Gilding by chemical means is known as angel gilding (Angel gilding - Wikipedia).

This account from Wikipedia describes the method:

Wet gilding is effected by means of a dilute solution of gold(III) chloride in aqua regia with twice its quantity of ether. The liquids are agitated and allowed to rest, to allow the ether to separate and float on the surface of the acid. The whole mixture is then poured into a separating funnel with a small aperture, and allowed to rest for some time, when the acid is run off from below and the gold dissolved in ether separated. The ether will be found to have taken up all the gold from the acid, and may be used for gilding iron or steel, for which purpose the metal is polished with fine emery and spirits of wine. The ether is then applied with a small brush, and as it evaporates it deposits the gold, which can now be heated and polished. For small delicate figures, a pen or a fine brush may be used for laying on the ether solution. The gold(III) chloride can also be dissolved in water in electroless plating wherein the gold is slowly reduced out of solution onto the surface to be gilded. When this technique is used on the second surface of glass and backed with silver, it is known as "Angel gilding". (Gilding - Wikipedia)

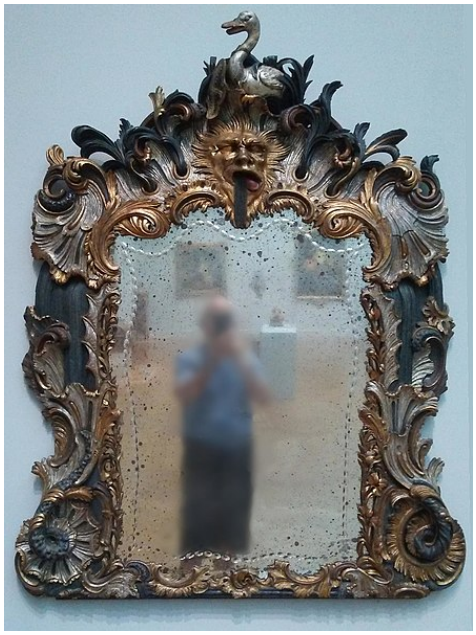
The history of mirrors

Cheap, affordable mirrors are one of the wonders of the modern world that we take for granted. The earliest mirrors were polished metals – copper or bronze, or silver. Later a coating of tin, produced from a tin-mercury amalgam was applied and then heated to drive off the mercury! Mirror makers suffered the

same neurological problems as (mad) hatters. They were mad mirror makers. This process was invented and used initially in Venice. See The Ugly History of Beautiful Things: Mirrors (longreads.com) for an interesting history of mirrors.

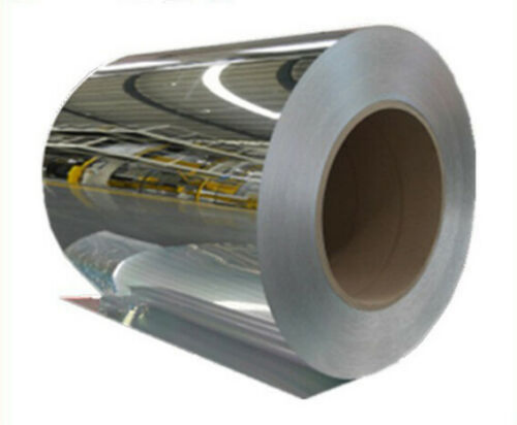
Liebig's discovery of silvering enabled the large-scale production of mirrors, affordable by anyone, and much safer for the workers. Large telescope mirrors are often now 'silvered' using the vapour-deposition of aluminium. They have high reflectivity despite a thin surface coating of oxide, which protects the surface from corrosion.

The mirror below dates to 1740 – notice the signs of corrosion on the silver backing.



File:Von Gymnich mirror--Germany--ca 1740--WIKI.jpg - Wikimedia Commons

Flexible mirrors can now be made by coating plastic film with aluminium. These are useful in teaching optics to show the change from concave, to plane, to convex mirrors and they are unbreakable!

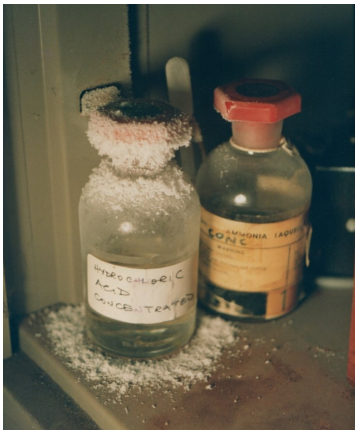


Mirror on a roll!

□

Demonstrating diffusion

What would you think if you found this situation in a cupboard? Two unopened bottles – one of conc. Ammonia and one of conc. hydrochloric acid? One is heavily coated with white powder? When placed in the cupboard the bottles were clean. Both bottles tend to fume in air and thus are best stored in a fume cupboard, not in the open lab. Why is one and not the other covered in white solid? The clue is in the chemistry.

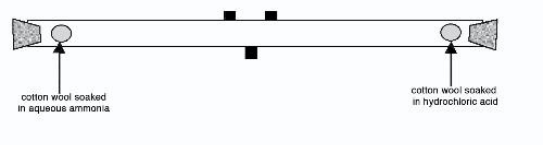


When we allow HCl vapour and NH_3 vapour to mix they produce white clouds of solid ammonium chloride. This is clearly what happened here. The gases escaped the bottles, diffused through the air and mixed, forming a white solid.

$$\mathbf{HCl(g) + NH_3(g) \rightarrow NH_4Cl(s)}$$

The solid sublimes easily and dissolves in water forming a conducting solution which gives a positive test for chloride. All consistent with the formula $NH_4Cl(s)$. **But why only on the conc. HCl bottle?**

Time to do another simple, visual and effective demonstration. Find a glass tube about 1 m long and ideally 10 mm or more in diameter. Find a stopped for both ends. Put some cotton wool in the ends and put a few drops of conc. HCl on one and conc. NH3 on the other (see diagram below). Stopper both ends, clamp horizontally and wait.



Diffusion of ammonia and hydrogen chloride gas | IOPSpark

Get your students to predict what they expect to see. When the two vapours meet they will form a white solid. But will the deposit be in the centre, or to the left (ammonia) or right (hydrochloric acid) sides?
When it appears ask them to explain why it is found where it is. The demonstration illustrates diffusion of gases through air – ammonium chloride is only found where the two gases meet. But the white deposit appears closer to the hydrochloric acid side than to the ammonia side.

Get your students to discuss why this is. This introduces the idea of the kinetic theory of gases. Gas molecules are in continuous random motion and are widely separated from each other. This allows molecules to diffuse (move) through the container. If they start at one side, eventually they will end up everywhere. Thus we have NH_3 molecules and HCl molecules moving in from each side and when they meet they will form $NH_4Cl(s)$. If they moved at equal average speeds, they would meet in the middle. But in face they meet closer to the hydrochloric acid side than the ammonia side. This must mean that ammonia molecules move faster than hydrogen chloride molecules and thus travel further before they meet.

Why is this so? This is an illustration of Graham's Law of Diffusion. Smaller molecules at the same temperature move faster than heavier molecules. Ammonia molecules (GMM 17 g/mol) are lighter than hydrogen chloride molecules (GMM 36.5 g/mol), and so will move faster.

Graham's law of diffusion or effusion:
The rate of effusion or diffusion of a gas is inversely proportional to the square root of the molar mass of its particles. The molecules have the same kinetic energy ($1/2\ mv^2$), but the heavier molecules move slower than lighter ones. Rate of diffusion is proportional to the average velocity.

$$\frac{\text{Rate}_1}{\text{Rate}_2} = \sqrt{\frac{M_2}{M_1}},$$

Thus: rate (NH_3)/rate (HCl) = $\sqrt{17/36.5}$ = 0.682 Thus we would expect to find the white precipitate forming about 70% of the way along the tube from the ammonia side.
See (583) diffusion of a gas - YouTube for a simulation.

You can do this as a student experiment in microscale using two glass droppers, joined with a short piece of silicone tubing. Dip one end in conc. HCl and the other end in conc. ammonia, and clamp horizontally.

□

CheMiscellany

Anecdote about Justus Liebig

It may, perhaps, be interesting to many to know, that, owing to his moderate organ of Language, Liebig was distinguished at school as booby, -the only talent then cultivated in Germans schools being verbal memory. On one occasion, being sneeringly asked by the master what he proposed to become, since he was so bad a scholar, and answering that he would be a chemist, the whole school burst into a laughter of derision. Not long ago, Liebig saw is old schoolmaster, who feelingly lamented his own former blindness. The only boy in the same school, who ever disputed with Liebig the station of booby, was one who never could learn his lesson by heart, but was continually composing music, and writing it down by stealth, in school. This same individual Liebig lately found at Vienna, distinguished as a composer, and conductor of the Imperial Opera House, I think his name is Reuling. It is to be hoped, that a more rational system of school instruction is now gaining ground. Can anything be more absurd or detestable, than a system which made Walter Scott and Justus Liebig boobies at school; and so effectually concealed their natural talents, that, for example, Liebig was often lectured before the whole school, on his being sure to cause misery and broken hearts to his parents, while he was all the time conscious, as the above anecdote proves, of the possession of talents similar in kind to those he has since displayed, and while he felt entirely unable, from a natural defect, to perform the allotted tasks of verbal memory, even when trying his utmost! This defect of verbal memory has adhered to him ever since; and is now frequently a cause of great annoyance. I may add, that he suffers also considerable inconvenience from his deficient Number, which leads to frequent errors in the details of his numerical calculations.

The Phrenological Journal, volume 18, issues 32-33, William Gregory, 1845, pp 59-60

Don't write off your students

Sir John Gurdon, who won the Nobel Prize for Medicine in 2012, was once told by his biology teacher*: "I believe he has ideas about becoming a scientist. On his present showing this is quite ridiculous; if he can't learn simple biological facts he would have no chance of doing the work of a specialist, and it would be a sheer waste of time, both on his part, and of those who have to teach him.'*

A Munich schoolmaster wrote in Albert Einstein's school report in 1895: *"He will never amount to anything."*

Oil on troubled waters

Benjamin Franklin could still the waves of a stream just by waving his walking stick. It worked because his stick was hollow and contained oil.

It is told that Franklin learned the principle behind this trick when on a boat trip he noticed that the water behind the ship became calmer after the cook cast greasy water overboard.

Clerihews

The clerihew is a poetic form invented during a chemistry class by a 16 yr old schoolboy, Edmund Clerihew Bentley (1875-1956). His classic was:

Sir Humphry Davy
Abominated gravy.
He lived in the odium
Of having discovered sodium.

The English magazine *The Spectator* ran a competition recently for the best scientific clerihews. (Clerihews on scientists | The Spectator)

The young Marie Curie
Reacted with fury
When they said don't worry your pretty little cranium
About uranium
David Silverman

Alexander Fleming
Made a great discovery, stemming
From a mouldy dish, which made the future cheerier
For all of us — except, of course, for the bacteria.
Sylvia Fairley

They make fun of some famous scientist, rhyming AABB. More examples fro E C. Bentley.

Sir James Dewar
Is smarter than you are
None of you asses
Can liquify gases.

"Corruptio optimi pessima!"
Grinned Sir Henry Bessemer.
"Judicio vulgi demens!"
Snorted Sir William Siemens.

Can you write one or get your class to write some?
Marie Curie worked hard
Boiling up pitchblende in her yard
But O what a lark!
She now glows in the dark.
P. E. Childs

Scientific anecdotes

A number of good stories are told about Lord Kelvin, William Thomson.

Kelvin worked out an improved method for measuring the depth of the sea, using piano wire and a narrow-bore glass tube, stoppered at the upper end. While experimenting with this invention, he was interrupted one day by his colleague James Prescott Joule.

Looking with astonishment at the lengths of piano wire, Joule asked him what he was doing,

"Sounding," said Thomson.

"What note?" asked Joule.

"The deep C," returned Thomson.

The famed physicist William Thomson (later Lord Kelvin) was a professor of natural philosophy at Glasgow University for some fifty years. Unable to meet his class one day, he posted a note on the door of his lecture room: "Professor Thomson," it said, "will not meet his classes today." As a joke, some of his mischievous students erased the "c," leaving a message reading: "Professor Thomson will not meet his lasses today." The following day when the pranksters assembled in anticipation of the effect of their joke, they were chagrined to find that the professor had outwitted them. The note was now found to read: "Professor Thomson will not meet his asses today."

At Glasgow University one day, Lord Kelvin found himself delivering a lecture in a room directly beneath another colleague whose students, at the end of the lecture, showed their appreciation in the customary manner—by stamping vigorously on the floor. "Ah," Lord Kelvin remarked, as chucks of plaster fell from the ceiling, "I see Dr. Campbell's conclusions don't agree with my premises."

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We hope to make more of them available in future.

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In the next issue:

Proceedings 40th ChemEd-Ireland

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