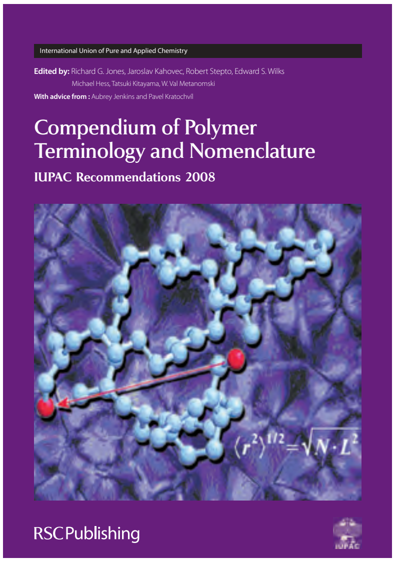
IUPAC in Polymer Education

by Christopher Fellows and Patrick Theato

For as long as the Polymer Division of IUPAC has existed, it has put a high priority on education. In 1996, it first supported a dedicated educational project in the form of the UNESCO/IUPAC Postgraduate Course in Polymer Science, which continues to be organised annually by the Institute of Macromolecular Science in the Czech Republic and supported by the Polymer Division. In 2005, the Division IV Subcommittee on Polymer Education (SPEd) was established "to bring existing educational activities under one roof, to emphasise the importance of polymer education as well as the dedication of the IUPAC Polymer Division to this important field" [1]. Since then, educational projects have been the focus of this subcommittee. It has provided a forum for exchange of practice in polymer education worldwide, supported workshops in polymer science for undergraduates and postgraduate students on most continents, developed its own educational resources for free distribution to the world, and provided a website linking to other groups active in polymer education and other education resources.



The "Purple Book" [2]

What do chemists need to know about polymers? What do people in general need to know about polymers? These are questions that do not really have a good answer. The answer will depend on the chemist, or the person, their individual situation and what goal they are trying to accomplish at a given time.

A secondary school student will require different information than an employee of a company wanting to source a product for a food processing application, who will in turn require different information from a government officia investigating an incident caused by materials failure or a biomedical researcher seeking an appropriate substrate for a therapeutic biomolecule. Within chemistry, there is no consensus on what content is essential for a chemist to know — this is frequently driven by which industries are important locally and which research specialties have historically been important. Polymers are often one of the fir t topics to be omitted from a chemistry program, sitting as they do on the margins of physics and engineering, relatively far from the core topics of chemistry.

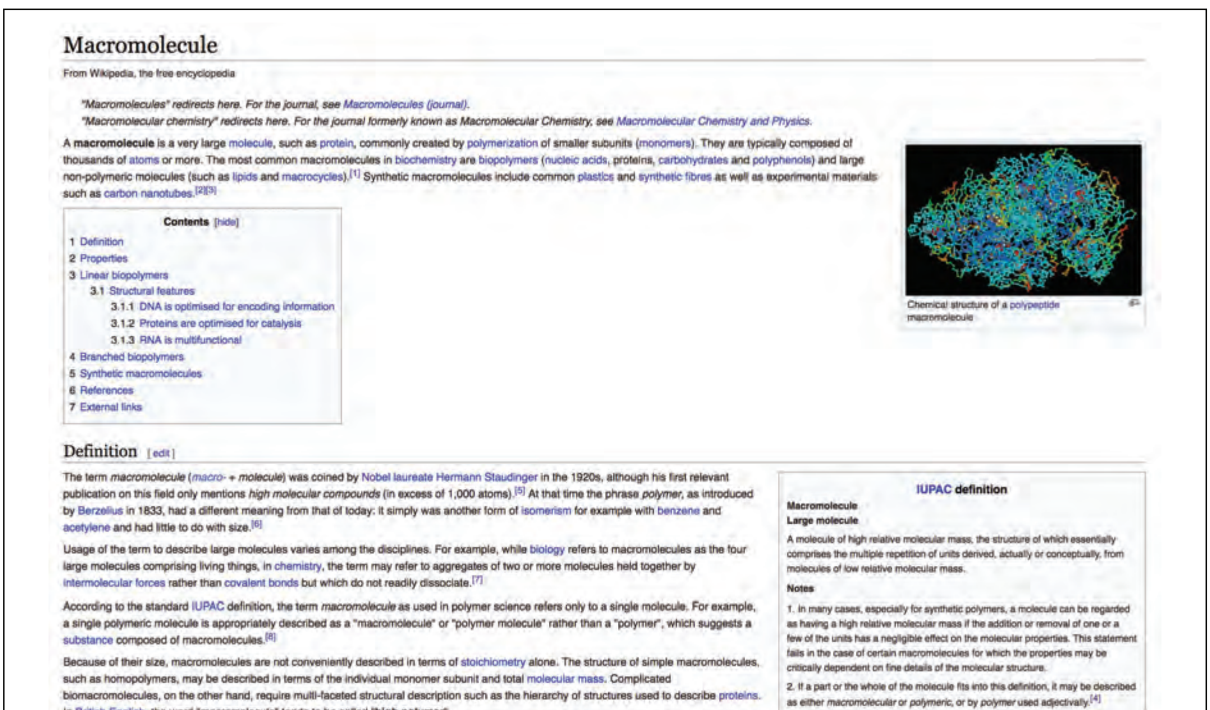
So, leaving behind the difficult question of what people ought to know about polymers, we will move on to an easier one: assuming someone wants to know *something* about polymers: **Which source should they refer to when they need to know about polymers?** The correct answer to this question is almost always: "IUPAC's Compendium of Polymer Terminology and Nomenclature" [2] (*i.e.*, the 'Purple Book'). This compendium of definitions has been subjected to many iterations of exhaustive discussion and contains the definiti e, internationally agreed-upon explanations of the many terms that lurk in wait to confuse newcomers to polymer science. Now available with a purple title page and free to the world on the internet, it is as far as possible comprehensive, accurate, and usable. While it might not answer all of your questions, the Purple Book will almost certainly give a solid start to your quest for polymer knowledge and provide you with the correct search terms to help you find the answer to the question you really want to answer, whatever it may be. The next question that should be asked is: **In practice, what source does someone typically refer to when they need to know about polymers?**

While around the world there are many sources of information of differing degrees of accessibility and quality, the answer to this question is, more and more, "Wikipedia." There is nothing wrong with this, because Wikipedia is a fantastic place to begin your search for information on just about anything. In recognition of the shift in the behaviour of learners worldwide, who seek help fir t from a few pervasive online resources, SPEd has, over the past several years, sought out every opportunity to incorporate Purple Book definitions into polymer-related Wikipedia articles. There is no point in providing beautifully curated up-to-date and accurate information in a place where no one will read it, so SPEd has sought to go where the learners are. This is not a project where IUPAC editors ride roughshod over other Wikipedia editors — an unhappy possibility that is impossible at any rate — but one that ideally results in a negotiated outcome, where the IUPAC definitions are clearly branded and prominently displayed as inalterable nuggets within the Wikipedia entry, while the open philosophy of Wikipedia continues to prevail elsewhere. An example of how this works in practice is shown below for 'macromolecule'. (It should be noted that to date this is only implemented in this manner in the English Wikipedia. In other languages, which are independently handled, it has not yet been possible to negotiate this implementation.)

In order to go where the learners are, it is also becoming more and more important to move beyond the traditional strongholds of chemistry and polymer chemistry in North America, Western Europe, and Northeast Asia. An ever-increasing fraction of the world's chemists and the world's polymer industry is located in developing nations, as advances in knowledge and its application have lifted billions out of poverty. Linking polymer science and education closely to the needs of local industry is critical to spanning the 'middle income gap', in which nations escape absolute poverty but fail to achieve developed status [3]. As synthetic polymers have become a more important part of material culture around the world, it has also become a priority that they be part of a typical student's primary and secondary education:

> *"During the last 30 years the world's materials around us have changed … to new materials … Emphasis is on polymers, advanced materials for the electronic and medical industries and novel ceramics, amongst others. Yet, a school leaver often doesn't know … what a plastic bag is and how to recycle it. There is an urgent need to address the improved teaching of materials (and polymer) science, especially in Africa. We are of the opinion that new courses could do much to improve science teaching in Africa and make the matric student much more conscious of materials around him/her."* [4]

Fortunately, the omnipresence of the internet and mobile devices to access it means that it has never been easier to reach out to learners worldwide, at all levels. A core belief of SPEd is that educational materials should be freely available for all users anywhere in the world, not quarantined behind university firewalls for the exclusive use of fee-paying students. The website of the SPEd, https://iupac.org/polymer-edu/, provides links to the polymer education resources developed under the auspices of the IUPAC Polymer Division. For example, 'A Brief Guide to Polymer Nomenclature' [5] carefully picks enough detail out of the Purple Book to answer most everyday questions about naming polymers. The educational materials developed for the postgraduate courses held around the world under SPEd auspices — whether in Prague, Stellenbosch, or Kathmandu — are also available online. There is still much work to be


Macromolecule

From Wikipedia, the free encyclopedia

"Macromolecules" redirects here. For the journal, see Macromolecules (journal).
"Macromolecular chemistry" redirects here. For the journal formerly known as Macromolecular Chemistry, see Macromolecular Chemistry and Physics.

A **macromolecule** is a very large molecule, such as protein, commonly created by polymerization of smaller subunits (monomers). They are typically composed of thousands of atoms or more. The most common macromolecules in biochemistry are biopolymers (nucleic acids, proteins, carbohydrates and polyphenols) and large non-polymeric molecules (such as lipids and macrocycles).[1] Synthetic macromolecules include common plastics and synthetic fibres as well as experimental materials such as carbon nanotubes.[2][3]

Chemical structure of a polypeptide macromolecule

Contents [hide]

Definition [edit]

The term *macromolecule* (*macro-* + *molecule*) was coined by Nobel laureate Hermann Staudinger in the 1920s, although his first relevant publication on this field only mentions *high molecular compounds* (in excess of 1,000 atoms).[5] At that time the phrase *polymer*, as introduced by Berzelius in 1833, had a different meaning from that of today: it simply was another form of isomerism for example with benzene and acetylene and had little to do with size.[6]

Usage of the term to describe large molecules varies among the disciplines. For example, while biology refers to macromolecules as the four large molecules comprising living things, in chemistry, the term may refer to aggregates of two or more molecules held together by intermolecular forces rather than covalent bonds but which do not readily dissociate.[7]

According to the standard IUPAC definition, the term *macromolecule* as used in polymer science refers only to a single molecule. For example, a single polymeric molecule is appropriately described as a "macromolecule" or "polymer molecule" rather than a "polymer", which suggests a substance composed of macromolecules.[8]

Because of their size, macromolecules are not conveniently described in terms of stoichiometry alone. The structure of simple macromolecules, such as homopolymers, may be described in terms of the individual monomer subunit and total molecular mass. Complicated biomacromolecules, on the other hand, require multi-faceted structural description such as the hierarchy of structures used to describe proteins. In British English, the word "macromolecule" tends to be called "**high polymer**".

IUPAC definition

Macromolecule
Large molecule

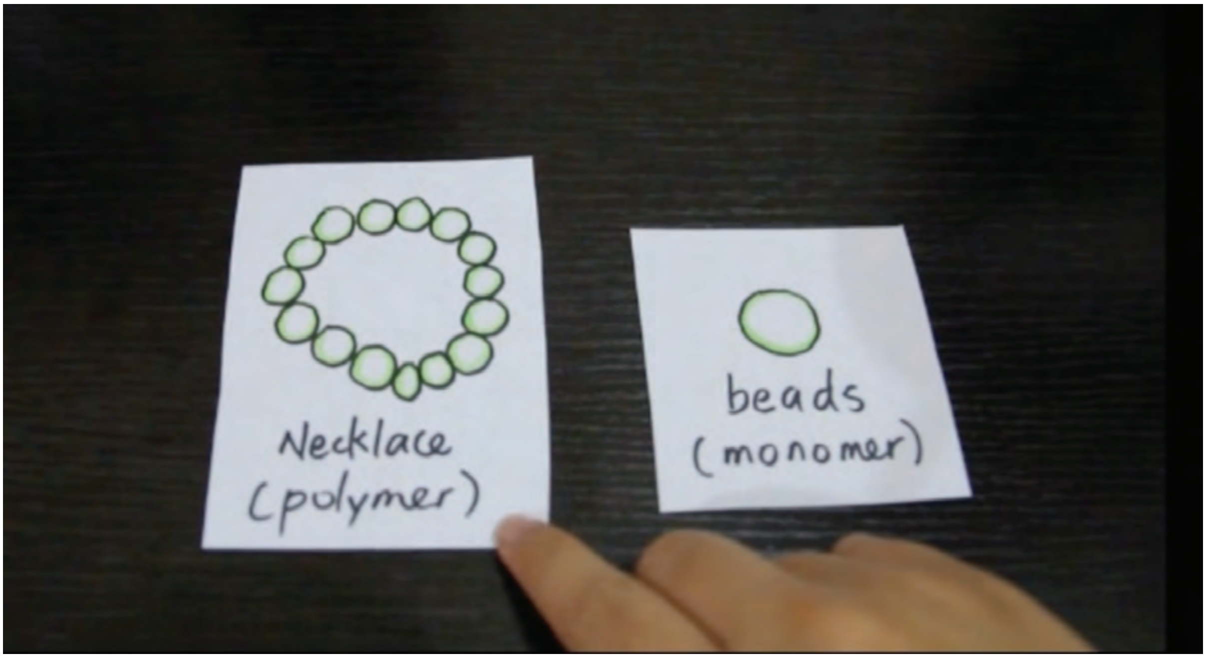
A molecule of high relative molecular mass, the structure of which essentially comprises the multiple repetition of units derived, actually or conceptually, from molecules of low relative molecular mass.

Notes

1. In many cases, especially for synthetic polymers, a molecule can be regarded as having a high relative molecular mass if the addition or removal of one or a few of the units has a negligible effect on the molecular properties. This statement fails in the case of certain macromolecules for which the properties may be critically dependent on fine details of the molecular structure.

2. If a part or the whole of the molecule fits into this definition, it may be described as either *macromolecular* or *polymeric*, or by *polymer* used adjectivally.[4]

Wikipedia Screenshot, https://en.wikipedia.org/wiki/Macromolecule, accessed 15 September 2017



A screenshot from Yvonne Choo's prize-winning 2011 IYC 'A World Without Polymers' video [6]

done to raise awareness of IUPAC's polymer education resources and improve their usability, but it has never been easier to access information. The number one current priority of the SPEd is making existing IUPAC educational resources available on this website.

Since most SPEd members are drawn from academia and spend a great deal of their time teaching at the tertiary level, it has primarily engaged in educational activities at that level, with relatively few projects to engage secondary school students and the general public. These are areas where we can and should do more in the future. One event where SPEd did engage with the general public was held at the time of the International Year of Chemistry (2011), when SPEd ran a video essay contest entitled 'A World Without Polymers'. In this project, young people were asked to imagine the impractical possibility of life in a world with only low molar mass compounds: many of these videos can be found in the great sea of information which is the internet, and a number, including the winning entry by Malaysian final year secondary student Yvonne Choo, can be found on the SPEd website [6].

It should not be assumed that only SPEd is involved in polymer education within IUPAC. Most members of the IUPAC Polymer Division are active educators, while polymer-related educational projects are also carried out under the banner of the IUPAC Committee on Chemical Education. Those activities that form part of formal projects within SPEd are very much the tip of the iceberg in terms of IUPAC's involvement in polymer education.

At the Macro 2014 meeting in Chiang Mai, Thailand, SPEd organised a session on activities in polymer education worldwide, which has been captured for posterity in a special issue of *Macromolecular Symposia* (doi.org/10.1002/masy.v355.1). At this symposium, SPEd considered a wide range of questions in education, from broad fundamental principles to the details of how learning about polymers takes place at specific events. For example, it considered appropriate development of resources and curriculum in secondary school education [7] and the effectiveness both of short postgraduate courses in polymer science and of even shorter tutorial events held in conjunction with conferences [8, 9].

The chair of the IUPAC Subcommittee on Polymer Terminology, Dr. Roger Hiorns, spoke at the Macro 2014 meeting on the uptake of resources such as the 'Brief Guide to Polymer Nomenclature', which has been linked to by a large number of organisations involved in both formal and informal secondary and tertiary education. Dr. Hiorns also spoke on the development of new polymer-related laboratory activities that can be carried out with household items for secondary school students and stressed the importance of the fundamental work of IUPAC for education in general:

"Misunderstanding between different communities creates more work and hinders

science and education! Rigorous, worldwide definitions facilitate understanding, communication, scientific endeavour, and education." [10]

The SPEd session at Macro 2014 also considered common pitfalls in tertiary polymer education of particular relevance to developing countries. Frequently, there is an emphasis on the relation between synthesis and structure, while the all-important links between structure and macroscopic properties which are critical for the application of polymers are neglected. The habit of thinking in 'disconnected mental boxes' must be broken down so that students can better integrate what they learn in separate chemistry, physics, and engineering units to obtain a useful mental model they can apply when they are faced with challenges involving polymers in the workforce [3].

Reviews of the state of tertiary polymer education at the time in a number of countries — Zimbabwe, Vietnam, Thailand, Tanzania, South Africa, Nigeria, New Zealand, Malaysia, Korea, Japan, Germany, China, Brazil, Australia — were also presented at Macro 2014 [11-20]. These reports together give a valuable benchmark for assessing global trends. It will be important to revisit these same countries in another decade or so to assess where polymer education is moving. Significantl , similar challenges and opportunities exist all over the world: polymer education is on the fringe of most secondary and tertiary degree programs and lack of general knowledge of polymers is widespread among decision makers and the public at large, while at the same time polymer education is fundamental to the operation of industries of enormous scale and importance.

In summary, IUPAC can play a significant role in polymer education worldwide and has many members who are passionately committed to this goal. Within IUPAC, these efforts are localised most strongly in SPEd, which strives to be the central source of information for polymer education resources. Yet, as a project run solely by the voluntary work of polymer scientists worldwide, progress is never as rapid as we would like, and SPEd welcomes support from anyone who is interested in contributing to our work. Please feel free to drop in on our next full face-to-face meeting at Macro 2018 in Cairns, Australia!

Acknowledgements

The kind advice of Prof. Werner Mormann in the preparation of this article is gratefully acknowledged.

References

1. From http://www.iupac.org/body/403. Quoted in W. Mormann, *Macromol. Symp.* 355 (2015) 8-12; doi.org/10.1002/masy.201500094
2. R. G. Jones, E. S. Wilks, W. V. Metanomski, J. Kahovec, M. Hess, R. Stepto, T. Kitayama, "Compendium of Polymer Terminology and Nomenclature", Royal Society of Chemistry, London, 2009.
3. A. M. North, *Macromol. Symp.* **355:**32-38 (2015).
4. R. D. Sanderson, J. Makawa-Mbewe, J. J. De Kock, *Macromol. Symp.* **165:**143-154 (2001).
5. R. C. Hiorns, R. J. Boucher, R. Duhlev, K.-H. Hellwich, P. Hodge, A. D. Jenkins, R. G. Jones, J. Kahovec, G. Moad, C. K. Ober, D. W. Smith, R. F. T. Stepto, J.-P. Vairon, J. Vohlídal, *Pure Appl. Chem.* **84:**2167-2169 (2012).
6. Y. Choo, "A World Without Polymers", https://vimeo.com/143514726.
7. J. L. Enlow, D. M. Marin, M. G. Walter, *Macromol. Symp.* **355:**43-51 (2015).
8. A. Šturcová, P. Kratochvíl, *Macromol. Symp.* **355:**20-25. (2015).
9. M. Hess, *Macromol. Symp.* 355 (2015) 26-31.
10. R. C. Hiorns, *Macromol. Symp.* 355 (2015) 13-19.
11. H. Pasch, *Macromol. Symp.* **355:**96-103. (2015).
12. L. Van Thu, N. Van Khoi, N. T. Tung, *Macromol. Symp.* **355:**90-95 (2015).
13. N. R. Edmonds, J. McKee, P. N. Plimmer, *Macromol. Symp.* **355:**39-42 (2015).
14. C. H. Chan, C.-C. Ho, *Macromol. Symp.* **355:**75-81 (2015).
15. C. H. Do, P. Theato, *Macromol. Symp.* **355:**68-74 (2015).
16. P. Theato, *Macromol. Symp.* **355:**119-125 (2015).
17. T. Nakano, *Macromol. Symp.* **355:**61-67 (2015).
18. J. He, *Macromol. Symp.* **355:**52-60 (2015).
19. C. G. dos Santos, M. L. Dias, S. V. Canevarolo, *Macromol. Symp.* **355:**111-118 (2015).
20. C. M. Fellows, *Macromol. Symp.* **355:**104-110 (2015).

Christopher Fellows <cfellows@une.edu.au> is an Associate Professor in the School of Science and Technology at the University of New England at Armidale in Australia, and Patrick Theato <theato@chemie.uni-hamburg.de> has been W2 Professor at the University of Hamburg in Germany from 2011 to 2017 and will be Full Professor from 2018 at Karlsruhe Institute of Technology (KIT) in Germany. They each joined IUPAC in 2016 and as well as contributing to projects within the remit of the Subcommittee on Polymer Terminology and they jointly are the Chair of the Subcommittee on Polymer Education.