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Toward Non-Taxonomic Structuring of Scientific Notions: The Case of the Language of Chemistry and the Environment †

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† This paper is an extended version of our paper published in Proceedings of the 2nd International Conference on Multilingual Digital Terminology Today. Design, representation formats and management systems (MDTT 2023) (https://ceur-ws.org/Vol-3427/ (accessed on 1 December 2023)).
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Abstract: This paper addresses the crucial question of the structuring of scientific Notions for the purpose of their proper teaching/acquisition. It aims to demonstrate that non-taxonomic structures, derived from the systematic lexicographic definition of terminological lexical units, can be rigorously constructed and are adequate for implementing a non-isolationist approach to terminology modeling: one that embeds the description of terminological units within a more global model of the general lexicon. Using theoretical and descriptive principles of Explanatory Combinatorial Lexicology and the lexicography of lexical networks known as Lexical Systems, we apply our approach to the core terminology of chemistry and chemistry-related environmental terminology. This allows us to propose Notion building road maps for three languages—English, French and Russian—that can be used as guides for the teaching/acquisition of chemistry Notions. Additionally, exploiting the special case of the noun *carbon*—which pertains to chemistry, environmental science and, even, general language—we demonstrate the potential of our non-isolationist approach for interfacing distinct sectors of terminological knowledge.

Keywords: Explanatory Combinatorial Lexicology; lexicographic definition; core terminology; chemistry; environmental science; taxonomy; Notion building

Citation: Gotkova, Tomara, Francesca Ingrosso, Polina Mikhel, and Alain Polguère. 2024. Toward Non-Taxonomic Structuring of Scientific Notions: The Case of the Language of Chemistry and the Environment. *Languages* 9: 95. https://doi.org/10.3390/languages9030095

Academic Editors: Giorgio Maria Di Nunzio, Rute Costa and Federica Vezzani

Received: 11 December 2023
Revised: 27 February 2024
Accepted: 4 March 2024
Published: 13 March 2024

1. Introduction

The research we present addresses the crucial question of the structuring of scientific Notions for the purpose of their proper teaching and acquisition. While taxonomies are the dominant approach to the structuring of Notions, the present paper aims to demonstrate that non-taxonomic structures, derived from the systematic lexicographic definition of terminological lexical units, can be rigorously constructed. In other words, it proposes to have recourse to 'defined_by' relations instead of 'is_a' relations as a structuring principle. Another important characteristic of our approach is its non-isolationist nature: one where the description of terminological units is embedded within a more global model of the general lexicon. This introductory section is organized as follows: first, we present principles of Notion building, which presupposes a clear identification of what is meant here by *Notion*, *Concept* and *Term* (Section 1.1); next, we position and justify our proposal in the context of current terminological models, which are to a large extent based on taxonomic organizations (Section 1.2); in the following section (Section 1.3), we introduce the core element of our descriptive methodology: the lexicographic construction of network models of natural language lexicons called *Lexical Systems*; finally, we propose theoretical and descriptive foundations for the ‘defined_by’ lexical relation, which is the cornerstone of our approach to the structuring of scientific Notions (Section 1.4).

1.1. Notion Building: From the Foundations to the Roof

Let us begin with some core nomenclature that will be playing an essential role in the rest of the discussion. In this paper, we take a *Concept*—with a capital *C*—to be any **unit of reasoning**, whether institutionalized (in the semiotic sense) or created on the fly in a given instance of inference performed by an individual. A *Term*—with a capital *T*—is a **lexical unit** that denotes an *institutionalized* Concept belonging to a conceptual system of a knowledge domain (or a set of knowledge domains). A *Notion*—with a capital *N*—is a Term ↔ Concept **association**; names of Notions are written in sans serif font. Note that a given scientific Notion, while being built on one well-specified Concept, can encompass several Terms:

- by synonymy—e.g., in chemistry, the Term CARBON **I.1** (chemical element) is an exact synonym of ATOMIC NUMBER 6;
- semantic derivation—e.g., ION and IONIC **1** ‘relating to ions’ pertain to the same chemistry Concept and therefore to the same Notion.

We return to this issue in Section 2.1, while discussing the Term↔Notion pairings that have been identified in the course of our research on the core terminologies of chemistry in English, French and Russian.

While the nouns *concept* and *notion* are often used interchangeably in the literature, we believe that the understanding of the interplay between Concepts, Terms and Notions is vital to the elaboration of a logical approach to the mastering of sciences, both from a theoretical and practical/applied point of view. For instance, to fully master the chemical Notion of element, one has to master (i) the corresponding scientific Concept (its role in chemistry, the set of elements identified in the Periodic Table, etc.) and (ii) the linguistic properties of the English Term ELEMENT **III.3a** (definition, grammatical characteristics, combinatorial properties, etc.), this latter being a specific terminological sense of the (mainly) general language vocable ELEMENT (see Sections 1.4 and 2.2).

Notional systems, in order to be acquired, should be structured according to a *Notion building* logic, one that allows for the proper acquisition of a Notion on top of other Notions it presupposes. For this, we strongly believe that Terms themselves and their lexicographic modeling are the key to establishing what we later call (Section 2.2) *Notion building road maps*. These road maps are designed to adequately encompass the realm of scientific Concepts and that of scientific Terms, thus giving access to both proper reasoning and proper linguistic expression in scientific fields (the two being in reality inseparable). For this reason, we approach the problem of the structuring of notional systems through the lens of the modeling of terminologies.

1.2. Issues with Lexical Taxonomies

The mainstream approach to the structuring of terminological models is undoubtedly one based on formal (computerized) ontologies (Munn and Smith 2008). Such models are predominantly organized as ‘is_a’ class hierarchies (Montiel-Ponsoda 2022). Ontology-based terminological models are Concept-driven, rather than Term-driven: they graft the modeling of Terms onto a taxonomy of domain Concepts. Underlying such models lies the Linnaean principle of taxonomic organization of the world and the credo that taxonomies are the most efficient information structures for organizing the various realms of “things”. From the so-called Tree of Porphyry (Barnes 2003) inspired by Aristotle’s defining principles to modern formal ontologies, via Linnaeus’s classification of species (Linnaeus 1735), the taxonomic approach has established itself as *the* frame of reference for putting into order the natural messiness of physical and cognitive things that surround us.

It is worth noting that the taxonomic approach often finds its limits once applied and confronted with the complexity of natural entities as it tries to project onto them a unique classifying principle that is not devoid of philosophical and ideological prejudices (Ereshefsky 1994). Additionally, one of the drawbacks of this approach is that it favors relations between hypothesized classes of entities over relations between actual entities themselves (Sloan 1976). In contrast, other relational models are increasingly being constructed and applied: ones that represent given domains as huge sets of entities individually connected by multiple types of relations forming networks with specific topological properties known as *small-world networks* (Watts and Strogatz 1998). We adhere to the hypothesis that such structures are better suited than taxonomies to model all the complexity of the relational systems that connect natural entities—see the expression *terrain network* coined by B. Gaume (Gaume 2004). Due to space constraints, we will not attempt to justify further this hypothesis at the general level but rather focus on natural language lexicons and terminologies in particular.

For a long time, the taxonomic approach has been applied to lexical units of natural languages through the recourse to hyperonymic/superordinate relations (Goddard 2011, section 1.5.2). In contemporary lexical research, the most well-known instance of the approach is, for the English language, the Princeton WordNet (Fellbaum 1998, 2014) with its multiple offsprings for other natural languages (e.g., Vossen 1998).

In our opinion, the main problems posed by the taxonomic/hyperonymic structuring of lexical units in general, and Terms in particular, are the following:

- Hyperonymy applies mainly to nominal lexical units—cf. the separate structuring principles used in WordNet for nouns vs. verbs, adjectives and adverbs (Miller 1990); however, Terms are of other main parts of speech as well, such as verbs and adjectives (L'Homme 2012a).
- As for all types of taxonomic models, it favors relations between postulated lexical classes over relations between individual lexical units (see earlier remark on taxonomies).
- The 'is_a' (or 'kind_of') relation accounts only for a small subset of all relations holding between Terms and between the corresponding domain Notions; terminological taxonomies may therefore be insufficient from a pedagogical point of view, where the acquisition of scientific and technical Notions is at stake.
- Finally, the structuring of terminologies into specific domain taxonomies leads to an isolationist approach where terminologies are modeled in close circuit systems, whereas they interact with and are fully integrated to the system of the general language.

1.3. The Lexical System Approach

We now present an alternative to taxonomic terminological models where 'defined_by' relations holding between Terms—rather than 'is_a' relations holding between Concepts (Johansson 2008)—are the organizational principle of terminologies, motivated by pedagogical/acquisition considerations. In our approach, the 'defined_by' relation is one among many different types of relations holding between lexical units of a language, forming what is termed a *Lexical System* (Polguère 2014). Let us briefly characterize this type of model.

Lexical Systems are designed to be compatible with fully relational models of the *Mental Lexicon* as postulated from both psycholinguistic and lexicological perspectives (Aitchison 2012; Gaume and Duvignau 2004; Szubko-Sitarek 2015). They are lexicographically built according to theoretical and descriptive principles of *Explanatory Combinatorial Lexicology* (Mel'čuk 2006), except for the fact that they are lexical network models rather than "textual" dictionaries, such as Mel'čuk and Zholkovsky (1984) and Mel'čuk et al. (1984, 1988, 1992, 1999). Formally, they are small-world networks (see Section 1.2 above). Their nodes are mainly lexical units of the language; their arcs are lexical relations of various types, listed below by order of importance to the small-world network structuring of Lexical Systems:

- paradigmatic (semantic) and syntagmatic (combinatorial) relations corresponding to so-called Meaning–Text *lexical functions* (Mel'čuk 1996; Mel'čuk and Polguère 2021);
- copolysemy relations (extension, metonymy, metaphor, etc.) holding between senses of polysemous vocables (Polguère 2018);

- 'defined_by' relations that connect each given lexical unit L_1 to other lexical units L_2, $L_3 \ldots L_n$ whose meaning is embedded in the meaning of L_1—see details in Section 1.4 below;
- formal inclusion relations—e.g., the *lexico-syntactic structure* (Pausé 2017) of the idiom ⌜PUSH BUTTONS⌝ 'irritate someone' is formally built from the lexemes PUSH and BUTTON.

> The research presented in this paper is based on the lexicographic modeling of terminologies within three Lexical Systems developed at the ATILF laboratory, namely, the *English Lexical Network*—hereafter **en-LN**–the *French Lexical Network*—hereafter **fr-LN**–and the *Russian Lexical Network*—hereafter **ru-LN**.

1.4. Nature and Role of 'defined_by' Relations

Though Meaning–Text paradigmatic and syntagmatic lexical functions are the leading principle for the structuring of Lexical Systems, 'defined_by' relations have long proved to be essential in the organization of terminologies, especially from a pedagogical perspective. For instance, the set of lexicological Notions introduced in the manual Polguère (2016) is entirely structured according to this principle, which determines the flow of Notions making up the teaching program implemented by the manual. We formally specify the 'defined_by' relation as follows:

> A 'defined_by' relation holds between two lexical units L_1 and L_2 if L_1 is lexicographically defined in terms of L_2—i.e., if L_2 appears in the *lexicographic definition* of L_1. Such a relation is noted $L_1 \xrightarrow{\text{def\_by}} L_2$.

Let us illustrate 'defined_by' relations with data in Table 1: the lexicographic definition of the chemistry Term ELEMENT **III.3a** proposed in Mikhel (2022) and encoded in the **en-LN**. Note that such lexicographic definition follows the format and structuring principles of Explanatory Combinatorial Lexicology detailed in Mel'čuk and Polguère (2018). Additionally, the lexicographic numbering used in this paper was established in Mikhel (2022) and takes into consideration the polysemy of the corresponding vocables both for general and specialized senses—see Mikhel (2022, chap. 6).

Table 1. Lexicographic definition of ELEMENT **III.3a** encoded in the **en-LN**.

Element **III.3a** *X* :	type of <u>atoms</u> **I.2** • that is identified by the number X corresponding to the quantity of <u>protons</u> in the <u>nucleus</u> **I.2** of the <u>atoms</u> **I.2**.
Ex.: *How is an atom of the **element** 54 (Xe) likely to act during a chemical reaction?*	

In Table 1, terminological 'defined_by' relations are signaled by underlying the Terms that (i) participate in the lexicographic definition of ELEMENT **III.3a** and (ii) are themselves accounted for in the **en-LN**. Three 'defined_by' relations emerge from the above definition:

- ELEMENT **III.3a** $\xrightarrow{\text{def\_by}}$ ATOM **I.2**;
- ELEMENT **III.3a** $\xrightarrow{\text{def\_by}}$ PROTON;
- ELEMENT **III.3a** $\xrightarrow{\text{def\_by}}$ NUCLEUS **I.2**.

These three relations form in reality a heterogeneous set as two types of 'defined_by' relations need to be distinguished in natural language lexicons.

Generic 'defined_by' relations. A *generic* $L_1 \xrightarrow{\text{def\_by}} L_2$ relation is such that L_2 is the *central component* of L_1's definition (Mel'čuk and Polguère 2018, section 2.4). Such is the case of ATOM **I.2** in Table 1, though the definition stipulates that chemical elements are not atoms per se but *types* of atoms and therefore belong to a more abstract level of conceptualization of chemical entities. Generic 'defined_by' relations between Terms are by nature closely related to 'is_a' taxonomic relations between Concepts.

Specific 'defined_by' relations. A *specific* $L_1 \xrightarrow{\text{def\_by}} L_2$ relation is such that L_2 belongs to a *peripheral* (= non-central) component of L_1's definition. Such is the case of PROTON and NUCLEUS **I.2** in the definition of ELEMENT **III.3a**.

It is essential to note that generic and specific 'defined_by' relations are **equally** important from the point of view of Notion acquisition. Because Notions are Term ↔ Concept associations (cf. Section 1.1), the definition in Table 1 tells us that the mastering/understanding of the Notion of chemical element necessitates the mastering/understanding of not only the Notion of an atom, but also the Notions of an atom's nucleus and of protons—see Section 2.2 below for further discussion.

We advocate a descriptive approach where terminological models are organized by a system of (generic and specific) 'defined_by' connections that aims to account for a Notion building perspective on terminologies. Simultaneously, however, the terminographic description of each individual Term should be embedded into the Lexical System of the corresponding natural language—for arguments in favor of such an *integrated* approach, see Ingrosso and Polguère (2015) and Section 2.3 of the present paper.

2. Application to the Core Terminology of Chemistry, and Beyond

In this section, we demonstrate the applicability of our descriptive approach with work performed on the 'defined_by' structuring of the core terminology of chemistry and related Terms of environmental science. For this, we draw from two interrelated doctoral projects: Mikhel (2022) and Gotkova (2023). These interdisciplinary projects were jointly supervised by two researchers, each contributing their expertise from their respective field: theoretical/descriptive lexicology and theoretical/green chemistry.

We start with an explanation of the method applied for the identification of core chemistry nomenclatures for English, French and Russian (Section 2.1). Next, we describe the work performed on inferring Notion building road maps from the lexicographical structuring of these nomenclatures (Section 2.2). Finally, we examine issues raised while expanding the approach to the heavily multidisciplinary domain of environmental science, using the lexicographic and conceptual analysis of the English noun *carbon* as a testbed (Section 2.3).

2.1. Core Terminology of Chemistry

Chemistry, a typical "hard science," is an established discipline with an apparently well-defined theoretical background. In theory, the organized nature of chemistry should allow for a straightforward approach to the treatment of its terminology. Mikhel (2022) presents multilingual research on the formal modeling of chemistry terminology across three natural languages—English, French and Russian—within the three corresponding Lexical Systems—**en-LN**, **fr-LN** and **ru-LN**. One of the research objectives consists of identifying the notional core of the discipline via the methodical study and modeling of its corresponding Terms. In Mikhel (2022, p. 14), the *core terminology* of chemistry is characterized as consisting of Terms that possess two characteristics:

- they are taught in introductory courses in general chemistry;
- they are "shared by most subdomains of chemistry" without belonging to a given subdomain.

Specialized corpora on chemistry were utilized in order to extract highly recurrent Terms and establish the nomenclature of core chemistry Terms. The project benefited from a specialized corpus of chemistry journals—e.g., the *Journal of the American Chemical Society*—compiled in the framework of the STRÉTCH project (Ingrosso and Polguère 2015). Additionally, a set of multilingual corpora were built from textbooks on general chemistry, research papers, reports and instructional texts in the three languages. In the case of English, twenty basic chemistry Terms were extracted from the available corpora based on their frequencies and under the supervision of the chemist involved in the research.

It was hypothesized that the most frequently occurring Terms determine the notional foundation of the discipline: i.e., Notions—such as the atom, (chemical) bond, molecule, etc.—from which the bulk of the notional system of general chemistry is derived. In the course of lexicographic description of such Terms, the nomenclature was further expanded up to a hundred plus units in each of the three languages considered (English, French and Russian)—for terminological gaps between these languages, see Mikhel (2022, chap. 7, section 7.1.2). The expansion mostly accounted for lexical connections established between Terms. While the final core chemistry nomenclature includes mostly chemistry Terms, it also features Terms from the domain of physics (e.g., MATTER **I.a**) and a few general language lexical units (e.g., MICROSCOPIC **I**).

Table 2 gives the number of Terms and corresponding Notions for the resulting English, French and Russian core nomenclatures.

Table 2. Term↔Notion pairings in the three core chemistry nomenclatures.

Languages	Term↔Notion pairings		
English	107 core Terms	↔	53 corresponding core Notions
French	103 core Terms	↔	53 corresponding core Notions
Russian	102 core Terms	↔	52 corresponding core Notions

The discrepancy between the number of core Terms and the number of core Notions, for each language, is explained by the fact that a core Term T can have one or more semantic derivatives T′, T″, ... with a unique corresponding core Notion. For instance, all six core Terms, ION, IONIC **1**, IONIZATION **1**, IONIZE **a** (non-causative), IONIZE **b** (causative) and IONIZED$_{(Adj)}$, are connected by semantic (and morphological) derivations, and they have one unique corresponding core chemical Notion: the ion (see also explanations at the beginning of Section 1.1).

All Terms of the above nomenclatures have been lexicographically modeled in the **en-LN**, **fr-LN** and **ru-LN**, which resulted in the structuring of the corresponding sets of chemical Notions by 'defined_by' relations. This is the topic of the next section.

2.2. Lexicographical Structuring of the System of Core Chemistry Notions

As mentioned at the beginning of the Introduction, the theoretical and descriptive foundation of the present research is Explanatory Combinatorial Lexicology, the lexicological component of Meaning–Text linguistics. In this respect, it relates to previous terminological work anchored in the same linguistic framework, such as the *DiCoEnviro* project presented in L'Homme (2012b). A distinctive feature, however, is the fact that the core terminology of chemistry has been modeled in the context of the lexicography of Lexical Systems (Section 1.3) where Terms are integrated in the small-world network of the general language. Another difference lies in the importance we place on lexicographic definitions, which are the core of the description of each Term. In contrast, the lexicographic resource on the environment *DiCoEnviro* mentioned above does not include definitions but proposes semantic descriptions for Terms inspired by *frame semantics* instead (Fillmore 1982).

To demonstrate the interconnection of core chemistry Notions with the definitions of their corresponding Terms, we will now refer back to the definition of ELEMENT **III.3a** —see Table 1, Section 1.4, p. 4. As we indicated, this definition embeds three 'defined_by' relations, which are repeated below for the sake of convenience:

- ELEMENT **III.3a** $\xrightarrow{\text{def\_by}}$ ATOM **I.2**;
- ELEMENT **III.3a** $\xrightarrow{\text{def\_by}}$ PROTON;
- ELEMENT **III.3a** $\xrightarrow{\text{def\_by}}$ NUCLEUS **I.2**.

We take recursively into consideration three additional 'defined_by' relations that the "defining" Terms PROTON and NUCLEUS **I.2** feature in their own lexicographic definition—given, respectively, in Tables 3 and 4 below:

- PROTON $\xrightarrow{\text{def\_by}}$ ATOM **I.2**;
- NUCLEUS **I.2** $\xrightarrow{\text{def\_by}}$ ATOM **I.2**;
- NUCLEUS **I.2** $\xrightarrow{\text{def\_by}}$ PROTON.

One can infer the bottom-up *Notion building* organization shown by the graph of Figure 1, where a bottom-to-top $\mathsf{N}_1 \rightarrow \mathsf{N}_2$ link indicates that the acquisition of Notion N_1 is required for the acquisition of Notion N_2.

Table 3. Lexicographic definition of PROTON in the **en-LN**.

Proton of X interacting with Y :	⌜subatomic particle⌝ of the atom **I.2** X • that interacts **I** with the ⌜subatomic particle⌝ Y of X; • that is ⌜positively charged.⌝
Ex.: *In a hydrogen atom, a negative electron orbits a positive* ***proton*** *because of the electromagnetic force, not the gravitational force, between the two particles.*	

Table 4. Lexicographic definition of NUCLEUS **I.2** in the **en-LN**.

Nucleus **I.2** *of X* :	central part of the atom **I.2** X • that is made of protons and neutrons; • that is ⌜positively charged.⌝
Ex.: *An unstable* ***nucleus*** *that decays spontaneously is radioactive, and its emissions are collectively called radioactivity.*	

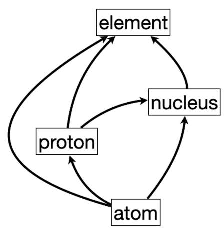

Figure 1. Notion building inferred from the definition of ELEMENT **III.3a**—to be read from bottom to top.

As illustrated in Figure 2, a bottom-to-top $\mathsf{N}_1 \rightarrow \mathsf{N}_2$ acquisition link is the direct product of a **converse** 'defined_by' relation between the corresponding Terms: $T_{N_2} \xrightarrow{\text{def\_by}} T_{N_1}$.

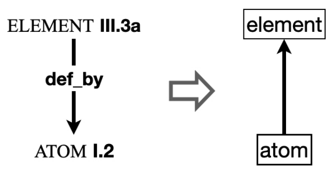

Figure 2. Notion acquisition link (**right**) induced from a converse 'defined_by' relation (**left**).

At the level of the complete core terminology of chemistry, the whole set of Term definitions determines a hierarchical organization of corresponding core Notions induced from 'defined_by' relations. Such hierarchical organization of Notions functions as a *Notion building road map* for the teaching/acquisition of chemistry as a scientific discipline, based on the following general principle:

> One can fully master a chemistry Notion (and Term) only if the Notions (and Terms) that define it are themselves fully mastered.

Traditional teaching techniques, however, often neglect the proper order of introducing the chemistry Terms in class, as the students' understanding of the most basic Notions is taken for granted. For instance, the introduction of the English Term *atom*, which is usually taught at the first lessons, should be preceded by simpler Terms, e.g., *interact*, *particle*, etc. Thus, the Notion building road map proposes a specific order in which chemistry Terms should be introduced in class. This road map is illustrated in Figure 3 below, which gives a broader perspective than Figure 1 by presenting a sample of the complete system of core English chemical Notions derived from 'defined_by' relations connecting the corresponding Terms in the **en-LN**. Like Figure 1, it has to be consulted from bottom to top: from the most "primary" Notions to those directly or indirectly built on them via lexicographic definition of the corresponding Terms. For the sake of precision, each Notion is identified in the graph by the name of the Term (terminological lexical unit) whose lexicographic definition has been used to establish the road map. The pink color signals Notions that correspond to chemical *entities*; amber signals Notions that correspond to chemical *facts* (properties, interactions, etc.). The complete Notion building road maps for English, French and Russian can be found in Appendices A–C.

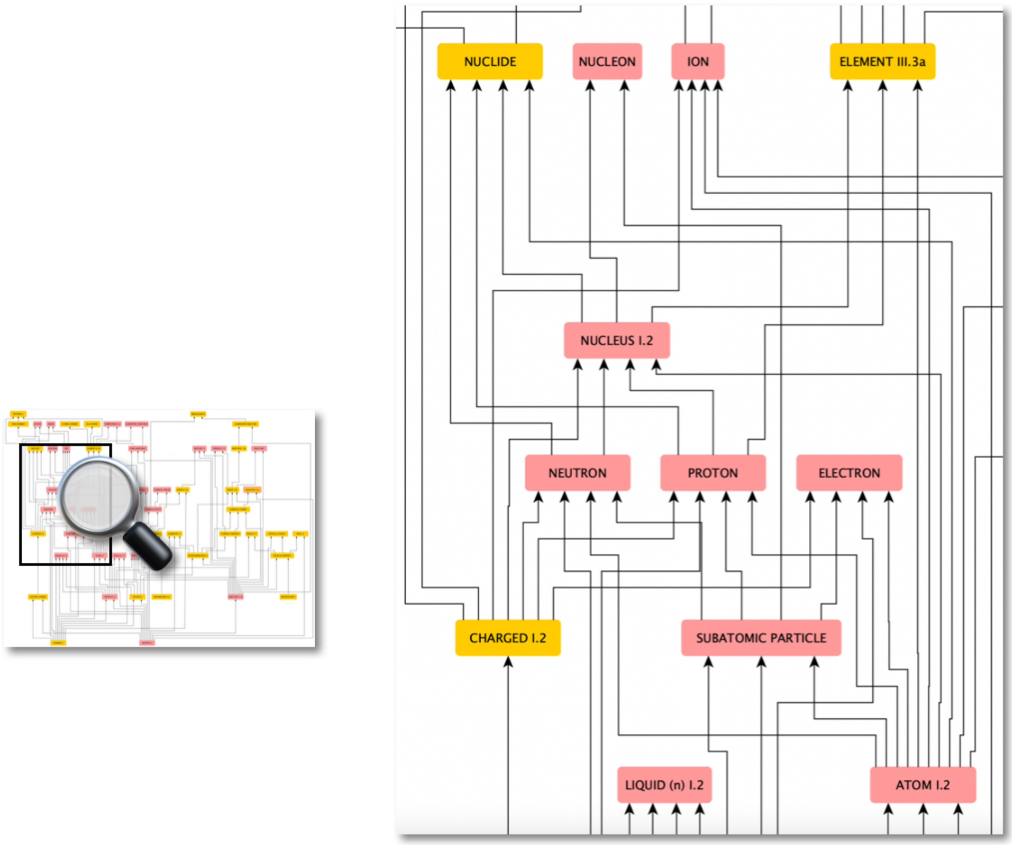

Figure 3. Sample of the Notion building road map for chemistry derived from 'defined_by' relations weaved in the **en-LN** (from Mikhel 2022)—to be read from bottom to top.

To conclude on Notion building road maps for chemistry, note that—in the case of English—the two Notions matter and interact are situated at the very bottom of the road map and function as notional "beginners". This reflects the fact that the corresponding Terms—the noun MATTER **I.a** and the verb INTERACT **I**—have emerged through the definition process as terminological semantic primes: it is impossible to analyze their meaning in terms of simpler specialized meanings. The next (upper) level of Notions, as well as the rest of the system, is built on top of these two Notions.

2.3. Case Study: Carbon, at the Interface of Chemistry and Environmental Science Terminologies

The work presented in the previous section on the core terminology of chemistry was the first large-scale application of the lexicography of Lexical Systems to a terminological domain. As it proved successful in structuring a Notion building road map for this discipline (more on our results in Section 3), we anticipate that this approach can be applied to terminologies across various domains. However, this may not be suitable for *any* discipline. Specifically, while working on the domain of the environment (Gotkova 2023), we found it challenging to identify a core terminology of environmental science following the strategy devised for chemistry.

Unlike chemistry, which is an institutionalized discipline, environmental science is a highly multidisciplinary field with often blurred boundaries. As asserted in Miller and Spoolman (2014, p. 7), environmental science draws on at least twelve fields, including biology, ecology, chemistry, physics, geology, etc. Consequently, environmental terminology encompasses a cluster of sub-terminologies with Terms borrowed from these fields—e.g., *carbon* (chemistry), *bioremediation* (biology), *erosion* (geology), etc. Such heterogeneity defies global 'defined_by' systematization, as semantic decomposition of environment-related Terms would inevitably generate branches of Terms specific to only one related field. For instance, to define *biodiversity* properly, we would need to "descend" to the Term *metabolism*, which belongs to biology and is only marginally relevant to the environment. Furthermore, it appears impossible to establish the notional foundation of environmental science because of its context-dependent applications and the absence of established academic curricula to serve as a universal reference.

The above-mentioned points imply that the identification of a core terminology implemented in the field of chemistry is not suitable for environmental science. Nevertheless, Gotkova (2023, Chap. 3) proposes and puts into practice an approach to the identification of a *terminology of current and emerging environmental issues* based on four criteria; Terms belonging to this terminology have the following properties:

1. they shape the current environmental agenda;
2. they correspond to overarching Notions pertinent to various environment-related topics;
3. they belong to semantic clusters of environment-related Terms—e.g., the Term *carbon*, on which we focus below, is closely related to *greenhouse gas*, *emission*, *methane*, etc.;
4. they function at the interface of specialized and general language discourse, which emphasizes their indispensability.

Due to the profound social implications of the environmental topic, environmental vocabulary is often incorporated in the general language. Hence, adopting a terminographic approach that integrates Terms with general language lexical units within a unique Lexical System (Ingrosso and Polguère 2015) proves particularly relevant to environmental terminology. To illustrate this, we use the case of the noun *carbon*, which originates from the field of chemistry and is now omnipresent in today's media/political discourse and daily conversation and is even printed on goods' labels and travel tickets. With the evidence of an ongoing environmental crisis, it has also become a buzzword with sometimes fluctuating and fuzzy semantic boundaries, as shown by a recent study of the use of *carbon* and related idioms on social media (Gotkova and Chepurnykh 2022). The most recurrent use of *carbon emissions* refers to the emission of the greenhouse gas carbon dioxide. Interestingly, within this conceptualization of *carbon* as a gas, two conflicting uses were identified in texts extracted by Gotkova (2023) from the two social networks Twitter (now X) and Reddit. Some users of these networks employed *carbon* as an overarching Term to refer to both carbon dioxide (chemical formula CO_2) and methane, as in (1). Others explicitly disassociate carbon, i.e., carbon dioxide, and methane, as in (2):

(1) You realize when they say **carbon emissions** that doesn't just mean CO_2 right? **Methane** is far more problematic.
[Twitter, ID: 1301372101039976448];

(2) [Selling less meat] would help reduce **carbon** and **methane emissions** a bit.
[Twitter, ID: 1303055296131145735].

The difference in the way the public perceives and uses *carbon* may lead to serious issues in communication. Furthermore, many Terms have been coined from *carbon* in relation to the environment: *(de-)carbonize*, *carbon(-iz-)ation*, *carbon footprint*, *carbon sequestration*, etc. To sort out this plethoric presence of *carbon* in modern discourse, one has to start with the English vocable CARBON itself and its rich polysemy, which is detailed in Table 5, following the principles of *relational polysemy* established in Polguère (2018).

Table 5. Polysemy of the vocable CARBON as modeled in the **en-LN**—two senses, unrelated to chemical Notions, are omitted.

I.1	**spec** 'element **III.3a** with atomic number 6'
I.2	[Extension of I.1] **(spec)** 'substance **I.1a** that is the materialization of carbon **I.1**' [Ex.: ***Carbon*** *is a solid, with a blackish brownish color resembling charcoal.*]
II.1	[Metonymy of I.1] **(spec)** 'gas **I.2** that contains carbon **I.1** atoms **I.2**'—cf. CO_2 [Ex.: *Coal-fired power plants, which produce the majority of Georgia's electricity and emit the most* ***carbon****, would pay the most.*]
II.2	[Metonymic metaphor of II.1] **quasi-spec** 'symbolic substance **I.1a** as if it were carbon **II.1**' [Ex.: *Most people emit* ***carbon*** *every day simply by using a non-renewable resource, such as coal, natural gas or oil.*]

Note. In the glosses above, lexicographic numbers for core chemistry Terms (ELEMENT **III.3a**, SUBSTANCE **I.1a**, ...) originate from Mikhel (2022)'s study.

Table 5 shows that CARBON is clearly a *terminological vocable*: a vocable whose basic lexical unit (CARBON **I.1**) is a Term, as indicated by the usage note **spec**(ialized). However, the polysemy of CARBON is particularly tricky to handle from a terminology viewpoint due to the fact that it contains three other senses that display various degrees of specialization. Gotkova (2023) studied the environmental lexicon through the prism of the *domestication* of Terms, i.e., the migration of specialized vocabulary from technical discourse into the general language. In this regard, she proposed the following typology of (non-)terminological senses based on their semantic properties and their pertinence:

- *full Terms*—marked with the usage note **spec**;
- *runaway Terms*, which are popularized Terms occurring equally in specialized and non-specialized discourse—marked with the usage note **(spec)**;
- *quasi-Terms*, which are not bona fide Terms but general language lexical units originating from a lay interpretation of Terms—marked with the usage note **quasi-spec**.

Within the vocable CARBON, the full Term CARBON **I.1** cohabits with the runaway Terms CARBON **I.2** and CARBON **II.1**, marked as **(spec)**. Note that the use of these runaway Terms tends to be criticized for various reasons. Runaway Terms fully belong to an organized terminology but tend to be used equally in non-specialized discourse by speakers who do not necessarily master the corresponding Notions. For instance, CARBON **II.1** has its origins in specialized texts on the environment, but it has also migrated into the general language due to the social consequences of greenhouse gas emissions. To top it all, the vocable CARBON contains a non-terminological sense—the **quasi-spec** lexical unit CARBON **II.2**—that possesses a terminological flavor without being associated with a well-structured notional system. Specifically, the general public often conceptualizes *carbon* (in the **II.2** sense) as a by-product of one's unsustainable lifestyle, as in (3) below. Such perception results from the widespread motivational environmental discourse that encourages individuals to control their emission of pollutants.

(3) Most people emit **carbon** every day simply by using a non-renewable resource, such as coal, natural gas, or oil.
[Web, https://www.wise-geek.com/what-is-a-carbon-footprint-test.htm (accessed on 2 December 2023)]

Clearly, *carbon* literally escaped from the terminology of chemistry to develop into closely related senses. This situation is potentially harmful for the proper acquisition and exploitation of corresponding Notions. This illustrates well why it is necessary to have an integrated approach to the modeling of terminologies, one that takes into consideration the fact that terminologies are fully contained in natural language lexicons.

3. Results

The outcome of the research presented in Section 2 is two-fold. It concerns (i) the issue of adopting a 'defined_by' non-taxonomic structuring principle to organize scientific Notions; (ii) the relevance and applicability of an integrated, non-isolationist approach to terminology modeling.

As regards our 'defined_by' structuring principle, we have succeeded, through lexicographic work, in validating the hypothesis that an organized system of core chemistry Notions can be derived from Terms' lexicographic definitions.

We followed a multilingual strategy (English, French and Russian) in order to test the limits of the "universality" of core chemistry Notions (cf. Table 2, Section 2.1). All lexicographic work on the core terminology of chemistry mentioned in Sections 2.1 and 2.2 has been performed simultaneously on the three corresponding Lexical Systems: the **en-LN**, **fr-LN** and **ru-LN**. For non-core, carbon-related terminology studied in the context of environmental science (Section 2.3), only English Terms have been modeled.

As a result, 'defined_by' relations weaved within the lexicographic models of our three core terminologies have allowed us to propose corresponding Notion building road maps, which are presented in their entirety in Appendices A–C.

On the topic of the implementation of a non-isolationist approach to the modeling of terminologies, our terminological models have been smoothly integrated into general language Lexical Systems through definitional, paradigmatic, syntagmatic and copolysemy relations.

The positive effect of the extensive description of a vocable's polysemy—with terminological and non-terminological senses—was particularly clear in the context of the research performed on chemistry-related Terms of environmental science (Section 2.3). For example, the integration of the "domesticated" **quasi-spec** sense CARBON **II.2** into the polysemy structure of the vocable CARBON contributes to the completeness of the lexicographic description and emphasizes the intertwining of specialized vocabularies and general language. This is illustrated in Figure 4, which graphically displays the result of performing a semantic clustering on the lexical graph surrounding the quasi-Term CARBON **II.2** by means of the *Spiderlex* interface to the Lexical System (Ollinger et al. 2020).

Figure 4 features both (i) lexical clusters that are clearly terminological—e.g., the cluster controlled by the full Term CARBON **II.1** linked to CARBON **II.2** by a copolysemy relation—and (ii) general language clusters—e.g., that of the adjective SYMBOLIC **2**, which participates in the definition of CARBON **II.2** defined as 'symbolic substance **I.1a**' (cf. Table 5, Section 2.3).

Such clustering, automatically computed from the topological structure of Lexical Systems (Polguère 2014), demonstrates the descriptive potential of our non-isolationist approach.

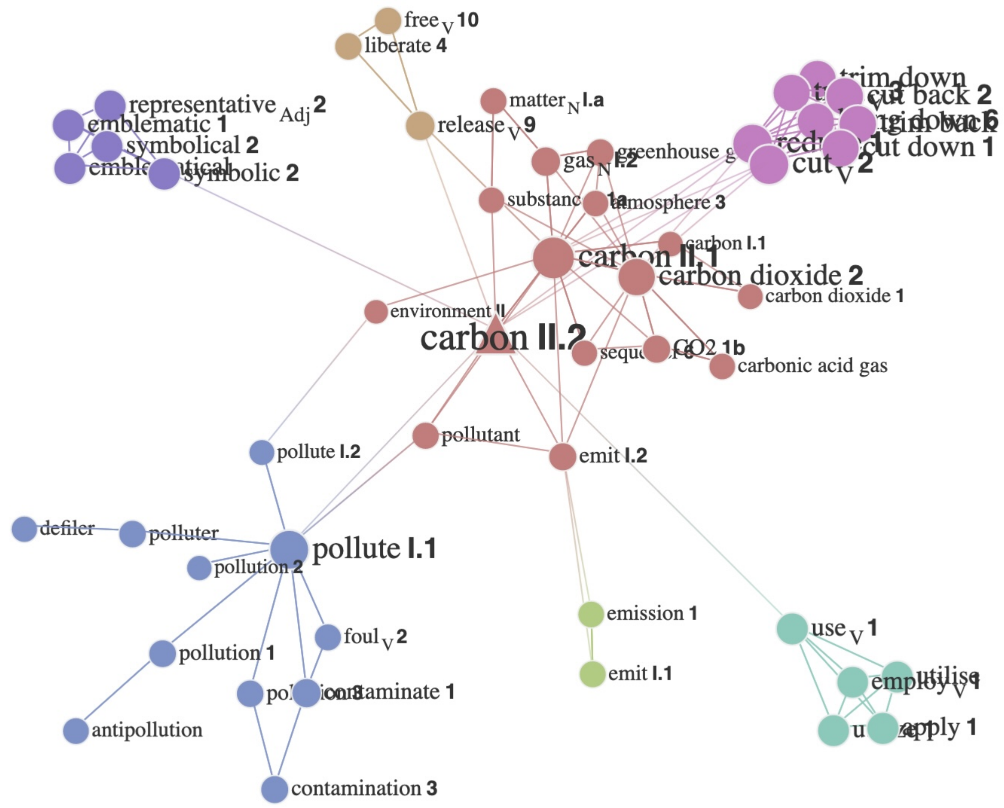

Figure 4. Spiderlex's visualization of the contact between terminology and general language around the quasi-Term CARBON **II.2** within the **en-LN**.

4. Discussion

We shall briefly discuss here two questions raised by our work. They concern (i) the use of Notion building road maps vs. taxonomies in the acquisition of scientific Notions; (ii) the criticism that our non-isolationist approach "dissolves" well-structured terminologies into general language.

4.1. Should Notion Building Road Maps Structured by 'defined_by' Relations Be Used as the Sole Guideline for the Teaching/Acquisition of a Scientific Domain?

Definitely not. Taxonomies remain valid and, probably, necessary models for structuring rather small categorization systems. For example, the grammatical meta-models of our Lexical Systems are organized as taxonomies—for usage notes, parts of speech, etc.

Additionally, it may be that it is justified to use well-circumscribed taxonomies during early stages of the acquisition of scientific Notions, when the recourse to intuition can compensate for a partial understanding of Notions.

4.2. Does Our Integrated Approach to Terminology Modeling "Dissolve" Terminologies in General Language, Making Them Lose Their Systemic Organization?

The first point to note is that terminologies, even in hard sciences such as chemistry, do not possess the idealized systemic organization they are reputed to be built on. This became very obvious as we proceeded through our research and hit terminological walls while trying to clarify supposedly trivial chemistry Notions. The non-chemists among us realized that terminological discrepancies in this field were not totally unlike those that are so common in the humanities, such as in linguistics, for instance.

The second point is that it is beneficial to use the non-isolationist Lexical System approach to address specific terminological challenges associated with certain Terms, especially with regard to their use by the general public. In the context of environmental solutions that aim to reduce greenhouse gas emissions, for instance, it is crucial to differentiate between the chemistry Notion carbon ‘chemical element’ and the environmental Notion carbon ‘greenhouse gas’. In non-expert communication, these two Notions are often conflated or either one may be overlooked entirely. The polysemy structure of the vocable CARBON demonstrates how the corresponding Terms CARBON **I.1** and CARBON **II.1** coexist and are connected through a metonymic copolysemy relation (Section 2.3). Furthermore, the extensive use of *carbon* as an overarching noun in numerous environment-related idioms often leads the general public to mistakenly assume that it designates the same Concept in all instances of use. Interestingly, this Concept may vary based on the speaker’s depth of knowledge. The definitions developed for three *carbon*-related idioms—⌜CARBON CYCLE⌝, ⌜CARBON FOOTPRINT⌝ and ⌜CARBON CAPTURE AND STORAGE⌝—in the **en-LN** reveal that *carbon* actually refers to different Concepts in each of them: the chemical element, greenhouse gas and carbon dioxide, respectively. Eventually, our lexicographic articles can be used to supplement the existing educational materials to help educators resolve certain pain points in the public understanding of environmental terminology.

5. Conclusions

To conclude, let us (i) sum up the main insights gained in the research presented above and (ii) suggest further development and applications.

We believe that the most important achievement of our work is to have demonstrated the applicability of a lexicographic approach to scientific Notion structuring based on the systematic and rigorous lexicographic definition of Terms (cf. Tables 1, 3 and 4), followed by the exploitation of ‘defined_by’ relations among Terms to elaborate Notion building road maps. Furthermore, by integrating our terminological descriptions within essentially general language lexical networks developed at the ATILF laboratory, we have shown that extensive terminology modeling can be performed in a non-isolationist way. Terms are not only connected to each other; they are also connected to general language lexical units, in natural language lexicons as well as in texts.

As for further development, we wish to test the applicability of our lexicographic descriptions of Terms and Notion building road maps for the teaching of chemistry in secondary/high schools (in the French system, *collèges* and *lycées*). Our Notion building road maps are terminological counterparts of “mind maps” commonly used in schools. Their main advantage is that they are assembled with a clearly established methodology, without recourse to unspecified intuitions and preconceptions: they are the direct product of the semantic structuring (cf. lexicographic definitions) of terminological systems. Additionally, each Notion in a Notion building road map is not just a node in a graph: it points to a Term that possesses its full lexicographic description (definition, grammatical characteristics, derivations, phraseological cooccurrences and exemplification) that can be exploited to empower learners in the active mastering of scientific language.

Author Contributions: Conceptualization and methodology: all authors; supervision, project administration: F.I. and A.P.; resources: P.M. (chemistry) and T.G. (environmental science). All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded (i) by the FRONTERME doctoral project, reference 18_GE4_022, of the Grand Est Region (France) and (ii) by the French PIA project “Lorraine Université d’Excellence,” reference ANR-15-IDEX-04-LUE.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All the relevant data are available in this paper. The **en-LN** and **fr-LN** can be consulted with Spiderlex from the Lexical System website: https://lexical-systems.atilf.fr/en/lexical-systems/ (accessed on 5 December 2023).

Acknowledgments: Many thanks to Helen Lim and to three anonymous reviewers for comments on an earlier version of this paper.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

Lexical Systems (lexicographic models):

en-LN	*English Lexical Network*;
fr-LN	*French Lexical Network*;
ru-LN	*Russian Lexical Network*.

Usage notes marking (quasi-)Terms in their lexical entries:

spec	Specialized lexical unit, i.e., Term;
(spec)	Runaway Term, i.e., popularized Term;
quasi-spec	Quasi-Term originating from lay interpretation of a Term.

Appendix A. Core English Chemical Notions

The pink color signals Notions that correspond to chemical entities; amber signals Notions that correspond to chemical facts (properties, interactions, etc.).

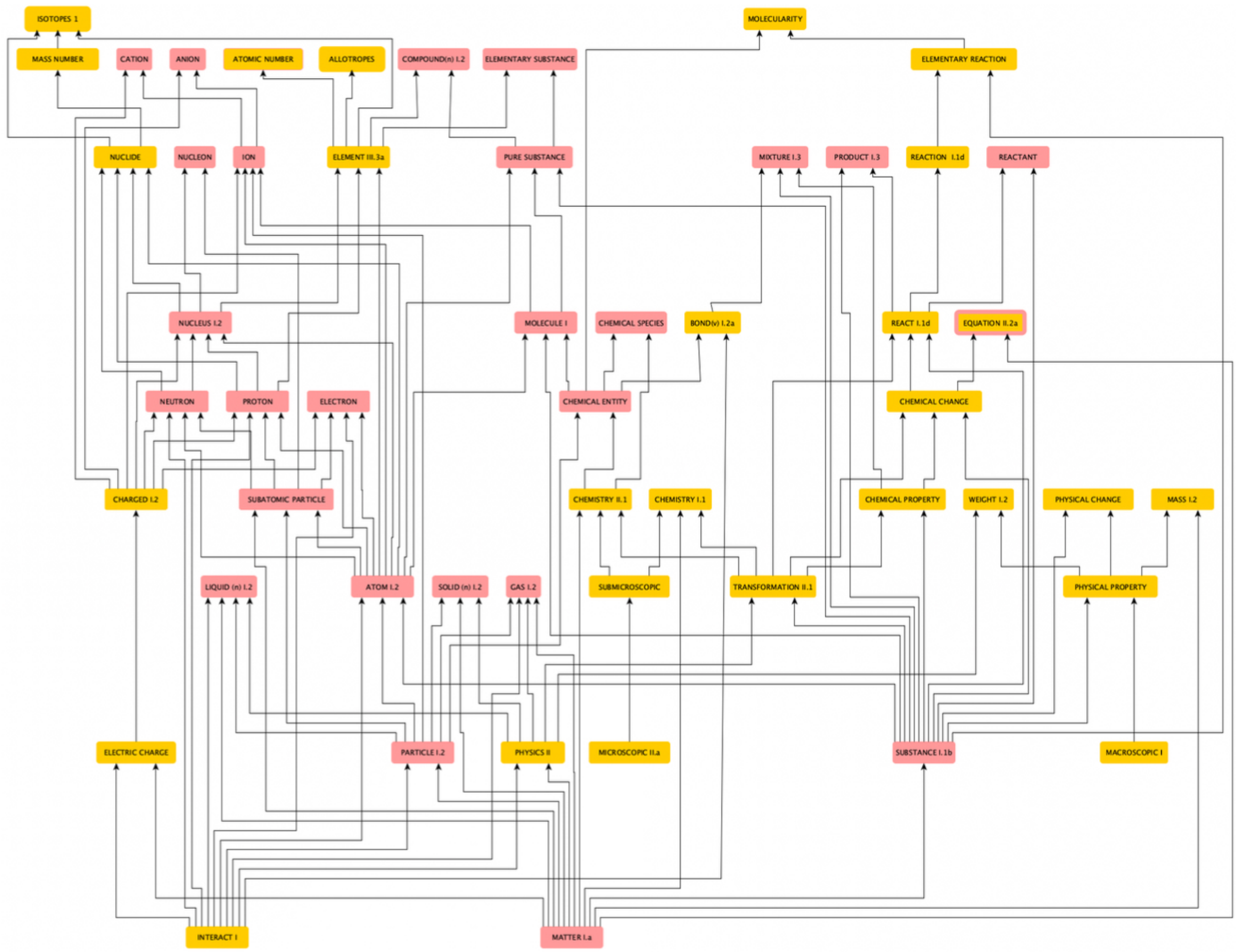

Figure A1. Notion building road map for core English chemical Notions (Mikhel 2022, p. 167)—to be read from bottom to top.

Appendix B. Core French Chemical Notions

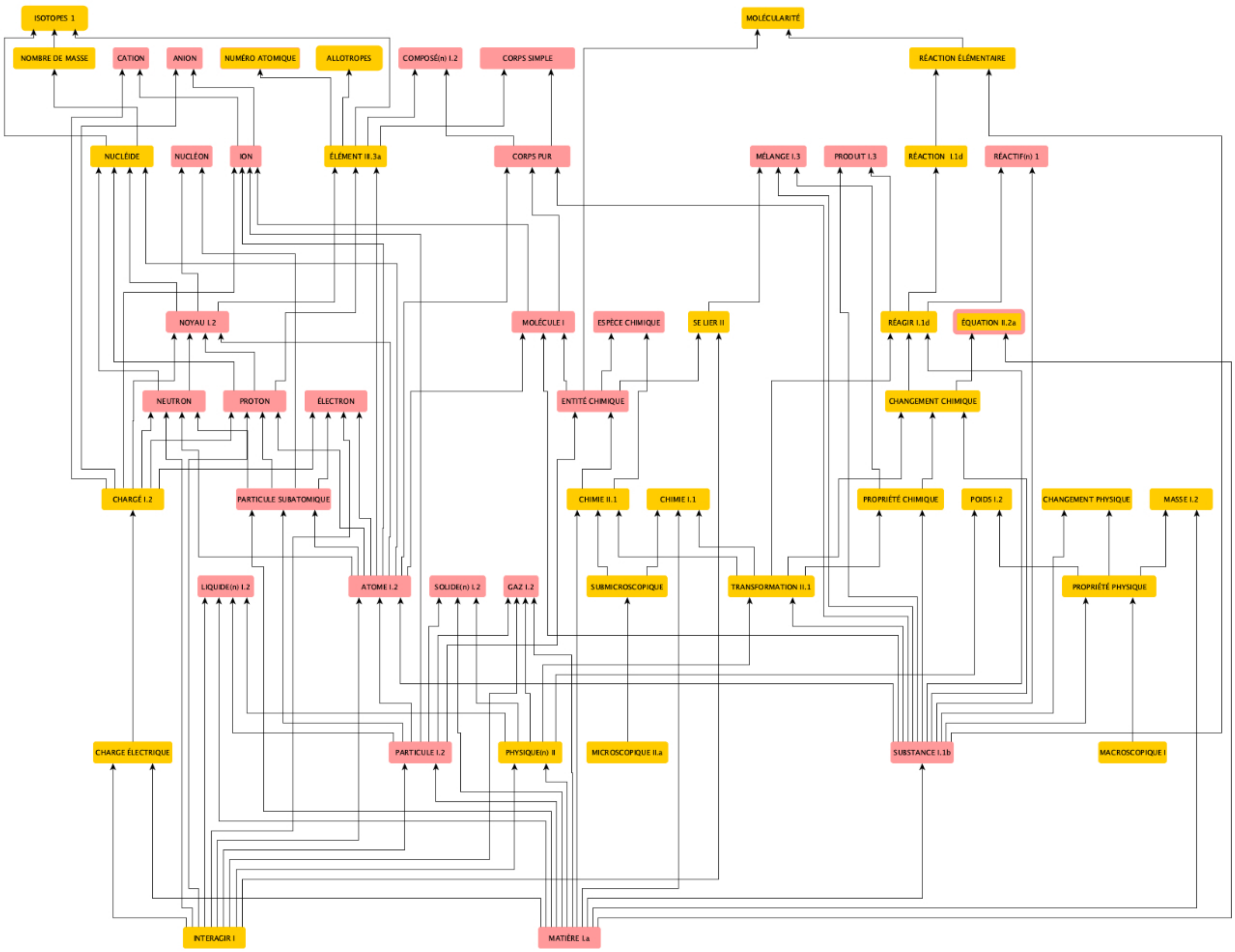

Figure A2. Notion building road map for core French chemical Notions (Mikhel 2022, p. 193)—to be read from bottom to top.

Appendix C. Core Russian Chemical Notions

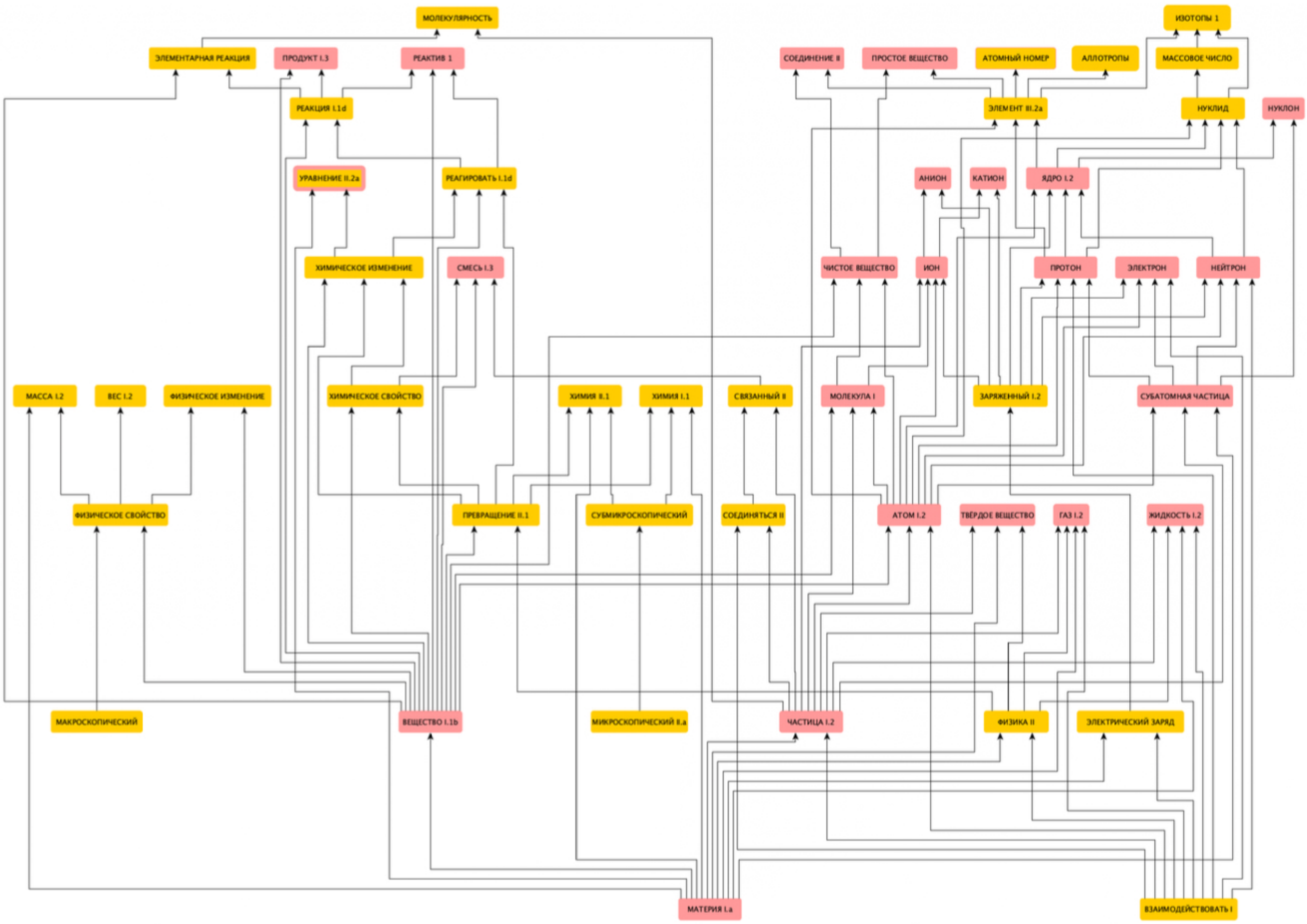

Figure A3. Notion building road map for core Russian chemical Notions (Mikhel 2022, p. 219)—to be read from bottom to top.

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