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Enrico Fermi and the making of the language of nuclear physics

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1 A note on the life and terms of Enrico Fermi

"Nam tibi de summa caeli ratione deumque
disserere incipiam et rerum primordia pandam,
unde omnis natura creet res, auctet alatque,
quove eadem rursum natura perempta resolvat,
quae nos materiem et genitalia corpora rebus
reddunda in ratione vocare et semina rerum
appellare suemus et haec eadem usurpare
corpora prima, quod ex illis sunt omnia primis."
(Lucretius, *De Rerum Natura*, I, 54-61)[1]

It has been been suggested that at certain times in history, when exchanges between scientists are intensifying and knowledge is accumulating fast, there is often the impression that language is under stress as it perhaps cannot encode the changing knowledge. Since 1900 this call has been heard again, heralded perhaps by de Broglie's famous observation that 'physics is in suspense because we do not have the words or the images that are essential to us'. The motif that 'language cannot cope' can be found in Einstein, Bohr and Heisenberg, for example. One may argue to the contrary that science owes at least part of its success to its language, paradoxically a powerful means of communication within the scientific community and a largely obscure system of meanings for laymen; Halliday (1992: 34) noted that scientific language has 'positive, meaning-creating power'. That language copes has been stressed by Boyd (1979: 382) as well with reference to acquisition of new knowledge and expoloration of new areas of enquiry when the linguistic usage is modified to articulate the new: 'such dialectical changes of reference are characteristic of referential continuity and represent perfectly ordinary vehicles for the reporting of new discoveries'.

We will argue that the relationship between language and science is a symbiotic one. Scientists create new terms, borrow them from other disciplines or general language and lend them new meanings, but also discard terms that no longer suit their purposes. Despite their worries about language not being able to cope, we can follow this motif through Einstein, Bohr and Heisenberg, down to the present day as it becomes increasingly specific (Halliday/Martin 1993: 108). Bilingual scientists, and a significant proportion of the 20th century physicists were bilingual, appear to have created words in one or more languages to articulate their thoughts quite successfully: Enrico Fermi, 'the last of the Universal scientists', one of the leading nuclear and theoretical physicists of the 20th century, was dextrous in Italian and latterly in English when it came to describing in Italian the nuclear atom or the *pila atomica* (the term *atomic pile* in English is a translation of the original Italian), the code name for what we now know as the nuclear reactor, in all its complexity in English.

The development of atomic theory of matter, wherein all material beings comprise the same unitary building blocks, has a long history that in some awesome way had an interlude in the discovery of the nuclear reactor and the nuclear fission and fusion bombs. Let us look at the recent history in reverse chronological order: in the late 20th century parlance all material beings comprise *quarks* and *leptons*; in 1960s and 1970s *elementary particle* physicists kept on finding more of these unitary building blocks grandiosely called *fundamental* particles (c. 500 or so); in the second quarter of the 20th century there were fewer *particles* including the *electron, proton, neutron* and *meson*; in the first quarter of the 20th century one sees the emergence of the idea that atoms comprising (chemical) elements may yet have a constituent structure; in the 19th century all materials were said to comprise the *atom* – a particle (*sic*) so small that it could not be further subdivided by mechanical means.

We see that in 150 years or so different, ever smaller constituents of matter have been proposed. Such an intellectual exercise contributes to, and relies on, novel ways of articulation of complex ideas – articulation using language, symbol systems and icons. Major changes in *atomic theory* have been signalled by changes in terminology, of physics and of philosophy. The notion of the atomic nature of matter can be traced back to Democritus and his followers, notably Epicurus. In 1 B.C. the Latin poet Lucretius' lyrical, and at times rather vivid 'translation' of Epicurus' *Peri Physeōs* (*On Nature*), from Greek into Latin he entitled *De Rerum Natura* (*On the Nature of Things*), comprises one of the earliest forms of the atomic theory albeit in poetry rather than in prose. Note that in the citation above Lucretius uses various inflections and derivations of the root, the adjective *primus*: he intensifies the notion of a fundamental, elementary, or a *prime* unit of material being, by using the derivations of the root to make it into a noun – *primordia* (pl. neuter of *primordium*). The adjective was suffixed with the verb *ordior* ('to begin' or 'to start') to form the word *primordium.* Also note the use of the compound, *corpora prima* and the colligation *genitalia corpora* or procreant bodies. This rhetorical device of using different morphological forms of a key word, together with its compounds continues to date in most sciences. Primordial bodies, chemical elements, atomic nucleus, confined quarks are good examples of this rhetorical device, of using different morphological forms of a key word together with its compounds, a device that is as pervasive in Lucretius' Latin, as it is in Galileo, Newton, Einstein, Fermi and distinguished scientists of today.

Lucretius had put common words to technical use and his 'building blocks' of the material Universe were *primordia* or 'first weavings, primal germs' in Latin. This term did not live long in that post-Lucretius thinkers and philosophers appear to have preferred the Latinate term *atomus* or 'smallest particle', which was in turn derived from the Greek *atomos* or 'indivisible'.

Atoms, according to our current scientific thinking, are divisible after all and their components were described; the term *atom* was thus retrofitted to take on this new meaning. In the late 19th and early 20th century, new atomic theories were proposed. In 1897 the English physicist Thomson discovered one of the constituents of the atom, the *electron*, and in the early 20th Century a number of models of the atom were proposed by the Japanese Hantaro Nagaoka, the Frenchman Jean Perrin, the British Ernest Rutherford and the Danish Niels Bohr. Now atomic theory is taught to most youngsters in their early teens. The vocabulary associated with the atomic theory of the various above mentioned periods has enriched most languages – as much of the work was carried out in Western Europe and the USA, we see that the vocabulary of atomic theory is based on various Indo European languages. The works of Thompson and Rutherford have enriched English, that of Bohr added to the stock of Danish language, Perrin's to French and Nagaoka to Japanese. Note that the term *atom* and its inflected forms and derivatives were initially used to refer to stable entities found in Nature – however much of that has changed: there are unstable atomic systems and one can synthesise nuclei of atoms in laboratories. Languages of all kinds appear to have coped well with this scientific *volte face*.

1.1 Enrico Fermi – his life and works (briefly)

As science knows no national boundaries, articulation of a discovery is translated from that of the discoverer into other languages, so that the borrowing of terms is not only intralinguistic as outlined above, but also interlinguistic. This point is particularly relevant to Fermi's work as in 20th-century science two major trends could be discerned: one national and the other global. Scientists are trained, sustained and initially flourish within a given national boundary. However, from relatively earlier in their careers scientists read the work of and interact with scientists within other national boundaries and form academic alliances. Furthermore, scientists migrate from one national boundary to another, sometimes the lure of better resources motivates migration, and at other times actual or perceived persecution by individuals, by academic organisations and even by national governments. Migration to escape totalitarian regimes and/or persecution shortly before and during WW2 favoured the latter trend, that is the internationalisation or denationalisation of science, though admittedly some fields of science were already well internationalised in the 1930s, most notably theoretical physics (Crawford/Shinn/Sörlin 1992). The national and the global communicative dimensions of science are of considerable import and this can be sometimes discerned in the work of the scientists, especially those who have to migrate.

Fermi is a case in point. He was born in Rome in 1901 where he was educated. In 1918 he went to the University of Pisa where he got admission to the prestigious *Reale Scuola Normale Superiore*. He graduated from the University of Pisa and got his diploma from the *Reale Scuola Normale Superiore* in 1922. He started his academic career at the University of Florence in 1924 as professor of 'theoretical mechanics and mathematical physics' and moved to the University of Rome in 1926 as Professor of Theroretical Physics. Soon after his appointment Fermi published a textbook on what was then called *modern physics* – a combination of emergent theory and novel experimentation that comprised atomic physics, quantum mechanics and electronics. His *Introduzione alla fisica atomica* (1928) was the first textbook in Italian on the subject; note that he had already italianized *atomic physics* into *fisica atomica.* During his period at Pisa (and Florence), Fermi worked on an Italian government scholarship and a Rockfeller grant in Germany where he met leading physicists of his time – Heisenberg, Pauli, Ehrenfest, Einstein, Uhlenbeck. Fermi enjoyed a period of relative success at Rome, funded by the state and the University of Rome, and he was able to contribute significantly to the landmark developments in physics, especially in the area of reactions between neutrons/protons with nuclei leading to the formation of new, usually unstable nuclei – the transmutation of one element into another then known as induced radioactivity or artificial radioactivity. Fermi was to call this phenomenon *radioattività indotta* or *radioattività prodotta* and the projectiles that induced the radioactivity – neutron bombardment – as *bombardamento di neutroni*.

In 1938 Fermi attended the Nobel Prize ceremony in Sweden and then travelled on to the United States with a view to migrate there. In the US he met many other fellow physicists who had left Europe to escape persecution and worked with them on the Manhattan Project. Fermi and his team were able to create the first 'self sustaining chain reaction' in a laboratory which was housed in a squash court. Fermi's sense of modesty and achievement, and his elaboration of terminology appears to have been preserved in English: In *Fermi's Own Story* (of the *First Pile*[3]*)* he begins by outlining that 'The history of the first self-sustaining nuclear chain reaction, like that of all scientific achievements, begins with man¹s first philosophical speculations about the nature of the universe. Its ultimate consequences are still unpredictable.' Fermi had not forgotten to elaborate terms like *chain reaction* and *atomic pile* that may be unfamiliar to his readers and tells us that:

> Here it may be well to define what is meant by the "chain reaction" which was to constitute our next objective in the search for a method of utilizing atomic energy.
> An atomic chain reaction may be compared to the burning of a rubbish pile from spontaneous combustion. In such a fire, minute parts of the pile start to burn and in turn ignite other tiny fragments. […] A similar process takes place in an atomic pile […].
> The pile itself was constructed of uranium, a material that is embedded in a matrix of graphite. With sufficient uranium in the pile, the few neutrons emitted in a single fission that may accidentally occur strike neighboring atoms, which in turn undergo fission and produce more neutrons […]

Fermi was influenced by his peers, he wrote extensively about developments in physics, in Italian, before he left Italy, he adopted a new language – English – as well as a new nationality – US citizenship, and wrote original papers and monographs in English. He worked as an academic, as a military scientist, and as an ambassdor of physics, especially in Italy after the Second World War. Fermi moved across different countries and just as easily between languages. He was an accomplished scientist in his own country, he was an accomplished migrant scientist in the USA, and he lectured in Italy as an expatriate national. His use of Italian and English LSP of physics is remarkable, and even more remarkable are his contributions to both the LSPs. He brought English, German and French terms into Italian, he coined new terms in both his native and adopted language.

A diachronic study of Fermi's writing offers a double insight into the making of nuclear physics – the descent into the atom to discover its components – and the making of the Italian and English LSP of nuclear physics. He was amongst the last of the great scientists of Italian origin who wrote in Italian. There are still accomplished Italian scientists but they write in English to get international attention and recognition: the Italian language of science is now by and large the language of popular science (Marazzini 1999). But before a diachronic study, let us have a brief look at some of the terms that were attributed to Fermi by way of coinage or elaboration.

1.2 Enrico Fermi and the LSP terminology of (nuclear) physics

Enrico Fermi has made significant contributions to a number of branches of physics – from nuclear reactor technology to the flow of electrons in semi-conductors, from quantum mechanics to the design and execution of experiments that helped to create new forms of matter, as is now a common practice in high-energy physics laboratories. Fermi was an enthusiastic teacher, prodigious researcher, and prolific writer. During a 16-year period (1938-54) he wrote the first monograph on nuclear physics and another on elementary particle physics, and his lecture notes were compiled by his students and colleagues and published as books. It is his contribution to the English and Italian LSP of physics which is perhaps a less investigated area of his life: again, like in all his endeavours, we see that the terms Fermi coined have survived the test of time and have made inroads into a number of general languages, especially English and Italian. A number of eponyms include Fermi by name, for example *Fermi-Dirac statistics* is a theoretical formulation of how electrons behave in semi-conductors and this statistic is used in the design of a whole range of electronic devices and circuits. A whole class of elementary particles are called *fermions* which includes the ubiquitous electron. Indeed, measurements made at subatomic scale are in *Fermis*, one Fermi, denoted as *fm*, is a hundreth billionth of a metre. The radii of particles like the proton and neutron, and even the never-to-be-seen quark is measured in *fermis.*

Fermi was both a theoretician and an experimentalist – a universal scientist. Theoreticians typically rely on abstract symbol systems, including mathematics and statistics, and are generally fairly articulate. Experimentalists usually focus on instrumentation, experimental design, and, by and large, their papers are ascetic in comparison with those of the theoreticians. In Fermi's writing, however, we see no rush to fill up papers with (transient) terminology when there was a need to explore and establish a fanciful idea.

In one of the first text books on nuclear physics Gamow and Critchfield note that Wolfgang Pauli was amongst the first (c. 1930s) to suggest that the β-decay, the emission of an electron during the radioactive transformation of a nucleus, involves the emission of a chargeless, almost weightless particle; Pauli named the hitherto undiscovered particle a *neutron*. When the British physicist, James Chadwick, discovered a neutral particle, with about the same weight as the proton, during (other) radioactive transformations, he insisted on calling this particle the *neutron* as well. Fermi was the peacemaker: he is reported to have said that Pauli's particle 'is not a *neutron* but a *neutrino*' (Gamow/Critchfield 1949: 6). The two authors note that Fermi used an Italian noun paradigm - 'neutrino and neutretto [one of the other names for what Chadwick called the neutron] being the corresponding diminutives in the Italian language' (*ibid*).

In his history of nuclear physics, Abraham Pais suggests that Fermi's paper on the theory of β-decay was 'a major document full of novelty' (Pais 1986:17-18), wherein Fermi elaborated on his theory of β-decay and showed how to compute the probability of a neutrino being scattered by a decaying nucleus. This 'major document' was published first in Italian and an elaborated version was then published in German – both in 1934. The document was entitled *Tentativo di una teoria della emissione di raggi* β; the prestigious British journal *Nature* had earlier rejected an English version of the document noting that the document was 'too speculative to be of any interest to the reader' (Pais 1986: 417). The papers in Italian and in German are still being cited in nuclear-physics text books and perhaps less frequently in journal papers! Elsewhere in his history of nuclear physics Pais reports that Fermi gave four lectures to the American Physical Society – the Ann Arbor workshop on theoretical physics – on quantum electrodynamics in the 1930s. These lectures made the subject of quantum electrodynamics more accessible to many despite the fact that Fermi had learnt his English 'at Berlitz School in Rome' (Pais 1986:366).

Whilst Fermi and his colleagues were working on how some of the naturally-occuring unstable nuclei decay through the emission of an electron (and the yet undiscovered neutrino) Frédéric Joliot and Irène Joliot-Curie were studying *artificial radioactivity.* The Joliots bombarded elements with *alpha particles* (a Helium nucleus – a helium atom without its electrons) and created new elements that were inherently unstable and emitted radiation: they had found a new phenomenon and retrofitted the term *radioactivity* by distinguishing *natural* radioactivity from artificial radioactivity.

Before these experiments *radioactivity* was used in the context of naturally occurring unstable nuclei, with the artificially created elements and hence *artificial radioactivity*. Fermi induced artificial radioactivity by 'bombarding' *slow* neutrons[4] on a target of a heavy element like Uranium then splitting into two nuclei that are roughly half the weight of the target, one fissioned nuclei is generally heavier than its sibling. In 1938 Fermi was awarded the Nobel Prize for physics "for his identification of new radioactive elements produced by *neutron bombardment* and for his discovery of nuclear reaction effected by slow neutrons". So, in the Nobel citation we have a new compound – neutron bombardment. The term bombardment is seldom used in the current literature in physics – the new less militaristic term is *irradiation* or *scattering*. Such irradiation experiments helped scientist to create one of the heaviest unstable elements in 1952 and this short-lived element is called Fermium in honour of Enrico.

German physicists Hahn, Meitner and Strassmann studied Fermi's experiments and suggested that many of the Uranium nuclei 'split' into nuclei of barium, krypton and other disintegration products. Hahn and colleagues suggested that there are enough neutrons produced in the fission such that these neutrons can cause more fission; note that the target 'Uranium' is essentially a kilogramme or so of Uranium containing literally billions of Uranium nuclei. This meant that, under certain conditions, the Uranium target had to be irradiated for a short while only after which enough neutrons could be produced to sustain the fission process on their own. Bohr suggested the possibility of a nuclear chain reaction and in 1942 Fermi was assigned the task of producing a controlled, self-sustained nuclear chain reaction that was eventually used in the production of the nuclear fission bomb, popularly known then as now as the atom bomb. Again, we have the versatile Enrico Fermi involved in the production of the so-called called the *atomic pile* – which was to be eventually used in relatively less offensive applications such as modern nuclear power reactor. The term 'atomic pile' has its origins in the Italian *pila atomica* which literally means an *atomic battery* – a battery producing rather a new and awesome form of energy.

As can be seen from the brief summary of some of the work that heralded the development of nuclear physics, advances in science and technology have on the one hand an impact on language and language helps scientists to articulate fairly complex concepts through the use of extant lexical items and grammatical patterns of a scientist's first (or second) language. Scientific progress rests on the challenging of some concepts while maintaining others. The progress can be accounted for by term creation and elaboration. The terminology of science may be and is often studied synchronically as if it were in a steady state of fixed concepts and fully established terms. But science and its language undergo changes. Especially in times of rapid development, the language of science is far from stable – scientists, being rather conservative beings, use existing terms to maintain a link with the past, whilst at the same time completely inverting the meaning of the term (cf. pre-Rutherford *atom* → *indivisible* but post-Rutherford it was divisible) or retrofit another extant term to explain two seemingly similar phenomenon. They may coin a term in their own language and this term is translated in other languages with the intent to refer to more or less the same concept. The history of the field can be followed by examining the crucial points at which its terminology has been created or consolidated. The acquisition of new knowledge and the exploration of new areas of inquiry imply a modification of linguistic usage to accommodate changes of reference in the reporting of new discoveries: 'Scientific terms must be understood as providing the sort of epistemic access appropriate to the level of epistemic success typical of scientific discoveries' (Boyd 1979: 384).

1.3 Lexicogrammar of nuclear discovery

Halliday and Martin (1993) have argued that in order to construct 'scientific reality' the author/scientist harnesses his or her vocabulary and the grammatical structures he or she uses to record scientific observations and to produce critique of ideas and theories. The vocabulary and grammar are inextricably linked and to emphasise this idea Halliday has used the term *lexicogrammar*. Scientists use a smaller number of grammatical structures – restricted to declarative and imperative sententces – together with a profusion of terms. This is in some way the opposite of general language writing where the number of grammatical structures is more varied and the number of lexical items smaller than, say, what one may find in a scientific text.

Nominalisation hallmarks specialist language and this appears to be a very productive, if at times frivolous use of such an important linguistic device available to the writers of texts. Nominalisations are nouns 'derived' from the corresponding verb (or adjective). Halliday and Martin have remarked that verbs are regrammaticised, in scientific discourse, into nouns; something that happens on a 'massive scale' in this discourse for reconstructing the nature of experience as a whole: 'The elaborated register of scientific knowledge reconstructs as an edifice of thing' (1993: 15): [things] which can be observed and experimented with. For instance, scientists will take *'stable, behave, occur, develop, useful'* and regrammaticise them, through derivational affixes, into *stability, behaviour, occurrence, development, utility*.

Contemporary research on scientific language as a special language or as part of the wider category of language for special purposes (LSP) stresses the need for studying scientific rhetoric with particular reference to historiographical studies of the rhetoric (see, for example, Atkinson 1999). A historiographic study, in our view, should use a linguistic framework, in addition to the socio-psycho-political dimensions that pervade such studies (Kuhn 1962, Feyerabend 1993, Hempel 1970). Halliday identifies seven features or 'difficulties' of scientific language: interlocking definitions, technical taxonomies, special expressions, lexical density, syntactic ambiguity, grammatical metaphor and semantic discontinuity (Halliday 1993: 71). In a diachronic study technical taxonomies, special expressions, that is patterns such as collocations, and lexical density, quantified as frequency of nouns and nominalizations, have been used to study change in the use of linguistic resources by a number of authors (Biber *et al.* 1998 and references therein). The work of Halliday et al, Biber and colleagues focuses on English LSP of science and technology. A number of proposals have been made on the structure and function of Italian LSP of science by Altieri Biagi (1990), Sobrero (1993), Dardano (1993a), De Mauro (1994) which will be useful for conducting a historiographical analysis of texts in Italian. Summarising trends in the Italian special languages of science in the 20^{th} Century, Altieri Biagi (1990) underlines a number of features that emerged in lexicogrammar of compounding, derivation and more generally the formation of terms and abbreviations or acronyms. In general, Italian special languages – like their English counterparts – are characterised by nominalisation, simplification of syntax, and frequency of new terms, semantically redefined words drawn from general language or terms borrowed from other disciplines. More specifically, however, the following features emerge:

(i) A sparing use of subordinating function words in compound terms and the replacement of function words with hyphens. In other words, links expressed – for example – in English through juxtaposition and in German through compounding normally need explicitation in Italian. In recent years, however, juxtaposition has become more frequent in Italian, mainly as a consequence of calques from English: *temperatura* di *colore* → *colore-temperatura* or *temperatura-colore* from English *colour temperature*.
(ii) Traditional affixation of Greek and Latin origin is still common, but English monosyllabic and polysyllabic words such as *up*, *down, bottom*, *strange* are increasingly used to form hybrid terms such as in *charmonio* and hybrid compound terms such as *spin dell'elettrone*. Some words take on new shades of meaning due to their suffix: *induttanza, riluttività*.
(iii) Abbreviations and acronyms give texts an 'international quality' as Italian tends to borrow rather than 'italianise' them, using *lhc* (*large hadron collider*) as an abbreviation of 'grande collisore di/per adroni'. The increasing number of loan words and loan translations in Italian may point to the internationalisation of science.
(iv) Some affixes such as *–metro*, *–scopio* and *–tore* appear particularly productive. An interesting case for physics is the high frequency of terms ending in *–trone* based on the 19^{th} century model *elettrone* which gave origin to *neutrone* and many other terms such as *ciclotrone, magnetrone* on the English model *cyclotron* and *magnetron* in the 20^{th} Century, though the model *protone* with the ending *–tone* also existed.
(v) Eponyms become more and more widespread: while celebrating famous scientists they lend authoritativeness to scientific discourse.
A study of these features with reference to nuclear physics will give an idea of the evolution of the Italian language from discovery to consolidation of the discipline and new frontiers in research.

1.4 Structure of the paper

Our analysis in this paper focuses on the Italian lexicogrammar of nuclear discovery compared and contrasted with contemporary nuclear physics. Our diachronic selection of texts covers three periods: 1925 to 1950 (Fermi's papers), 1960s (a selection of chapters from Persico's university handbook on nuclear physics, *Gli atomi e la loro energia*) and the present age (a selection of chapters on nuclear physics from secondary-school textbooks, popular science monographs on Fermi and Heisenberg, and syllabuses of university courses on nuclear physics and other material from the web). Corpus composition and size are summarised in the Table 1 below:

Author	Title	Publication date	Tokens
E. Fermi	Sopra l'urto tra atomi e nuclei di idrogeno [J]	1925	1,136
E. Fermi	Problemi di fisica nella chimica dell'atomo [J]	1926	2,434
E. Fermi	Sui momenti magnetici dei nuclei atomici [J]	1930	3,143
E. Fermi	Lo stato attuale della fisica del nucleo atomico [J]	1932	6,554
E. Fermi	Radioattività indotta da bombardamento di neutroni [J]	1934-1935	10,159
E. Fermi	Neutroni lenti e livelli energetici nucleari [J]	1938	652
E. Fermi	Conferenze di fisica atomica [J]	1949-1950	46,049
	Sub-Total		***70,127***
E. Persico	Gli atomi e la loro energia (Chapters 8-10) [B]	1967	22,267
U. Amaldi	La fisica per I licei scientifici 3 (Chapters on nuclear physics) [B]	1997	51,293
Battimelli/Stilli	Le vie della fisica 3 (Chapters on nuclear physics) [B]	1998	19,787
	TuttoFisica DeAgostini (Chapters on nuclear physics) [B]	1998	15,659
	Syllabuses of university courses in nuclear physics [Adv]	2000	4,493
	Webscuola (info on nuclear physics) [Adv]	2000	7,079
M. De Maria	LeScienze Quaderni - Fermi [Pop]	1999	46,203
M. Cattaneo	LeScienze Quaderni - Heisenberg [Pop]	2000	41,471
	Sub-Total		***185,985***
	Total tokens		**278,379**

Table 1: Composition of the Italian corpus on nuclear physics (J stands for journal paper, B for a book or chapter(s) from a book, Adv for advertising and Pop for popular science)

The lexicogrammar of this corpus was contrasted with a 100 million-word corpus of written Italian, CORIS (CORpus di Italiano Scritto, including a 12 million word component on scientific prose) and the 5 million word component of academic prose in the CODIS corpus (COrpus Dinamico dell'Italiano Scritto).[5]Both CORIS and CODIS have been developed by the University of Bologna (Rossini Favretti 2001: 374; De Santis 2002: 65).[6] Finally, for etymological reference was also made to general language Italian dictionaries, DISC 1997, Zingarelli 2000 and De Mauro 2000 in their electronic formats.

Our diachronic study in this paper covers three main areas - the frequency and patterns of usage of terms, the ways in which they are elaborated (inflection, derivation, compounding, eponyms and citation patterns), and their collocational behaviour. It is therefore divided into three sections: a) Fermi's signature terms, b) morphosyntax and discovery, and c) the lexicogrammatical environment of key terms. In our concluding remarks we summarise the features of the Italian language of nuclear discovery and provide a tentative assessment of the effect of 20th Century physics on the Italian language.

2 Fermi's signature terms

We start our study with an analysis of frequency of occurrence by distinguishing three different subcorpora in our collection – the Fermi collection, the Persico text and the contemporary Italian corpus – to identify any changes in the patterns of usage over the years. In a corpus the most frequent words are mainly closed-class or function words. In our corpus the 20 most frequent words (over 28% of the total) are the following closed-class words: *di, che, si, e, il, un, in, la, è, per, una, a, del, i, le con, della, non, da, dei*. *Nel* is the only exception as it is used more frequently than *dei* in the contemporary Italian subcorpus compared to the Fermi collection and Persico's text.

An analysis of open-class words among the most frequently occurring tokens can give an idea of the topics the texts in the corpus focus on. An examination of the 100 most frequent tokens in the Fermi subcorpus shows that there are 33 open-class words and the atomic/nuclear physics 'trademark' is already evident. These 100 most frequent tokens comprise 5 stems (*atom-*, *elettron-*, *neutron-*, *nucle-*, *particell-*) – in various inflected forms: singular, plural or derived adjectives – to do with the atom and its structure (*neutroni, nucleo, particelle, elettroni, nuclei, particella, neutrone, atomico*). *Neutroni* (neutrons) and *nucleo* (nucleus) are the most frequent terms and thus point to the focus of Fermi's research from the mid-1920s to the 1950s. A comparison with the 100 most frequent tokens in Persico shows that the atom and its constituents are still prominent. There are 12 tokens relating to the atom and its constituents (*nucleo, nuclei, neutroni, protoni, protone, atomi, particelle, neutrone, nucleari, nucleare, nuclide, atomico*) out of 31 open-class words. When contrasting these data with those gathered from the contemporary Italian subcorpus on nuclear physics, one notices that tokens referring to the atom are still quite frequent (9 out of 34 open-class tokens), but the most frequent term is now *particelle*. Focus seems to have shifted from the neutrons and the nucleus. The term particle is used in physics to stand as a hyperonym for the subatomic particles including electrons, neutrons, protons, mesons, and so on. Indeed in this way a whole subdiscipline – particle physics – was created as the constituents of the atom were identified. Table 2 summarises the twenty most frequent open-class words in the three components of our corpus. Open-class words are listed in groups of 5:

Fermi (1925-50)	Persico (1967)	Contemporary Italian (1997-2000)
neutroni, nucleo, due, particelle, momento	nucleo, nuclei, numero, due, raggi	Fermi, particelle, fisica, energia, nucleo
numero, campo, modo, caso, elettroni	fig., massa, neutroni, protoni, forze	Elettroni, numero, Heisenberg, *prima*, massa
elementi, parte, nuclei, massa, particella	periodo, protone, atomi, radioattivo, isotopi	teoria, particella, neutroni, Werner, *stato*
neutrone, teoria, atomico, esempio, *stato*	quantità, pari, superficie, particelle, Ra	nuclei, elettrone, valore, *secondo*, anni

Table 2: The 20 most frequent open-class words in each component of our Italian corpus on nuclear physics. [Italics is used to mark tokens that can also be closed-class words, depending on context]

A closer look at how terms designating the atom and its constituents were used by Fermi over the years confirms that in the early papers the focus of attention was on the atom (*f* = 1.32% in 1925 and 1926), the electron (*f* = 1.23% in 1925 and 0.9% in 1926) and the nuclei (*f* = 1.58% in 1925 and 0.66% in 1926). Reference to the nucleus peaked in the interwar period (*f* = 1.59 in 1932) while the 'new' elementary particle *neutron* came into prominence in the 1938 paper (*f* = 1.84% in the plural form). Terms like *nucleone/i* (*f = 0.03%* each) can only be found in Fermi's last publications (1949-50), and *protone/i* were used in 1934-35 for the first time and then in 1949-50 only. Fermi was amongst the pioneers who strongly believed in the *multiplicity* of elementary particles. The postwar era in physics was marked by the emergence of dozens of elementary particles and here we see Fermi celebrating their discovery or their prediction: the *meson*, the *neutrino*, and the awareness that the neutron and the proton belong to the family of *nucleons* and that the *photon* and the *meson* to the family of *bosons*. Such was the impact of Fermi on physics that Paul Dirac invented the term *Fermion*, for particles with spin ½ which, in turn, obeyed the Fermi-Dirac statistics; Fermi also coined the term Bose-Einstein statistics, and the bosons obey Bose-Einstein statistics.

How is Fermi's terminological legacy being preserved in both modern Italian specialist and general language? Most of the single terms used or coined by Fermi are still in use, some to a greater degree and others to lesser. The term *neutrone* and its plural were amongst the most frequent in Fermi's writing comprising 0.64% of his writings over the 1920-1950 period; our own specialist corpus (c. 185,000 words) shows that Italian physicists still use *neutron* quite frequently amongst other single terms but the term only covers 0.22% of their texts. The specialist sub-corpus, CODIS, also indicates that the term *neutron* is not infrequent and accounts for 0.023 of the corpus and the general language CORIS corpus shows that the term comprises 0.0009% of the 100 million word corpus. The current generation of Italian physicists tend to use the term *bosone* about 30 times more than Fermi and the term *positrone* about the same; in all the CODIS corpus *bosone* is used 5 times for every other million words and for CORIS the term is used 6 times for every 10 million words used. The term *neutrino*, recall that Fermi actually coined the term and this particle was just about discovered in his times, is used 1.5 times more in the specialist Italian corpus when compared to Fermi. *Positrone* shows significant presence in the CODIS corpus, appearing 30 times per million words and also in CORIS appearing 3 times per million words. Table 3 shows the use of 12 most frequent terms in Fermi and their comparative use in Modern Italian specialist and general language. We have shown the frequency of the terms used per million words.

Corpus	Fermi	Ital Contemporary	CORIS	CODIS
Size	70,127	185,985	100,000,000	5,000,000
Era	1920-50	1997-2000	c. 2000	c. 2000
neutrone/neutroni	6400	2209	230	9
nucleo/nuclei	5860	3441	189	46
particella/particelle	4560	4648	205	23
elettrone/elettroni	4550	3308	133	11
atomo/atomi	2240	1397	174	17
protone/protoni	1730	2076	66	5
mesone/mesoni	1310	156	5.6	1
nucleone/nucleoni	370	542	4.2	0.3
neutrino/neutrini	310	436	30	3
fotone/fotoni	190	1956	37	4
positrone/positrone	40	382	18	2
bosone/bosoni	10	320	5	0.6
Total	27570	20869	1095	122

Table 3: The 12 most frequent terms in Fermi and their comparative use in modern Italian specialist and general language [Frequency is indicated per million words]

3 Morphosyntax and discovery

Morphology suggests that (new) word forms are created through one of the following devices: inflection and derivation (3.1) compounding and blending (3.2), loan words (3.3) abbreviations and eponymous words (3.4).

3.1 Affixation

Morphology with reference to special languages is generally studied in terms of a) inflectional affixation or the use of affixes for signalling grammatical relationships between number (singular vs plural), time (present vs past and future) and possession relations and b) derivational affixes changing the grammatical class of stems to which they are attached (Ahmad & Rogers 2001: 741-742).

3.1.1 Inflection and derivation

Inflection and derivation at work can be seen through an analysis of *nucleo/i* and its derivatives, *nucleare/i* and *termonucleare/i*. The taxonomy created with the derivatives of nucleus is even more elaborate and could be grouped in different classes: a) nuclear theory (*fisica nucleare, modello nucleare, statistica nucleare*), b) nuclear description and measurement (*struttura nucleare, massa nucleare, forma nucleare, dimensioni nucleari, asse nucleare, orbita nucleare, forza nucleare, livello energetico nucleare, momento (magnetico) nucleare, spin nucleare*) and c) nuclear phenomena (*fenomeno nucleare, disintegrazione nucleare*, *reazione (termo)nucleare*, *risonanza nucleare*). This is, however, only part of the terminology relating to nuclear reactions.

Further, the adjectives deriving from *atomo – atomico, biatomico* and *interatomico –* are used to form compound terms: *numero atomico*, *modello atomico*, *elettrone atomico*, *nucleo atomico*, *peso atomico*, *struttura atomica*, *pila atomica; molecola biatomica* and *distanza interatomica*. However, *biatomico* in the collocation *molecola biatomica* is only used once in the singular and in the plural in the 1932 paper while the compound term *distanze interatomiche* (pl.) only appears once in the 1949/50 conference papers. Evidence from our Fermi subcorpus shows that as the centre of attention shifts from the atom to its constituents, the atom is referred to indirectly through derivation and compounding. The importance of the terms formed by derivation and compounding is that they begin to create ‘a complex lexical taxonomy, for a defined branch of physics (Halliday 1993: 62) now known as nuclear physics. Table 4 lists all the adjectives derived from atom compared and contrasted with atom as a noun (*atomo/atomi*) in terms of occurrences over the years.

Period	1920's	1930's	1940's
Dates	1925-26	1930-38	1949-50
Tokens	3,570	20,508	46,049
atom*o*	13.17	1.12	0.80
atom*i*	3.08	0.49	0.63
atom*ico*		4.00	0.48
atom*ici*		1.56	0.09
atom*ica*			0.17
atom*iche*	0.28		0.07

Table 4: Derivatives of *atomo*: occurrences of adjectives compared with occurrences of the original noun (*atomo/atomi*) over the years

Derivation can be used to investigate this domain of nuclear physics further. Halliday's notion of grammatical metaphor is useful here in that Halliday suggests that scientists use a shift whereby a process, originally construed as a verb, is reconstructed in the form of a noun (Halliday 1993: 13). Fermi does not use extensive nominalization in the earlier part of his work (c. 1925-1930), but later on there is evidence of considerable use of nominalization. In the Fermi subcorpus, nouns designating processes such as *attivazione, eccitazione, emissione* and *interazione* (activation, excitation, emission, interaction) or entities such as *forza* and *velocità* (force and velocity) are quite frequent. Other relevant items are the adjectives *stabile* and *lento* relating to fundamental aspects in the development of nuclear physics, the stability of elements and slow neutrons necessary for nuclear reactions. When verbs are used, they mainly appear in the present indicative tense.

Evidence of affix productivity in the Fermi corpus concerns the two suffixes *–tore* and *–trone.* The former does not appear so much in new coinages as in terms that are elaborated. Indeed, though terms such as *rivelatore*, *collimatore* and *assorbitore* were already in existence before Fermi's time, their use in the Fermi corpus points to elaboration in that their meaning is extended or narrowed to cover atomic/nuclear physics as collocations from our corpus clearly show:

LH co(n)text	**Term**	**RH co(n)text**	**Paper year**
il cilindro di paraffina e il rivelatore, a 6 cm. Dal	**rivelatore,**	Possono interporsi gli strati delle	1934
la variazione della intensità dell'attivazione del	**rivelatore**	di Rh in funzione della distanza dalla	1934
inistra, due rivelatori eguali dei neutroni lenti. I	**rivelatori**	erano in alcune esperienze di manga	1935
esempio mediante paraffina, e poi inviati su un	**rivelatore**	posto ad una certa distanza, è chiaramente	1949
osservare i neutroni riflessi occorre predisporre un	**Rivelatore di neutroni,**	per lo più un contatore a	1949
nza tra le attivazione dell'argento, con e senza	**assorbitori,**	è dovuta a diffusione + assorbimento	1934
ioni geometriche delle esperienze sono tali che l'	**assorbitore**	intercetta esattamente i raggi prov	1934
solito della proprietà del cadmio di essere un	**assorbitore**	fortissimo per i neutroni termici,	1949
nsità. Nella fig. 6 è disegnato nuovamente il	**collimatore di neutroni,**	unitamente all'appare	1949
mio provvisto di un foro centrale, si ottiene un	**collimatore**	Tale che solo i neutroni che lo att	1949

Table 5: A concordance of three terms ending in *–tore/i*

As can be seen, Fermi uses the three terms in the context of his experiments with neutrons, in particular with reference to the system he had devised to reduce neutron speed by passing neutrons through paraffin (*cilindro di paraffina* and *paraffina* in 1 and 4 of Table 5). In the case of *rivelatore* (detector), it should be noted that in Italian there are two terms to designate a detector, *rilevatore* and *rivelatore*. *Rilevatore* can be regarded as the hyperonym and is used to refer generally to many different kinds of detectors such as metal detectors (*rilevatori di metalli*). Conversely, *rivelatore* – with the stem *rivela-* from the verb *rivelare* (to reveal, to disclose) – is more frequently encountered in compounds such as *rivelatore di particelle* (particle detector) or indeed *rivelatore di neutroni* as used by Fermi. According to OED an *absorber* is 'one, who or something which, absorbs' and its use is marked as chiefly technical. In nuclear physics this technical meaning is narrowed to indicate a 'material for capturing neutrons without generating more neutrons' and Fermi uses the Italian term *assorbitore* in this more restricted sense as examples in Table 5 above show.

Another interesting feature emerging from our corpus concerns the use of *–trone*. As Altieri Biagi (1990) points out, *-trone* is based on the 19^{th} Century model *elettrone* that prevailed over the *–tone* suffix of the *protone* model. Accordingly, Fermi uses *positrone/i* while Persico prefers *positone/i*. Both forms are currently listed in Italian dictionaries, but *positrone* is by far the most common, as an analysis of our contemporary subcorpus confirms. Evolution and consolidation of usage is also suggested by another pair of suffixes, *-ico* and *–istico*, which can be used interchangeably in Italian to form relational adjectives, though the ending in *–istico* frequently indicates an adjective deriving from a noun ending in *–ismo*: *arte* → *artistico*. The suffix *–ico* is used in chemistry to indicate a higher or lower valency of an element (Serianni 1991: 192, 641). In the Fermi subcorpus one notices ambivalence in the use of these suffixes – *quantum phenomenon* and *quantum mechanics* can be either *fenomeno quantico* and *meccanica quantica* or *fenomeno quantistico* and *meccanica quantistica*. In all other cases, when these two adjectives are collocated, the deriving compounds have no variant using the other adjectival form: *legge quantica, numero quantico, salto quantico*, but *elettrodinamica quantistica, teoria quantistica, moto quantistico, transizione quantistica* and *vettore quantistico*. Persico only uses *numero quantico* and *stato quantico*, but *meccanica quantistica*. In the comtemporary Italian component of our corpus the distribution between one variant or the other appears to have consolidated. *Quantico* only features in connection with *numero, stato, orbita* and *salto*, all other terms combine with *quantistico* to form compounds. Data from the CORIS/CODIS corpus indicate a considerable elaboration in compounding using both adjectives. *Quantico* still co-occurs with *numero* and *stato*, but *salto quantico* now has a synonym, *balzo quantico*. New hypothesis and applications are also described: *confinamento quantico, laser a cascata quantica* and *strutture laser a buca quantica*. Variants with *quantistico* and *quantistico* are still frequent; terms typically co-occurring with both adjectives are *stato, comportamento, cromodinamica, fenomeno, effetto Hall, cancellatore, calcolatore (ottico).* Occurrences in the CORIS/CODIS corpora indicate that the 'picture' in quantum theory has become more complex (*teoria di campo quantistica, cromodinamica quantistica*) and applications begin to emerge – *calcolatore* or *computer quantistico, cavo quantistico, bit quantistico, circuito quantistico, transistor quantistico teletrasporto quantistico, crittografia quantistica* and even *eterostrutture a pozzi quantistici tensionati*. Quantum theory appears to have gone 'philosophical'; in the CORIS corpus, beside *logica quantistica, formulazione quantistica* and *coerenza quantistica* one also finds *dialettica classico-quantistica*.

3.2 Compounding and blending

Compounding, another relevant aspect in special languages, includes processes implying both morphology and syntax as in romance languages such as Italian the units forming the compound can be joined by function words and by juxtaposition according to Italian word formation or according to foreign patterns (e.g. following the English system of premodification). In Italian compounding inflectional considerations also come into play.

Whenever two language forms are juxtaposed to create a compound the result is always a noun except in the case of *verde* (adj.) + *bottiglia* (noun) → *verde bottiglia* (bottle green, adj.) and when the two forms are both adjectives, in which case the outcome is a compound adjective, for instance *dolceamaro* (bittersweet). In juxtaposed compounds the position of the head gives and indication of the origin of the compound. Compounds with a right-hand head are either of Latin origin (*mano<u>scritto</u>*, manuscript) or of English origin (*scuolabus* from English *school bus*) while productive compounds have left-hand heads (*<u>pesce</u>cane*, shark) (Scalise 1994: 131). In contemporary Italian the latter type is the most frequent, but there is a tendency to juxtapose forms using a hyphen instead of joining them with function words – again following an English model: proton-neutron <u>force</u> → *<u>forza</u> protone-neutrone* (head underlined) to create phrasal compounds or sequences (Dardano 1993: 349). A study of our corpus produces the following results:

1. In the Fermi (1925-1950) subcorpus only *volt-elettrone* or *elettroni-volt, spazio-tempo* and *sistema elettrone-neutrone* are found. *Spazio-tempo* can be regarded as an exocentric or headless, compounded binomial (Scalise 1994: 132), *volt-elettrone* has a left-hand head – as it follows the Italian determined + determiner order – while *elettroni-volt* has a right head because it exhibits a determiner + determined order on the English model, though electron is plural, that is, inflected (Dardano 1993b: 349). This was replaced by the adapted loan *elettronvolt* (1948). *Sistema elettrone-volt* is a phrasal compound with a left-hand head as in Italian standard productive compounding, but it also shows juxtaposition of the argument *elettrone-volt* following English compounding (Scalise 1994: 147). In most other compounds the relation between the components is made explicit by function words: Fermi does not use *collisione protone-protone* but *collisione <u>tra</u> protone <u>e</u> protone*.
2. In Persico (1967), juxtaposition with hyphenation becomes more frequent. Here is a list of examples: *forza nucleare protone-protone, urto protone-protone, volt-elettrone, forza protone-neutrone, collissione protone-protone, esperienze neutrone-neutrone, esperienze neutrone-protone, grammo-atomo, leggi di forza protone-protone, leggi di forza protone-neutrone, azioni neutrone-protone*.
3. In our contemporary Italian subcorpus there are approximately 400 occurrences of this type. To give just a few examples: *collisione fotone-elettrone, annichilazione elettrone-positrone, interazione elettrone-fotone, dualismo onda-particella, particella-materia, particella-forza*.

One of the striking aspects of Fermi's languge in this respect is that he takes terms whose meaning has been 'renovated' by the use of an affix (Altieri Biagi 1990: 360; Section 3.1 above) such as *–anza* in *invarianza* from *invari(abile)* to further elaborate the term and designate new concepts. Thus he takes *invarianza,* a word which is said to have entered the Italian language in 1950 and is used by Fermi in our corpus in 1949, and further elaborates it creating *invarianza relativistica* and the calque from English *gauge-invarianza*. Other terms with the same suffix undergo a similar process; *risonanza* (resonance) is used in the compounds *risonanza nucleare* and *righe di risonanza*. Similarly, we find *penetranza* and *co-varianza relativistica*. However, the most interesting term, which gives a measure of the impact of discovery on language, is *radioactivity*. As early as 1934 Fermi refers to *radioattività beta* (beta radioactivity), that is a form of natural radioactivity, but also to *radioattività provocata da bombardamento di neutroni* (radioactivity produced by neutron bombardment) or *radioattività indotta* (induced radioactivity). In 1949 this is identified as *radioattività artificiale* (artificial radioactivity). The process of discovery has led to the identification of two forms of radioactivity – natural and artificial. In Table 6 another process is under way: in the early paper the Italian compound *momento intrinseco* is used, then it becomes even more complex as in 1949 *momento angolare intrinseco* is also used. In the 1949 papers Fermi finally indicates that in Italian the English equivalent, *spin*, is also used – a hint that borrowing was to become quite frequent in the Italian language of science.

LH co(n)text	Term	RH co(n)text	Paper year
ia magnetica di interazione tra il momento nucleare e il	**momento intrinseco**	dell'elettrone. I termini derivanti da	1930
atomici. Nel caso nel quale il nucleo atomico non ha un	**momento intrinseco**,	il suo stato è caratterizzato dalla	1932
rienta e l'energia mutua risulta diversa a seconda che il	**momento intrinseco**	è parallelo o antiparallelo a questo	1949
le orbite di un elettrone atomico, un accoppiamento tra	**momento intrinseco**	e momento orbitale. Lo ***spin*** della	1949
e precisamente quelli che corrispondono ai valori del	**momento angolare**	risultante delle varie orbite.	1949
e precisamente per tutte le particelle che hanno un	**momento angolare intrinseco**,	o, come si usa dire, uno ***"spin"***	1949

Table 6: A concordance of *momento* (momentum). Only occurrences of compound terms *momento intrinseco, momento angolare* and *momento angolare intrinseco* are shown.

To sum up, Fermi does not make much use of a compounding process that has now become quite common in Italian, i.e. the creation of compounds using a productive method of juxtaposition with a left-hand head and supplementing it with the non-explicitation of links through function words following the English model of compounding.

3.3 Loan words

Fermi uses loan words from English sparingly. In our corpus only *spin* (27 occurrences) is found. The term *gauge* is used only once, but it features in the hybrid compound *gauge-invarianza*. In other words, as to neologisms Fermi prefers patterns following more closely Italian word formation rules: *isotopo radioattivo* (radioactive isotope) instead of *radioisotopo* (from English *radioisotope* or *radio(active) isotope*), *volt-elettrone* rather than *elettronvolt*. On the other hand, if we look at the 74 terms related to atomic or nuclear physics that have entered the Italian language in Fermi's lifetime according to three recent Italian dictionaries (DISC, Zingarelli 2000 and De Mauro), only 5 are loan words (*down, magnetron, pickup, quantum, spin*). This could point to a stage in the internationalisation of science – Fermi's lifetime – when translating and adapting to Italian morphology and syntax still prevailed over direct borrowing.

3.4 Eponymous words and abbreviations

Eponyms are part of a wider phenomenon in academic prose, citation or referential behaviour to which we shall return below (cf. Section 4). Here we shall concentrate on eponymous words or compounds. In our Fermi subcorpus eponymous words or compounds indicating self-references are extremely limited in number. Of the 45 eponymous terms including Fermi's name and listed in the *Enciclopedia delle scienze fisiche* (Treccani 1996: VII, 292-293), none is quoted in Fermi's own papers. Though further evidence is needed, Fermi's sparing use of eponyms suggests that they are introduced to refer to consolidated knowledge and recognised achievement in science. In discovery – and hence in the Fermi corpus we have collected – stress is laid on the accumulation of contributions aiming at completion of a research puzzle.

A concordance of the other two components of our corpus – Persico and contemporary Italian – reveals that Persico refers to Fermi as an individual and a scientist (*Fermi* or *le esperienze di Fermi*) while in the contemporary Italian subcorpus many compound terms including Fermi's name, that is eponymous designations, and single terms as derivatives (eponyms) are to be found. Compounds can be grouped into three categories: a) objects or entities (*pila di Fermi, gas di Fermi, campo di Fermi*), b) processes (*transizioni di Fermi, interazione debole di Fermi*) and c) models and theories (*modello di Thomas-Fermi, modello a gas di Fermi, statistica di Fermi-Dirac* or *statistica di Fermi, teoria di Heisenberg-Fermi, teoria di Fermi-Urey, teoria di Fermi dei raggi* β or *teoria di Fermi del decadimento beta*). Single terms are usually units of measurements such as *fermi*, a unit of measurement of length. Indeed, through an analysis of Fermi's eponyms the Istituto Nazionale di Fisica Nucleare (Italian National Institute of Nuclear Physics, INFN) was able to summarise Fermi's lasting contribution to several domains in physics. Domains and eponyms are shown in Table 7 below.

Physical domain	**Fermi's eponymous designations (compound terms) in English**	**Physical domains and Fermi's eponymous designations (compound terms) in Italian**
Atomic physics	Thomas-Fermi Model and Thomas-Fermi Equation	Il modello e l'equazione di Thomas-Fermi
Cosmic ray physics	Fermi mechanism; Fermi level	Il meccanismo di Fermi, il pianerottolo di Fermi
Elementary particle physics: general	Fermionic field; anti-fermions; Fermi-Yang Model	Il campo fermionico, gli antifermioni, il modello di Fermi-Yang
Elementary particle physics: beta decay	Fermi diagram, Fermi transitions and Fermi selection rules	Il diagramma di Fermi, la transizione di Fermi e le regole di selezione di Fermi
Elementary particle physics: weak interactions	Fermi's universal constant, Fermi's theory	La costante universale di Fermi e la teoria di Fermi
Extra-terrestrial (life) research	Fermi's paradox	Il paradosso di Fermi
General relativity	Fermi coordinate; Fermi derivative; Fermi-Walker transport; Fermi co-efficient of rotation; Fermi's Weak Equivalence Principle	Le coordinate di Fermi, la derivata di Fermi, il trasporto di Fermi, il coefficiente di rotazione di Fermi, il principio di equivalenza di Fermi
Molecular physics	Fermi resonance	La risonanza di Fermi
Nuclear reactor physics	Fermi's age; Fermi pile	L'età di Fermi, la pila di Fermi
Quantum mechanics: general	Fermi golden rules governing the probability of transitions between two states in the unit of time	Le regole d'oro di Fermi per le probabilità di transizione fra due stati nell'unità di tempo
Quantum mechanics & many-body physics	Fermi gas; Fermi's liquid, Fermi's surface	Il gas di Fermi, il liquido di Fermi, la superficie di Fermi
Quantum mechanics: statistical mechanics	Fermi-Dirac statistics and distribution function; Fermi energy; Fermi impulse, Fermi temperature; Fermi condensation	La statistica e la funzione di distribuzione di Fermi-Dirac; l'energia di Fermi, l'impulso di Fermi, la temperatira (sic) di Fermi, la condensazione di Fermi
Solid state physics	Fermi hole; Fermi sphere; Fermi velocity; Fermi wave-vector	La buca di Fermi, la sfera di Fermi, la velocità di Fermi, il vettore d'onda di Fermi

Eponym	Description	Italian original text
Fermions	Obey Fermi-Dirac statistics and now comprise quarks, electrons, nucleons, neutrinos and nuclei	Innanzitutto i fermioni: particelle che obbediscono alla statistica di Fermi-Dirac ed al principio di esclusione di Pauli; includono i quark, elettroni, neutrini, nucleoni, nuclei.
Fermio-	An unstable element, atomic number 100	Eiste inoltre il fermio: l'elemento radioattivo artificiale di numero atomico 100
Fermi and Femtometer	A new unit of measurement of length – *fermi* measured in femtometre: 1 million billionth of a metre	Ma certametne il termine più significativo è proprio il *fermi*, l'unità di misura del microcosmo, coincidente con il femtometro, un milionesimo di miliardesimo di metro, che è approssimativamente la dimensione lineare di un protone

(Source: *Notiziario* of the Istituto Nazionale di Fisica Nucleare (INFN), April 2001, http://www.infn.it)

Table 7: Fermi's contribution to physics as evidenced by eponymous compounds and single terms.[7]

In our Fermi corpus use of abbreviations and acronyms is restricted to units of measurements and symbols, especially symbols of chemical elements, while in our contemporary Italian subcorpus they are much more frequent.

4. Citation patterns

Through references or citations scientific texts use background knowdedge, thus creating intertextuality, a pragmatic function that is central to scientific discussion and advancement. A distinction can be made between references – which is more or less explicit allusion to work of fellow scientists in the form of books or articles that are cited – and citation or quotation of the exact words used by the scientists. Here we shall not adopt this distinction and refer to citation patterns in general as indeed many linguists do. Several classifications of citations have been attempted. Swales (1990: 148) distinguishes between integral and non-integral citations, while Salager-Meyer (1999: 284) develops a more complex grid including verbatim quotes, general references, specific references, footnote patterns, end-list and self-references, which can fall in any of the previous categories. Citing well-known scientists lends persuasiveness to the text as it provides 'juxtification for arguments and demonstrates the novelty of one's position' (Hyland 1999: 342). Citation in scientific papers has changed over time. General references were typical of 19th-century scientific prose (Salager-Meyer 1999: 288-289) when, especially in physics, sources were only loosely related to specific findings. The emergence of a codified system of scientific documentation in the 20th Century marked the progressive disappearance of general and specific references as the number of publications increased enormously and individual scientists became less and less visible in the scientific community (Salager-Meyer 1999: 294).

In a study of 10 scientific research articles of contemporary physics in English Hyland (1999) finds an average of 24.8 citations per paper compared to 27.5 and 42.8 in mechanical and electronic engineering respectively – and 104 and 94.9 in soft sciences such as sociology and marketing. He ascribes these differences to the fact that in physical sciences journal styles often require numerical endnote forms 'which reduces the prominences of cited authors considerably' (1999: 346). Analysing the surface forms of citations Hyland further finds that in physics 83.1% consists of non-integral citations, 16.9 are integral ones, while 28.6 are subject quotations, 57.1 non-subject and 14.3 noun-phrase citations or eponymous citations. Moreover, Salager-Meyer (1999: 281) notes that the 1910-1949 period – which roughly corresponds to Fermi's lifetime – was an age of 'reference depression' in scientific research articles. If we compare and contrast these data with those from our Fermi corpus we find that in 15 papers Fermi cites 68 scientists for a total of 355 occurrences – equal to an average of 13.169 citations per paper, that is a lower average than that indicated by Hyland for contemporary papers on physics in English. Table 8 shows the 10 most frequently cited scientists, the number of occurrences and the percentage out of the total number of citations. All together the citations of these scientists make up 43.8% of the total number of citations. On the right hand columns of the table an indication is also given of the scientists' native language together with their nationality and dates of birth and death. These data give an idea of the degree of internationalisation in Fermi's work: in the table, 8 scientists out 10 are foreign while the two Italian ones, D'Agostino and Amaldi, belonged to Fermi's research team and are mainly referred to as co-authors of Fermi's papers. Information provided on the right of the table shows the number of eponyms used by Fermi out of the total citations in the table – 32 out of 156, approx. 1 out of 5.

Gamow	25	7.0%	En	American	1904	1968		Eponym		Laws
Dirac*	22	6.2%	En	British	1902	1984			Dirac Eq	1
Bohr*	20	5.6%	Da	Danish	1885	1962	Bohr Magneton	10		
Jukawa*	16	4.5%	Ja	Japanese	1907	1981			Yukawa Theory	4
Pauli*	16	4.5%	De	Swiss	1900	1958	Pauli Principle	6		
Joliot**	14	3.9%	Fr	French	1897	1958				
Einstein*	13	3.7%	De	American	1879	1955	Bose-Einstein Stats	11		
Rutherford**	11	3.1%	En	British	1871	1937				
D'Agostino	10	2.8%	It	Italian						
Amaldi	9	2.5%	It							

Table 8: Evidence of internationalisation: Citation patterns in Fermi's papers. Authors with single asterisk (*) were awarded Nobel Prize in Physics; those with two asterisks (**) were awarded the Prize in Chemistry. All authors except Einstein and Rutherford are of a similar age to that of Fermi.

Further analysis indicates that no verbatim quotes or end-lists are used, that footnotes are scarce and citations tend to be either general – scientists are cited as individuals (*Gamow ha supposto che, Bohr si propone di*) – or reference is made to their work in general (*il ragionamento di Gamow, la teoria di Dirac, le esperienze di Rutherford, i lavori di Gamow, l'idea di Jukawa).*

In short, our corpus data suggest that Fermi continued the 19th-century tradition of general reference and worked in a scientific community where individual scientists were – on average – much more visible than they are today. Evidence from our corpus also indicates that in Fermi's time physics was very much an international enterprise and that Fermi kept abreast of developments in atomic and nuclear physics on the international scene before he joined an international team of scientists in the United States.

5 Closing remarks

Our study has explored the making of nuclear physics and has focused on Fermi's contribution to its language in terms of lexicogrammar - that is through coinage and elaboration of terms, exploitation of morphosyntactic processes such as inflection and derivation, compounding and blending, borrowing and eponymous designations.

Starting from a base of Italian nouns Fermi has built up an edifice of atomic and particle physics (cf. *atomo/i/ico/iche* and *neutrino/i*), of nuclear physics (*forza nucleare, collisione tra protone e protone*), and of nuclear reactor engineering (*reazione a catena, pila atomica*). Together with our analysis of citation patterns as a continuation of the 19th-century tradition of general reference and greater visibility of scientists as individuals – especially when they are contemporaries – it also gives an idea of Fermi's writing or style in Italian. If one considers what is generally regarded as the striking aspect of any special language, terminology, evidence from our corpus shows that Fermi still used Italian creatively to accommodate the new meanings that discoveries in nuclear physics were exposing. On balance, to Fermi creation of new terms meant – more often than not – use of Italian devices for word formation such as inflection, derivation, compounding and blending rather than reliance on foreign devices such as juxtaposition and borrowing from other languages. In this respect, Fermi's elegant Italian derives from grammatical constructs which are linguistically connected. Even citations suggest that to the strict system of reference that was emerging in his time Fermi still preferred a more discoursive style where references were incorporated in the text and scientists were individuals.

Yet the pleasure an Italian native speaker can get from reading Fermi's papers goes deeper than this. As Steiner puts it, 'The true motives [for trying to incorporate science into the field of common reference] ought to be those of delight, of intellectual energy, of moral venture' (1984:440). Fermi's prose is fluent and elegant – evidence that Fermi was fully conversant with his subject, theoretically lucid and as clear in his exposition as only a skilful writer can be. His language is flexible and resourceful and through his writing he lets his passion for his work shine through. Describing the making of the largest Italian dictionary, the *Grande Dizionario* conceived by Battaglia in the 1950s, started in the 1970s and only completed in 2002, De Mauro points out that originally literary words and word senses were given priority; then, in the 1980s, when the dictionary had reached letter M, greater attention was given to technical and scientific language (Bernardini/De Mauro 2003: 101) and for the first time examples of technical and scientific vocabulary were taken from technical and scientific sources instead of literary texts. Indeed, down to letter M of the *Grande Dizionario*, no trace can be found of quotations from scientific texts for any of the terms designating the atom and its components as they were described in this paper. Then, under *nucleo* one finds the following quotation from Fermi:

> Senza ricorrere al meccanismo quantistico, non sarebbe in alcun modo possibile, per mezzo delle sole azioni elettrostatiche tra i nuclei e gli elettroni di due atomi, spiegare come essi, in certi casi, possano riunirsi per formare una molecola. (Battaglia 1981: XI-629)

This does not only provide a good example of how the term *nucleus* is used in physics, but also gives an idea of Fermi's style – his use of long, complex sentences full of subordinate clauses (*Senza ricorrere al meccanismo quantistico/come essi, in certi casi, possano riunirsi/per formare una molecola*) and parenthetical expressions (*per mezzo delle sole azioni elettrostatiche tra i nuclei e gli elettroni di due atomi*/*in certi casi*). The subordinate clauses at the beginning and end of the sentence and the parenthetical expressions in mid-sentence create a kind of balance which is typical of Fermi's elegant prose. Considerable sentence length is confirmed by comparing Fermi's corpus with other components in our corpus and with Maiorana's papers and a selection of articles on nuclear physics from the Italian daily *La Stampa*'s science supplement (1990-2000) as the following table shows:

	Fermi	Persico	Maiorana	Manual	Pop.science	LaStampa
Sent.length	35,19	26,67	21,41	35,82	35,32	26,44
Sd.sent.lngth	30,89	23,06	24,64	30,64	24,58	15,93

Table 9: Fermi's sentence length and standardized sentence length compared with other physicists of his time (Persico, Maiorana) and with contemporary Italian sources (manuals, and popular science components of our corpus and physics extracts from *La Stampa*'s science supplement (Sent. stands for sentence, Sd. for standardised).

As can be seen, sentence length in Fermi's papers compares with more discursive genres such as manuals and popular science. In a way his prose is not just clear scientific prose, but more generally the typical prose of learned Italian essays no matter what the contents are.

In describing contemporary scientific discourse, Montgomery (1996: 24) summarises its main features as 'its ability to split the speaking world, its erasure of origins and influences, and its repression of individual writer'. The kind of compression through substitution, redefinition, fusional reduction of terms and continual adding on of new and more precision-oriented nomenclature Montgomery (1996: 12) has in mind is therefore the current trend in scientific writing. Fermi's language is more the language of discovery than of established science so many concepts and hence terms – as our corpus shows – undergo redefinition, specification and alteration or are replaced by new terms over time. Though in this respect Fermi appeared to follow the prevailing trends in 20th-century scientific language, in syntax he preferred constructs which were connected both within and beyond sentence boundaries. In the following extract from one of Fermi's papers in our corpus, *Lo stato attuale della fisica del nucleo atomico*, published in 1932, anaphora (underlined), repetitions or variations (bold), contrasts (bold italics), and connectives (italics) creating cohesion give an idea of Fermi's style:

> Lo **stato attuale della fisica del nucleo atomico** puo pargonarsi, sotto diversi aspetti, ***allo stato della fisica dell'atomo, trent'anni fa***. *A quell'epoca*, *infatti*, nello studio delle proprietà dell'atomo ci si trovava dinanzi a una serie di **fenomeni** che non sembravano interpretabili colle **teorie** di *allora*, **teorie** basate essenzialmente sulla **dinamica** e sull'**elettrodinamica** classica, che hanno trovato il *loro* inquadramento naturale nella **teoria dei quanti**, *prima* sotto forma quasi esclusivamente qualitativa e *oggi* anche quantitativa, almeno nella maggior parte dei casi. *Naturalmente* le **leggi quantiche *non* sono *solamente valevoli*** per i **fenomeni** della **scala atomica**, ***ma anche*** per i **fenomeni** del ***mondo macroscopico***; *solamente*, per questi ultimi, la *loro* importanza finisce col diminuire e le **leggi classiche** danno una approssimazione perfettamente sufficiente. Ciò che determina la necessità di sostituire le **leggi quantiche** alle **leggi classiche**, è il cambiamento di **dimensioni** degli oggetti studiati quando si passa dalle **dimensioni ordinarie** alle **dimensioni atomiche**.

Fermi's writing therefore has the 'more leisurely pace of the writing of earlier generations, more clearly Latinate in their preference for unfolding hypotaxis' (Cortese (2000: 28). Reading Fermi's papers written 80 to 50 years ago a much higher degree of narrative coherence and logic can be observed as in those times scientists were still trained to be writers as well (Montgomery 1996: 41).

Summary

Each of the specialist communities, including for example scientists, technologists, bird watchers, football commentators, draws on the general languages of the members of the communities. The enthusiasm of scientists sometimes runs ahead of their natural languages and yet the more successful of the enthusiasts invariably harness their general language to lucid statements about the Universe here and a microbe there. Enrico Fermi is a good example of how scientists harness their general language and sometimes their second general language. In Italy, Fermi and his colleagues created the Italian LSP of atomic and nuclear physics during a 20-year period spanning 1920-1940. Fermi then worked in the USA with a number of non-native speakers of English to create and elaborate the English LSP of nuclear physics, of quantum mechanics, of nuclear (reactor) engineering amongst other subjects. We describe how a corpus-based diachronic study can reveal the manner in which Fermi and his colleagues used the lexicogrammar of Italian to create the Italian LSP of atomic and nuclear physics. The particularly productive use of inflectional and derivational morphology of Italian is noteworthy in Fermi's writings.

Résumé

Toute communauté spécialisée, comme par example celle des scientifiques, des technologues, les bird watchers, les reporteurs de football, puise abondamment dans les langues générales des membres des communautés, dans le patimoine de leur langue générale. L'enthousiasme des scientifiques, quelquefois, anticipe leur langue naturelle, cependant les enthousiastes les plus qui avec le plus de succès exploitent invariablement leur langue générale pour exprimer clairement leurs propos, que cela soit sur l'Univers our sur un microbe. Enrico Fermi est un bon example pour témoigner, montrer comment les scientifiques exploitent leur langue générale et quelquefois leur deuxième langue générale. En Italie, Fermi et se collègues créèrent la langue spécialisée italienne de physique atomique et nucléaire pendant une vingtaine d'années, allant del 1920-1940. Fermi, ensuite, travailla aux Etats-Unis avec des non-anglophones pour créer et élaborer la langue spécialisée anglaise de physique nucléaire, de la mécanique quantique, de l'ingéniérie nucléaire (de réacteur) entre autres. Nous décrivons comment une étude basée sur un corpus diachronique peut révéler la façon dont Fermi et ses collégues usèrent le système lexico-grammatical de la langue italienne pour créer la langue spécialisée italienne de la physique atomique et nucléaire. Notamment le recours fréquent de la morphologie flexionelle et dérivationnelle de la langue italienne est à remarquer dans les écrits de Fermi.

Zusammenfassung

Jede besondere Gruppe, z.B. Wissenschaftler, Techniker, Vogelbeobachter, Fussballkommentatoren, greift weitgehend auf die Gemeinsprachen seiner Mitglieder zurück. Die Begeisterung von Wissenschaftlern ist manchmal ihren natürlichen Sprachen einen Sprung voraus und dennoch bedienen sich die Erfolgreichsten unter ihnen gezwungenermaßen ihrer Gemeinsprache, um erhellende Aussagen zu treffen - sei es nun über das Universum oder eine Mikrobe. Enrico Fermi ist ein gutes Beispiel dafür, wie Wissenschaftler von ihrer Gemeinsprache, und manchmal der ihrer Zweitsprache, Gebrauch machen. In Italien gründeten Fermi und seine Mitarbeiter die italienische Fachsprache der Atom- und Nuklearphysik in einer Zeitspanne von 20

Jahren, von 1920 bis 1940. Danach arbeitete Fermi mit Kollegen, die ebenfalls keine englischen Muttersprachler waren, in den USA und hat dabei unter anderem die englische Fachsprache der Nuklearphysik, der Quantenmechanik und der Kerntechnik (Reaktortechnik) geschaffen und ausgearbeitet. Wir beschreiben, wie eine korpusgestützte, diachronische Studie darstellen kann, auf welche Weise Fermi und seine Mitarbeiter die Lexikogrammatik des Italienischen für die Gründung der italienischen Fachsprache der Atom- und Nuklearphysik nutzten. Beachtenswert ist der besonders produktive Gebrauch, den Fermi in seinen Schriften von der Flexions- und Derivationsmorphologie machte.

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Notes

[1] I prove the supreme law of God and sky,/And the primordial germs of things unfold,/Whence Nature all creates and multiplies,/And fosters all, and whither she resolves/Each in the end when each is overthrown./This ultimate stock we have devised/Procreant atoms, matter, seeds of things,/Or primal bodies, as primal to the world. [Translated by William Ellery Leonard, http://classics.mit/Carus/nature_things.1.i.html]
[2] http://www.anl.gov/OPA/frontiers96arch/unisci.html - site visited 9 September 2002
[3] http://hep.uchicago.edu/cp1.html - site visited 9 September 2002.
[4]Fermi and colleagues obtained neutrons that emanated from the naturally radioactive beryllium and passed the neutrons through paraffin (mainly Carbon nuclei) to slow them down. It is only slow neutrons that can cause nuclear fission.
[5]CORIS comprises 6 genres of text: news reportage and editorial (38 M), fiction (25 M), academic prose (12 M), legal and administrative prose (10 M), miscellanea (10 M), ephemera (5 M). The same components are to be found in CODIS, but subsections have shorter running texts (20, 13, 5, 4, 4 and 3 M respectively). Another difference between CORIS and CODIS concerns searches: in CODIS subsections of various sizes can be selected for search, whereas in CORIS only full corpus searches are possible. The academic prose component of CORIS includes texts on human sciences, natural sciences, physics, and experimental sciences (http://cilta.unibo.it/SITOCORIS_ENG.htm).
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