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General Part

Japanese-English Chemical Dictionary. Edited by Markus Gewehr

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1
Introduction to the Japanese Language

1.1
The Japanese Language[1)]

1.1.1
Characteristics of the Language

The Japanese language (日本語 *nihongo*) is spoken by over 127 million people. It has been heavily influenced by the Chinese language over a period of at least 1 500 years. Therefore, Japanese is written with a mix of Chinese characters (漢字 *kanji*) and two syllabaries that are also based on Chinese writing. Much vocabulary has been imported from China or created using the Chinese method of word formation. Today, three sources for words are used in the Japanese language:

- Original Japanese words were already used before the introduction of Chinese writing in the 4th–6th century. With the new possibility of writing down the language, suitable *kanji* had to be found. The pronunciation of *kanji* with the original Japanese sounds is called *on*-reading.
- Chinese words (漢語 *kango*) were introduced while the Japanese adopted Chinese characters and the pronunciation is called *kun*-reading. Chinese-based words comprise as much as 70% of the total vocabulary of the Japanese language and form as much as 30–40% of words used in speech. A small number of words has also been borrowed from Korean and Ainu.
- Words from Western languages have entered Japanese from the 16th century onwards, beginning with Portuguese and followed by borrowing from the Dutch during Japan's isolation in the Edo period. After the reopening in the Meiji restoration in the 19th century, vocabulary from German, French and English was introduced. Today, words from Western languages are transliterated and written in *katakana* (外来語 *gairaigo*).

As consequence, Japanese is written today with a mixture of *kanji*, syllables of two syllabaries (平仮名 *hiragana* and 片仮名 *katakana*), Roman letters and Arabic figures. The bulk of

1) Because some aspects are not relevant for the understanding of scientific publications, they are not described in this book, such as dialects, the honorific system of politeness, origin and characteristics of vocabulary, history of the language, orthographic reforms and the characteristics of standard Japanese forms.

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Japanese text is usually written in either *kanji* or *hiragana*. Within a sentence, words are not separated with spaces – this agglutinative nature gives the "word" a different definition from words in English.

Morphologically, Japanese is an agglutinative language, meaning that words are formed by joining morphemes together or adding affixes to the bases of words.

Japanese is characterized by a complex system of honorifics, reflecting the hierarchical structure of Japanese society. The language has an extensive grammatical system as well as its own vocabulary to express politeness and formality. Three levels of honorific speech are distinguished: plain Japanese (also called informal, 砕けた *kudaketa*, 普通 *futsuu*), simple polite form (also called plain formal, 丁寧語 *teineigo*) and the advanced polite form (敬語 *keigo*) that itself has different levels (respectful language 尊敬語 *sonkeigo*, humble language 謙譲語 *kenjougo*). The choice of the right level of honorifics is determined by various factors, including social position, age, job, gender and experiences, and, within the *keigo*, the content of the speech is also relevant. As will be discussed later, in scientific publications the plain form is exclusively used and, because of this, no detailed explanation of the honorific system and the grammatical measures of *teineigo* and *keigo* is given here.

Dozens of dialects are spoken in Japan. They typically differ in terms of pitch accent, inflectional morphology, vocabulary and pronunciation. As Standard Japanese is prevalent nationwide, dialects do not have to be considered while analyzing scientific literature from Japan.

1.1.2 Basics and Principles of the Japanese Grammar

Compared with some other important languages, the Japanese grammar is often characterized as "not too complicated". However, there are many differences to English and other European languages and there are many typical rules that are necessary to consider in the analysis of Japanese publications. In the following, some basics and principles are introduced. A comprehensive description of the Japanese grammar can be found in the books listed in the appendix.

Words in Japanese are classified into two broad categories, which are further divided as follows:

- independent words (自立語 *jiritsugo*) having internal meaning:
  - conjugable words (活用語 *katsuyougo*): verbs (動詞 *doushi*) and i-type adjectives (形容詞 *keiyoushi*);
  - non-conjugable words (非活用語 *hikatsuyougo*): nouns (名詞 *meishi*), pronouns (代名詞 *daimeishi*), na-type adjectives (形容動詞 *keiyoudoushi*), adverbs (副詞 *fukushi*), conjunctions (接続詞 *setsuzokushi*) and interjections (感動詞 *kandoushi*);
- ancillary words (付属語 *fuzokugo*) are modifiers without own meaning: particles (助詞 *joshi*), prenominals (連体詞 *rentaishi*), counter words (助数詞 *josuushi*) and auxiliary verbs (助動詞 *jodoushi*).[2)]

2) There is no common agreement about the definition of the word in the Japanese language. With conjugable words, stems of verbs and adjectives as well as some endings (as "auxiliary verbs") are own words in many grammar books. In this book, a word is the finally conjugated verb or adjective, i.e., the combination of verb- or adjective-stem and ending.

Because of their importance in scientific literature, verbs, i-type adjectives and particles are described in the following subsections. Conjunctions and interjections are discussed with the sentence analysis in Chapter 2 (Section 2.4).

Japanese nouns have neither number nor gender. To indicate more than one, either a suffix is added (e.g., 々, 達 and 等 are possible for a small number of selected nouns) or the quantity is named. Thus 分子 *bunshi* may mean "one molecule" or "molecules" without any implied preference for singular and plural. In addition, nouns do not inflect to show politeness or respect.

There is only a small number of true adverbs. Most adverbs are derived from other words; therefore, adverbs are often not considered as an independent class of words, but rather a function used by other words.

The most important part of the sentence is the predicate. It contains the conjugable words: verbs, i-type adjectives or the copula. The copula (だ, です) is a special word forming sentences like "A is B". All conjugable words consist of a stem and a changeable ending that expresses tense, negation, politeness, conditional and other functions. The predicate is, therefore, the most important part of the sentence.

There are two principle structures for word order and sentence structure in the Japanese language: The basic word order is "subject–object–verb" whereas most Western languages are classified as subject–verb–object languages. As consequence, each sentence ends in a verb, an adjective or a form of the copula, except if sentence-final particles are present and except in some rhetorical and poetic usage, which is of no relevance in scientific literature. The basic word order is also valid for sub-clauses, which facilitates understanding (Section 2.1.1).

The basic sentence structure is "topic–comment". Hence, the topic comes at the sentence-initial position and is indicated separately from the subject and both do not always coincide. Topic may also be other elements of the clause, such as objects, temporal or spatial information.

The order of the other sentence elements is relatively free, as long as the modifying element stands in front of the modified word (e.g., the adverb precedes the modified verb, the relative clause is in front of the modified noun and genitive nominal precedes the possessed nominal).

Elements of a sentence are not only defined by single words (単語 *tango*). It is grammatically more reasonable to speak of "phrases" (文節 *bunsetsu*) as the sentence-forming equivalents of English "words"[2]. A phrase consist of a word that is followed by auxiliary verbs, verb- and adjective-endings, suffixes and particles that modify its meaning and define its grammatical role. In addition, phonologically, the postpositional elements are part of the word they follow, because the pitch accent falls behind the combination. Particles like は, が, の or を indicate the topic of the sentence, define the function of words and regulate the relation of the sentence elements to each other. Section 1.1.3 gives a list of important particles.

Interrogative questions have the same structure as affirmative sentences, but with intonation rising at the end. Sentence-final particle, か or の, may be positioned at the end of the sentence, depending of the formality of the speech.

The subject or object of a sentence need not be stated if it is obvious from the context. Therefore, words are omitted from the sentence; this is preferred to referring to them with

pronouns. Although there are pronouns in the Japanese language, these are not used as frequently as pronouns in Western languages. They are only used in situations implying some emphasis and this is correlated with the honorific system. Personal pronouns are deleted unless it is necessary to emphasize who is speaking to whom.

1.1.3 Overview of Particles[3)]

Japanese particles (助詞 *joshi*) are used postpositionally and have a wide range of grammatical functions. The most important is the definition of the grammatical role of the term they follow. Particles indicate the topic of the sentence, emphasize words, define the function of words, stress the direction of actions, determine ownership and by this regulate the relation of the sentence elements to each other. They also indicate a question, the speaker's assertiveness and a wide range of emotions. Some Japanese particles work like prepositions in English, but they are unlike prepositions in many ways and Japanese does not have any equivalents of prepositions. Instead, nouns and verbs are used for modifying where English might use prepositions.

Particles are written in *hiragana* even if some have old *kanji* forms. For three common particles, *hiragana* diverge from its pronunciation: は is read "wa", へ is read "e" and を is read "o".

Particles can be classified into ordinary, sentence final and compound particles. Sentence-final particles indicate an interrogative sentence (か or の) and express emotions and emphasis and are of minor importance for the understanding of scientific literature. Compound particles are formed with one particle together with other words that might also be particles. Usually, their understanding can be derived from the single particle and, therefore, they are not discussed here.

For foreigners, the most difficult issue with particles is the distinction and correct use of は and が. Some rough ideas can be used as primers, as given in Table 1.1.

As an example, focus and emphasis are illustrated by the following pair of sentences:

モルホリンは有機塩其だ。= *moruhorin wa yuukienki da.*	Morpholine is an organic base. ("organic base" is stressed and there might be other organic bases among the molecules that are considered)
モルホリンが有機塩其だ。= *moruhorin ga yuukienki da.*	It is morpholine that is the organic base. ("morpholine" is stressed in the sense that it is morpholine of all the organic bases that is considered)

Table 1.2 describes the main functions of important particles. Particles and functions without relevance for scientific literature are not listed.

3) Sometimes, conjugations, interjections and particles are discussed together. In this book, conjugations are discussed in Section 2.4 as they are a suitable instrument for sentence analysis. Some words may be used as particles as well as conjugations. The table only contains the particle function, e.g., the sentence connecting function of *kara* or *demo* is not listed.

Table 1.1 Use of particles *wa* and *ga*.

	Use of は *wa*	**Use of が *ga***
Focus of the sentence	No emphasis; or emphasis of the predicate or an object	Emphasis of the subject
Translation into English	With the definite article (“the”)	With the indefinite article (“a”)
Question	Question for the object	Question for subject or object
Answer to a question	If question has a negative predicate or particle は	If question has affirmative predicate and particle が
Specific verbs and adjectives		• Existential verbs (いる, ある, 住む) • Verbs and adjectives that express abilities, desire and sympathy • The request form (-たい)

Table 1.2 Overview of important particles and their function.

Particle	**Following**	**Function**
は	Nouns, particles	• Indication of the topic of the sentence • Contrasting the current topic from other possible topics
が	Nouns	• Indication of the topic with emphasis of the subject • Determination of sentence topic in case with second subject • Marking of interrogative pronouns in W&H questions (who, where, what, . . . , how) • Marking of the direct object in case of – specific verbs (いる, ある, 住む) – verbs and adjectives which express abilities, desire and sympathy – the request form -たい
も	Nouns, phrases	• Indication of the topic with the meaning “also”, “either . . . or” or “neither . . . nor” • Marking the object indicating emphasis (translated as, for example, “even”) • Modification of interrogatives in terms of generalization, for example, when: いつ → always: いつも
を	Nouns	• Marking of the direct object • Marking of the indirect object for verbs of locomotion
の	Nouns	• Modification of nouns (combination of two noun phrases resulting in indicating an ownership between nouns)
	Phrases	• Sentence-final particle to indicate interrogative sentences

Table 1.2 *(continued)*

Particle	Following	Function
に	Nouns	• Indicating absolute dates that do not depend on the point of time they are mentioned • Marking of the indirect object referring to destination, target person or the goal of an action • Marking the object in passive clauses • Expressing the purpose of an action (“in order to”) • Indicating a place of existence
へ	Nouns	• Marking of the indirect object referring to destination, direction, target person or the goal of an action
で	Nouns	• Marking of the location of action (except place of existence) • Indicating the instrument of an action • Referring to a causal relationship (“because of”) • Marking of quantitative, temporal or spatial separation and temporal arrival point
と	Nouns	• Exhaustive listing of counted objects • Indicating the partner of activities • Marking of quotations, e.g., of indirect speech, thoughts, naming, expression of opinion and similar wording
から	Nouns	• Indicating the temporal, spatial or personal starting point of or the reason for an action
	Verbs (te-form)	• Indicating a point of time after a given action
まで	Nouns, verbs	• Indicating the temporal or spatial end point of an action • Marking of unexpected amounts (“even”) • Together with に (→ までに) indicating a time limit for an action as “by … (a certain time)”
か	Nouns, verbs	• Marking of alternatives (“or”) • Modification of interrogatives in terms of generalization, e.g., who: だれ → somebody: だれか
	Phrases	• As sentence-final particle indicating interrogative sentences
でも	Nouns, particles	• Marking of constrictions as “even” • Modification of interrogatives in terms of restriction, e.g., when: いつ → never: いつでも
ばかり, しか, だけ, きり, のみ	ばかり, しか, だけ: nouns, verbs きり, のみ: nouns	• Expressing limitations like “only”, “just”, “nothing but” or “nobody but”
くらい, ほど, ごろ	Nouns	• Expressing an approximate quantity (“about, around, approximately”)
ほど	Verbs, adjectives	• Indicating the extend, upper limit or degree of an action or property
より	Nouns	• Indicating the person or object of comparison
ずつ	Quantifier	• Modifying quantifiers by expressing equal distribution of quantity

Table 1.2 *(continued)*

Particle	Following	Function
など	Nouns	• Indicating exemplification (“like, for example, and similar, such as”)
ごとに	Nouns	• Indicating regular activities in terms of time or place (“every”)
って	Nouns, verbs, adjectives	• Indicating a topic in the meaning “speaking of …”
さえ, すら	Nouns	• Marking the object indicating emphasis (translated as, e.g., “even”), さえ with positive emphasis, すら with negative emphasis

1.1.4 Conjugation and Overview of Morphological Endings and their Use

The Japanese predicate contains the only conjugable words, fulfils many functions and is, therefore, considered as the most important sentence element. Apart from a few exceptions, it is constrained to the ends of clauses. It can be classified into:

- verbal predicate with conjugable verbs (the copula may be used);
- adjectival predicate with conjugable i-type adjectives (the copula may be used);
- adjectival predicate with non-conjugable na-type adjectives and the copula and
- noun-type predicate with the copula.

The most important functions of the predicate are the expression of tenses, voice, aspect, politeness and the formation of negative sentences. This is achieved by conjugating verbs, i-type adjectives or the copula. All three types of conjugable words consist of a stem, which expresses the meaning of the verb and which is written with *kanji*, *hiragana* or both. Behind the stem, the ending is attached, which indicates the above-described functions and which is written in *hiragana*. Some endings are also conjugable and, therefore, called “auxiliary verbs”.

The copula is used as conjugable word, if the predicate contains non-conjugable words like nouns or na-type adjectives. It is also called the “be-verb” in English. In scientific literature, its most important forms are the plain present forms である and だ. Further conjugated plain forms are given in Table 1.3.[4)]

Conjugated verbs[5)] consist of the verb stem, a stem extension and the ending. Whereas the ending of all verbs is usually the same (except the shift from -て to -で and -た to -だ for few

4) The affirmative polite form of the copula is です. It is not only used as predicate but also to modify a sentence predicate with stative verbs into a more polite form. です is further inflected like group-1-verbs, e.g., in it is affirmative past polite form でした.

5) There is an alternative description of verbs used in most of Japanese grammars by Western linguists. It uses “stem consonants”, “reduced stems” and the insertion of additional vowels between stems and endings for group-1-verbs. These terms are not used by Japanese as they think of syllables instead of isolated consonants and vowels. Because it is also a complicated approach with many exceptions, it was decided to use a more systematic description.

Table 1.3 Conjugation of the copula.

	Present tense	Past tense	Gerundive	Presumtion
Affirmative	だ *da*	だった *datta*	で *de*	だろう *darou*
	である *de aru*	であった *de atta*		
Negative	ではない *dewa nai*	ではなかった *dewa nakatta*	ではなくて *dewa nakute*	
	じゃない *ja nai*	じゃなかった *ja nakatta*		

types), the stem extension depends of the verb class. Except for the two irregular verbs する *suru* and 来る *kuru*, every Japanese verb is a member of one of the two main verb classes, both of which can be divided into sub-classes:

- The plain present form of group-1-verbs (五段 *godan*) ends with a syllable of the u-column. Because the consonant of the last syllable is different and determines the sub-class (く-, ぐ-, す-, つ-, ぬ-, ぶ-, む-, る- and う-verbs), verbs of this class are also called "consonantal verbs".[6] For all conjugations, a stem extension has to be placed between verb stem and ending. The stem extension is always a syllable of the same row (e.g., -ま-, -み-, -む-, -め-, -も-) but the row depends on the sub-class. There are also some irregular modifications for plain past, gerundive and conditional forms (Table 1.4).
- All group-2-verbs (一段 *ichidan*) consist in their plain present form only of verb stem and the ending -る. Depending on the vowel before, which can be either i or e, they can be divided into *iru*-verbs (上一段 *kamiichidan*, e.g., to discuss: 論じる *ronjiru*) and *eru*-verbs (下一段 *shimoichidan*, e.g., to heat: 温める *atatameru*). They are also called "vocal verbs". In contrast to group-1-verbs, there is no stem extension necessary for many conjugations and some endings are directly attached to the stem. Other stem extensions are not regularly derived from one row of the 50-sound-matrix as it is for group-1-verbs.

6) The only exception of the characteristics are consonantal verbs with the ending う, as they do not end with a consonant (e.g., 会う au, 言う *iu*). In former times, う was "*wu*" and this still can be seen in some forms, like the negative non-past form (e.g., 会わない *awanai*, 言わない *iwanai*). If the last syllable of a verb is る and if the syllable before る is from the e- or i-column it can't be decided by the plain non-past form whether the verb is group-1- or group-2-type. It either has to be known or it can be identified by other conjugated forms.

Table 1.4 Plain past, gerundive and conditional forms for group-1-verbs.

Sub-class	Example	Plain past		Gerundive	
		Ending	Example	Ending	Example
く-	書く *kaku*	-いた	書いた *kaita*	-いて	書いて *kaite*
ぐ-	泳ぐ *oyogu*		泳いだ *oyoida*		泳いで *oyoide*
す-	話す *hanasu*	-した	話した *hanashita*	-して	話して *hanashite*
ぬ-	死ぬ *shinu*	-んだ	死んだ *shinda*	-んで	死んで *shinde*
ぶ-	遊ぶ *asobu*		遊んだ *asonda*		遊んで *asonde*
む-	住む *sumu*		住んだ *sonda*		住んで *sonde*
つ-	持つ *motsu*	-った	持った *motta*	-って	持って *motte*
る-	掛かる *kakaru*		掛かった *kakatta*		掛かって *kakatte*
う-	言う *iu*		言った *itta*		言って *itte*

The combination of verb stem and stem extension is called "verb base". All endings can be attached to seven different bases, as summarized in Table 1.5.[7] The overview includes some important verb endings and the formation of the group-1-verb 足す *tasu* and the group-2-verb 見る *miru* as examples. The irregular verb する *suru* is included due to its importance for scientific literature (Section 2.1.3). The 連用形 base is used to attach many other additional verbs or other words, such as -すぎる (e.g., too big: 大きすぎる *ookisugiru*), -かた (e.g., the way of writing: 買いかた *kaikata*), -そうだ, -始める (e.g., to start to add: 足し始める *tashihajimeru*), -終わる (e.g., to finish to examine: 調べ終わる *shirabeowaru*), -安い (e.g., easy to understand: 分かり安い *wakariyasui*). Other group-1-verbs are modified in a similar way to 足す *tasu*, with some irregularities for plain past, gerundive and conditional forms, depending on the group-1-sub-class (Table 1.4). Table 1.5 lists the seven bases and some important endings.

Some endings may be conjugated as well, which leads to the formation of agglutinated multiple verbal endings. For instance, the polite ending -ます conjugates as a consonantal verb (e.g., -ます → -ました) and passive and causative endings conjugate as vocal verbs (e.g., -られる → -られられます, -させる → -させられた). The order of agglutinating endings is not arbitrary. For example, the combination of negative and causative forms is only possible by adding a negative ending to the causative form of the verb, e.g., 見る *miru* → 見させる *misaseru* → 見させない *misasenai* (not possible is the opposite approach adding causative ending the negative verb form 見ない *minai* → 見なさせる *minasaseru*).

7) Two basis have the same verb conjugation but conjugated verbs are used differently, either as sentence terminal verbs (終止形) or as attributes (連体形). The form 連用形 may be derived into two sub-classes, one for which no stem extension is necessary for class-2-verbs and a second for which -ら- and -さ- as stem extension are used.

Table 1.5 Japanese verb bases.

Base name	Form	Ending	Group-1-verbs example: 足す *tasu* (stem: 足- ta-)		Group-2-verbs example: 見る *miru* (stem: 見- *mi*-)		する *suru*
			Stem extension	Conjugated verb	Stem extension	Conjugated verb	
終止形 *shuushikei* 連体形 *rentaikei*	Plain present	(No ending)	-す	足す *tasu*	-る	見る *miru*	する *suru*
連用形 *renyoukei*	Polite present	-ます	-し-	足します *tashimasu*	(No stem extension)	見ます *mimasu*	します *shimasu*
	Polite present neg.	-ません		足しません *tashimasen*		見ません *mimasen*	しません *shimasen*
	Imperative	-なさい		足しなさい *tashinasai*		見なさい *minasai*	しなさい *shinasai*
	Request form	-たい		足したい *tashitai*		見たい *mitai*	したい *shitai*
	Purpose	-に		足しに *tashini*		見に *mini*	しに *shini*
	Plain past	-た (-だ)		足した *tashita*		見た *mita*	した *shita*
	Gerundive	-て (-で)		足した *tashite*		見て *mite*	して *shite*
	Conditional	-たら (-だら)		足したら *tashitara*		見たら *mitara*	したら *shitara*
未然形 *mizenkei*	Plain present neg.	-ない	-さ-	足さない *tasanai*	(No stem extension)	見ない *minai*	しない *shinai*
	Plain past neg.	-なかった		足さなかった *tasanakatta*		見なかった *minakatta*	しなかった *shinakatta*
	Passive	-れる		足される *tasareru*	-ら-	見られる *mirareru*	される *sareru*
	Causative	-せる		足させる *tasaseru*	-さ-	見させる *misaseru*	させる *saseru*
仮定形 *kateikei*	Conditional	-ば	-せ-	足せば *taseba*	-れ-	見れば *mireba*	すれば *sureba*
	Potential	-る		足せる *taseru*	-られ-	見られる *mirareru*	できる *dekiru*
命令形 *meireikei*	Imperative	(No ending)	-せ	足せ *tase*	-ろ	見ろ *miro*	しろ *shiro*
音便形 *onbinkei*	Volitional	-う	-そ-	足そう *tasou*	-よ-	見よう *miyou*	しよう *shiyou*

Table 1.6 Conjugation of i-adjectives and examples for i- and na-type adjectives.

Form	i-adjective ending	Example i-adjective: easily inflammable 燃え安い	Example na-adjective: viscous 粘稠な
Plain present	-い	燃え安い *moeyasui*	粘稠な *nenchou na*
Plain past	-かった	燃え安かった *moeyasukatta*	粘稠だった *nenchou datta*
Plain present negative	-くない	燃え安くない *moeyasukunai*	粘稠ではない *nenchou dewa nai*
Plain past negative	-くなかった	燃え安くなかった *moeyasukunakatta*	粘稠ではなかった *nenchou dewa nakatta*
Gerundive	-くて	燃え安くて *moeyasukute*	粘稠で *nenchou de*
Gerundive negative	-くなくて	燃え安くなくて *moeyasukunakute*	粘稠ではなくて *nenchou dewa nakute*
Conditional	-ければ	燃え安ければ *moeyasukereba*	粘稠なら/ならば *nenchou nara/naraba*
			粘稠であれば *nenchou de areba*

There are two types of adjectives in Japanese. na-type adjectives (形容動詞 *keiyoudoushi*) are not conjugable and, therefore, a form of the copula replacing the final な has to be used, indicating tense, politeness and other functions. They have some properties similar to nouns and many na-adjectives are nouns that are affixed with na and, because of this, they are also called quasi-adjectives or adjectival nouns.

i-type adjectives (形容詞 *keiyoushi*) inflect, i.e., they can become, for example, past or negative and because of this they have verbal character. However, they do not have the full range of conjugation seen for verbs. Conjugated i-type adjectives are formed by replacing the final -i with the appropriate ending. The polite form of the copula may follow to make the adjective more polite but this is not applied in scientific publications. In principle, the same bases exist for adjectives as described for verbs above. Some verb endings can be considered as i-type adjectives with the same further conjugation, such as the plain past form -ない or the request form -たい. Table 1.6 gives the conjugation of both types of adjectives and examples.

The two types of adjectives are also used differently in the case of adverbal use. In i-type adjectives, the ending is replaced by -く, and between na-type adjective and verb に is introduced. Nouns can be formed from some i-type adjectives by adding the ending さ to the adjective stem, such as for big: 大きい *ookii* → biggest: 大きさ *ookisa* and high: 高い *takai* → highest: 高さ *takasa*. For a few adjectives, the ending み *mi* is also possible, e.g., for weak: 弱い *yowai* → weakest: 弱み *yowami*.

1.2 Japanese Writing[8)]

1.2.1 Basic Principles

1.2.1.1 Types of Characters and their Use

Written Japanese is composed of a mixture of four systems of characters: two phonetic syllabaries, 平仮名 *hiragana* and 片仮名 *katakana*; 漢字 *kanji*, which are characters of Chinese origin; and, rarely, Japanese words written in Roman letters. The bulk of Japanese text is usually written in a combination of *kanji* and *hiragana*, but *katakana* are also common in scientific publications. After a brief introduction, each is described more detailed.

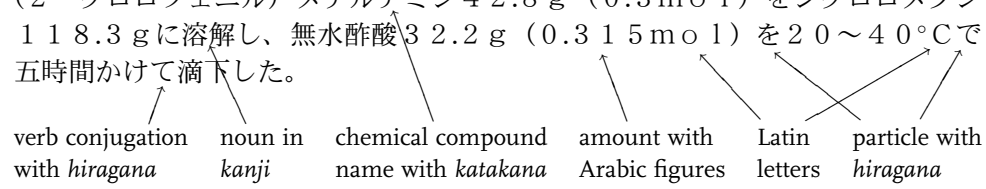
kanji are used in Japanese either as pictograms, ideograms or phonograms. They usually represent a concept or an idea, but are occasionally used simply for their sound. *kanji* are used for nouns, adjectives, the stems of verbs and verbal adjectives and Japanese names. Most have two or more readings.

hiragana syllables have a defined reading but are not connected to a specific meaning or content. They are used for the inflecting endings of verbs and adjectives (送り仮名 *okurigana*), for words with only grammatical function (e.g., particles), for all other Japanese words without *kanji*, such as する or きれい or for *kanji* that have recently became unpopular, e.g., for phosphorous (燐 *rin*): リン or りん. *hiragana* are also used for words for which the *kanji* form is too difficult and not expected to be known to the readers, is not known to the writer, or is too formal for the writing purpose. As 振り仮名 *furigana*, *hiragana* are also used as help to indicate the correct reading of difficult *kanji*.

To express words of foreign origin, the second syllabary *katakana* is used. It is more frequently found in chemical literature than in non-scientific publications, as many technical expressions, especially names of chemical compounds, are borrowed from foreign languages, i.e., English, Latin or German. Depending on the author's philosophy, plant and animal names may also be written in scientific literature with *katakana*, although original Japanese names exist (e.g., wheat コムギ in pesticide chemistry or mouse ネズミ in pharmaceutical publications). *katakana* can also be found for onomatopoetica, or if a Japanese expression shoud be emphasized, especially in signs and advertisements. Words to be emphasized in a sentence are also sometimes written in *katakana*, and, in some Japanese *kanji* dictionaries, *katakana* are used to indicate the *on*-reading of a *kanji*. In addition, *kanji* in scientific literature are sometimes replaced by *katakana* if the *kanji* is expected to be too difficult.

Finally, Latin letters and Arabic figures are also used in scientific literature. Numbers are often written with Arabic forms, especially for specification of quantity and temperature, for code numbers of pharmaceutical or pesticide drugs, and to indicate the position of substituents in the names of chemical compounds. In addition, some English expressions, such as abbreviations (e.g., "DMF" and "tert.") and the oxidation state in the names of inorganic compounds, are usually written with Roman letters. Empirical formulas are always written in the international way. The following sentence illustrates the different characters used in scientific Japanese literature:

8) The following aspects are not described in this book: Systems of encoding *kanji* and *kana*, e.g., unicode, EUC-JP, Shift-JIS, half-width and full-width *katakana*; industrial standards for the writing of *kanji* and *kana*; methods to write individual *kana* and *kanji*, e.g., stroke order.



For transliterating Japanese in the Roman alphabet, different methods may be used. The most important system is the Hepburn method, which is also used in this book and is described in Section 1.2.2. Transcribed Japanese is called ローマ字 *ro-maji*. Romanization is also the most common way to input Japanese words into word processors and computers.

All words in Japanese can be written in either *hiragana*, *katakana* or *ro-maji*. The choice of which type of writing to use depends on style, conventions, and, to some extend, the preference of the authors.

There is no fixed rule regarding the direction of writing. Whereas in newspapers, magazines and fiction, Japanese is still written traditionally in columns going from top to bottom, with columns ordered from right to left (縦書き *tategaki* or 縦組み *tategumi*), it is common to write horizontally from left to right in scientific and technical publications (横書き *yokogaki* or 横組み *yokogumi*). Independent from the direction of writing, all characters are placed directly one after each other. No special inter-space is used to separate words, or even sentences. All symbols (*kanji* and *kana*), including the punctuation marks, get the same space, i.e., they are written into an imaginary square of the same size.

1.2.1.2 **Punctuation Marks**

There are no standardized rules for the use of punctuation marks in the Japanese language. It is left to the author's discretion when and how to use them. The number of marks that can be found in scientific literature is very limited, as grammatical constructions like indirect speech are uncommon. Because of the generally close relationship of chemical literature to the English language, the use of marks and signs has been adapted to the standard of international publications.

The two most important Japanese punctuation marks are the small dot "。" (丸 *maru*) and the drop shaped comma "、" (点 *ten* or 読点 *touten*, "reading point"). *maru* is used to finalize all types of sentences (therefore, it is also called 句点 *kuten* "sentence point"), including interrogative and exclamatory sentences, as there are traditionally no interrogation and exclamation marks in Japanese. *ten* may be inserted, if it helps in understanding complex sentences by grouping parts of the sentence that belong together. There are few cases in which the *ten* is essential for understanding the sentence, such as in following examples:

> 研究者が、昨日研究室へ来た時に塩酸ヒドロキシルアミンを反応混合に添加した。
>
> *kenkyuusha ga, kinou kenkyuushitsu e kita toki ni ensanhidorokishiruamin o hannoukongou ni tenka shita.*
>
> When the researcher yesterday came to the laboratory, he added hydroxylamine hydrochloride to the reaction mixture.

研究者が昨日研究室へ来た時に塩酸ヒドロキシルアミンを反応混合に添加した。

kenkyuusha ga kinou kenkyuushitsu e kita toki ni ensanhidorokishiruamin o hannoukongou ni tenka shita.

When the researcher yesterday came to the laboratory, somebody (e.g., the researcher or another person; subject not named) added hydroxylamine hydrochloride to the reaction mixture.

ten is also used to separate successive numbers (e.g., 二、三時間 *ni, san jikan* = "two, three hours") and to partition four- and multi-digit numbers in triple-digit groups, such as in 五、二九〇キロ (*gosen nihyaku kyuuju kiro*). Table 1.7 gives further punctuation marks that are used in the scientific literature.

Table 1.7 Punctation marks.

Mark	Japanese name	Description
・	中点 *nakaten*, 中黒 *nakaguro*	• Used to separate items in lists of nouns and names, e.g., "fluorine, chlorine, bromine and others" = 弗素・塩素・臭素など *fusso* ・ *enso* ・ *shuuso nado* • Indication of the beginning of decimal places of fractions (reading: *ten*), e.g., 六・五％ • Separation of components of chemical names and terms for clearer understanding, e.g., "in vitro": イン・ビトロ; trimethylacetaldehyde: トリメチル・アセトアルデヒド
～	波形 *namigata*	• Indication of the range between figures like "from … until"
「 」	鉤 *kagi*, 鉤括弧 *kagikakko*	• Quotation marks to indicate beginning and end of citations
『 』	二重鉤 *futaekagi*, 二十鉤括弧 *nijuukagikakko*	• Quotation marks for double quotes (used for citations within citations or when indicating a book title)
…	点線 *tensen*	• Indication of an incomplete sentence, thought or thread
〔 〕	亀甲 *kikkou*	• Used to insert comments into quoted text
【 】	すみつき括弧 *sumitsukikakko*	• Used in headings, e.g., in dictionary definitions
( ) [ ] 〈 〉	括弧 *kakko*, 丸括弧 *marugakko* かぎかっこ *kagikakko* 山括弧 *yamakakko*	• Further types of brackets
《 》 ≪ ≫	二重括弧 *futaekakko*	• Brackets within brackets

1.2.2 The *kana* Syllabaries and the Japanese Sound System

1.2.2.1 Introduction to the *kana* Syllabaries

The Japanese language consists phonetically of syllables. They are represented by the two phonetic syllabaries, 平仮名 *hiragana* and 片仮名 *katakana*. Each sound may be written down by one *kana* character. In addition, the phonology of *kanji* is subject to the same system. Each *kana* is either a vowel (e.g., あ), a consonant followed by a vowel (e.g., き) or the nasal sonorant ん.

When *kanji* were introduced in Japan, each native Japanese word could be written down, but the longer the word, the more characters were necessary (with each character consisting of few to many stroke numbers). To make writing less difficult and time-consuming, the *kanji* were increasingly simplified, resulting in the *hiragana* syllabary (8th century). *hiragana* first gained popularity among women, who were not allowed access to the same level of education as men (''women's writing'', 女手 *onnade*). Later, the *katakana* syllabary matured finally from the *kanji* during the early Heian period, when monastery students of Buddhism used simple characters to make notes to explain the pronunciation of difficult *kanji*. Later, *hiragana* was used for unofficial writing because of its flowing style, e.g., for personal letters, while *katakana* was used for official documents.

To express the sounds of the Japanese language for non-Japanese, the syllables are converted into the Latin alphabet. Today, there are several different romanization systems but, mainly, two methods are used for the transcription process.[9] Preferred among foreigners and in scientific literature is the Hepburn system (ヘボン式ローマ字 *hebonshiki ro-maji*). It was developed 1885 by a commission of Japanese and foreign scientists and became popular after publication by the American linguist J.C. Hepburn. Some optimization has taken place since then, and the currently used version is called the ''Revised Hepburn system''. The method is geared to the English language, following English phonology for consonants, and vowels also to the German and Roman (i.e., Spanish) languages. This book uses the Hepburn system, with only a few exceptions, which are described below.[10]

9) There are other methods besides the Hepburn system for romanization. The *kunreishiki ro-maji* (訓令式ローマ字) was developed by the Japanese authorities. It does not consider the irregular reading of some *kana* characters (し, ち, つ, ふ and for palatalized *kana* derived from し and ち, e.g., しゃ, ちゅ, じょ) and, therefore, looks neater because of greater consistency. In total there are only a few differences from the Hepburn system. It is recommended by the Japanese government and taught to Japanese elementary school students.

The *nihonshiki* (日本式) is the least used of the three main systems. It strictly follows Japanese phonology and the syllabary order and, therefore, is the only method that allows lossless mapping to and from *kana*.

10) In this book, there is no use of apostrophes (like ''*n'i*'' for ンい) to distinguish between the syllable combinations of ン with vowels (ンあ n + a, ンい n + i, ンう n + u, ンえ n + e and ンお n + o) and the syllables な, に, ぬ, ね and の.

1.2.2.2 **The Japanese Sound System**[11)]

The "basic" Japanese sounds can be arranged in a 50-sound-matrix (五十音 *gojuuon*) that associates each syllable with one *kana* character.[12)] The syllables are traditionally arranged in rows by vowels in the order "a-i-u-e-o" and in columns by consonants in the order "no consonant, k-s-t-n-h-m-y-r-w". Nowadays, it has changed into rows for the consonants and the new arrangement is also used in this book. In recent centuries, linguistic development has led to the loss of some sounds because of their disuse. The number of official approved characters for basic *hiragana* and *katakana* today is 46 each, including the only sound that is not part of the syllable system but later introduced to express nasal sounds, ン. The *kana* を, originally read as *wo*, is only used as a grammatical indicator. The transcription of the syllables with the Hepburn system into the Latin alphabet takes the irregular phonology of the syllables し, ち, つ and ふ into account.

Changes of sounds during the centuries and the appearance of new sounds that were not represented by a basic character of the 50-sound-matrix made it necessary to add auxiliary markers for the existing *kana*, creating new ways of reading. Therefore there are additional derived sounds and characters besides the 50-sound-matrix, called "modified syllables": starting from the syllables of the か-, さ-, た- and は-rows, a marker (濁り点 *nigoriten* or 濁点 *dakuten* = adding two small lines to the top-right corner of the *kana* character) turns an unvoiced consonant into a voiced one, such us k into g or h into b. By this, "clouded sounds" (voiced sounds, 濁音 *dakuon*) are formed, such as ば, じ, で or ご. To *kana* beginning with an h, a small circle (半濁り点 *hannigoriten* or 半濁点 *handakuten*) can also be added, changing the h into a p and forming the "semiclouded sounds" ぱ, ぴ, ぷ, ぺ and ぽ (半濁音 *handakuon*). Figures 1.1 and 1.2 summarize the *hiragana* and *katakana* characters of the 50-sound-matrix, including clouded and semiclouded sounds and their transcription by the Hepburn system.

With clouding, there are two cases in which a sound may be expressed with two *kana*: There are two *kana* pronounced *ji* (*hiragana* じ and ぢ, *katakana* ジ and ヂ) and two *kana* pronounced *zu* (*hiragana* ず and づ, *katakana* ズ and ヅ). These pairs are not interchangeable. Usually, the *kana* characters of the s-row are used, i.e., *ji* is written as じ or ジ, and *zu* is written as ず or ズ.

Sounds that are represented by only one *kana* character are called unpalatalized (直音 *chokuon*). Besides these, there are further derived sounds that are called palatalized (拗音 *youon*). They are formed by combining some syllables of the i-column (き, し, ち, に, ひ, み and り) or the clouded sounds ぎ, び, ぴ or じ followed by a subscript version of the *kana* for ya, yu or yo, e.g., きゃ *kya*, にゅ *nyu*, ひょ *hyo*, みゃ *mya*, りょ *ryo*, *gyo*, びゃ *bya* and ぴゅ *pyu*. For the syllables し, ち and じ, the "y" is skipped, giving pronunciations such as しゃ *sha*, じゅ *ju* and ちょ *cho*. Figure 1.3 gives all of the palatalized sounds.

11) Although the expressions "vowels" and "consonants" are used here, it has to be kept in mind that Japanese do not think of their sounds in the Japanese language in terms of vowels and consonants but in terms of syllables. In addition, whereas Westerners think in terms of letters, Japanese think in terms of *kana*.

12) Besides the *gojuuon* ordering, an old-fashioned *iroha* ordering is sometimes used. The ordering is derived from a Buddhist poem and, therefore, is not useful for foreigners.

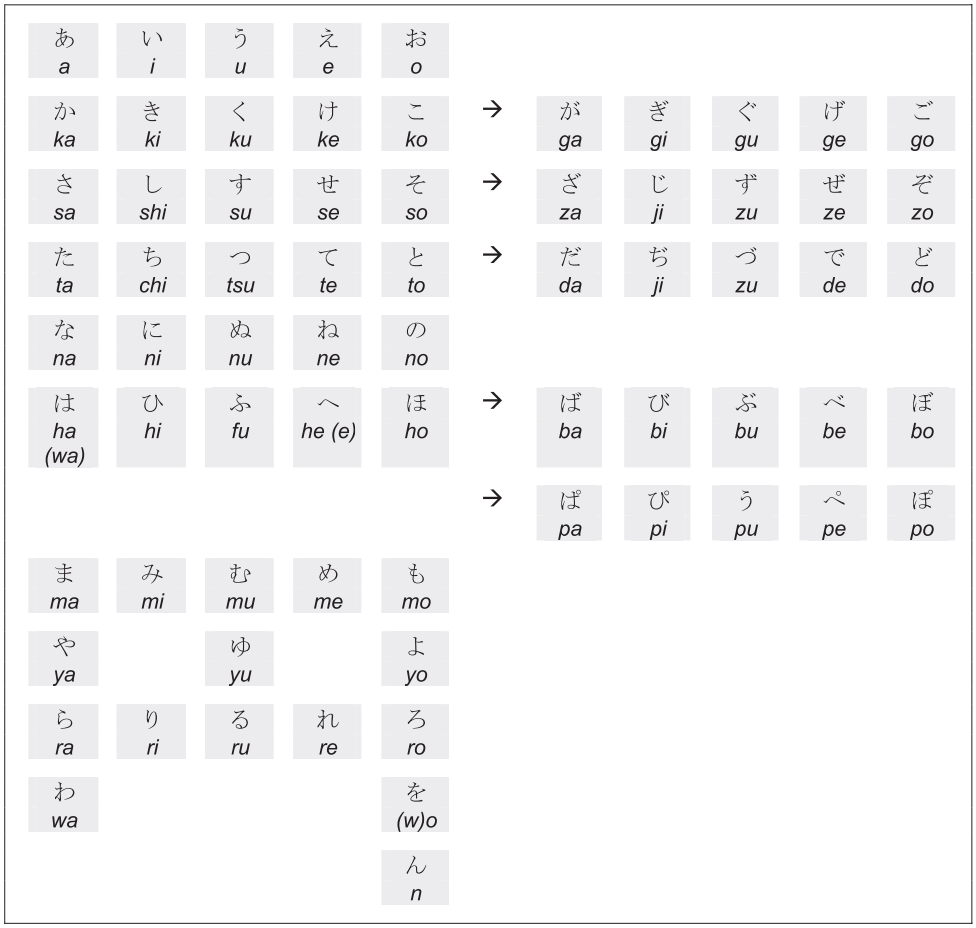


Fig. 1.1 *hiragana* Characters: 50-sound-matrix, character *n*, *hiragana* for clouded and semiclouded sounds and their *ro-maji*, transcribed by the Hepburn system.

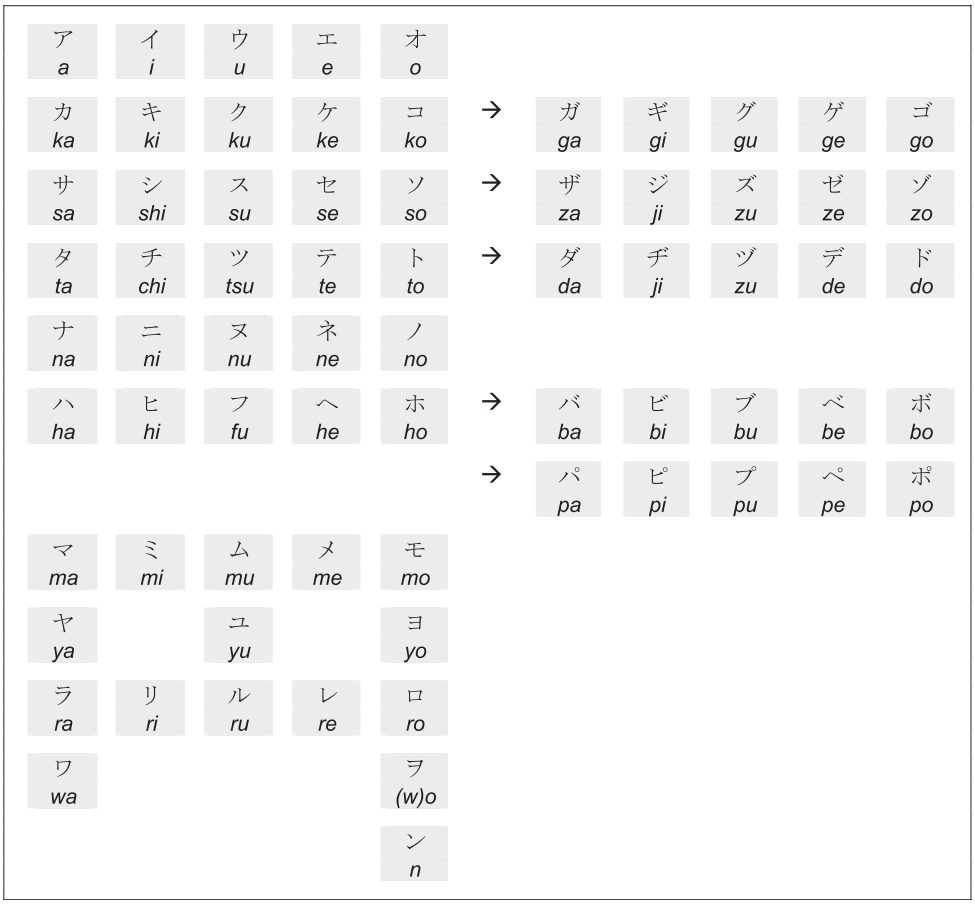


Fig. 1.2 *katakana* Characters: 50-sound-matrix, character *n*, *katakana* for clouded and semiclouded sounds and their *ro-maji*, transcribed by the Hepburn system.[13)]

13) Because of the similar shape, there are two pairs of *katakana* that can be easily mixed up and, therefore, have to be carefully distinguished: ソ so and ン n; and シ shi and ツ *tsu*.

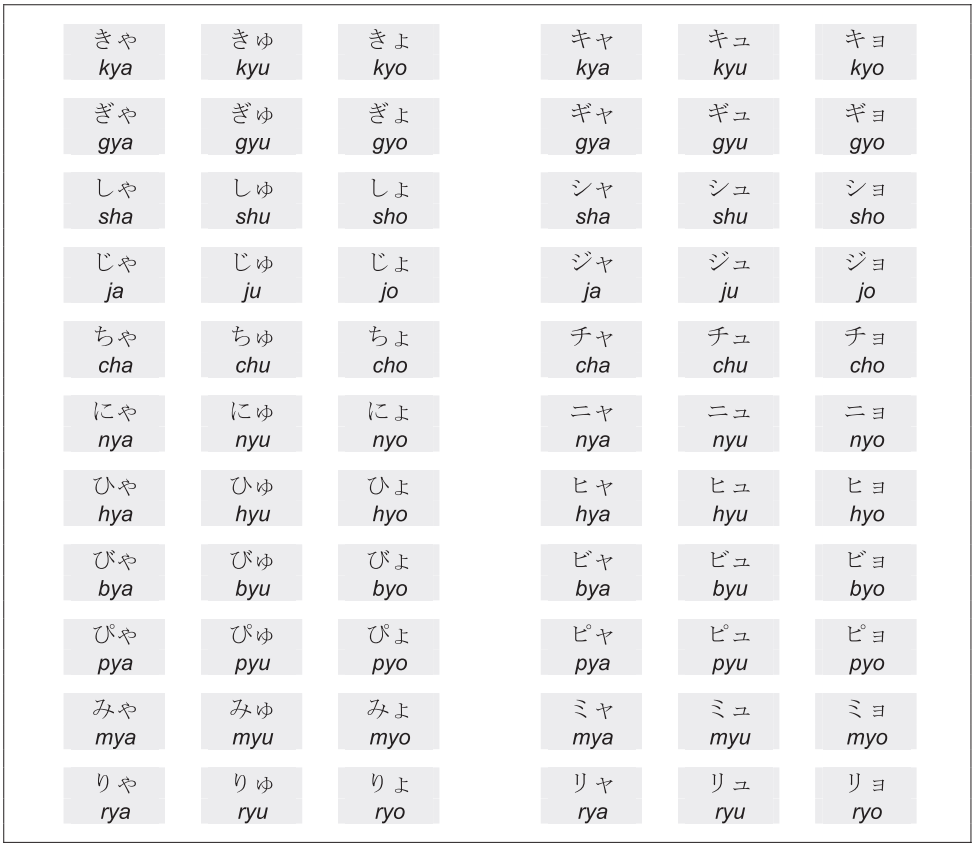


Fig. 1.3 Hepburn system for the transcription of *hiragana* and *katakana*: palatalized sounds.

1.2.2.3 **Long Vowels**[14)]

The writing of long vowels (also called doubled vowels) depends on the origin of the word. For originally Japanese words (*kun*-readings), the same vowel is added to the vowel that should be elongated, such as かあ, みい or ふう.[15)] For words of Chinese origin (*on*-

14) The expression "long vowel" is only applied for vowels within words that are written by only one *kanji*. There is no vowel elongation with noun- or *kanji* combinations, if the first noun ends with the same vowel the second noun is starting with. Then, a short break in speaking is applied and the rules explained here are not applicable, e.g., in zinc oxide: さんかあえん (酸化亜鉛) *sankaaen* (酸化 *sanka* + 亜鉛 *aen*), dolomite: はくうんせき (白雲石) *hakuunseki* (白 *haku* + 雲 *un* + 石), stereoisomerism: りったいいせい (立体異性) *rittaiisei* (立体 *rittai* + 異性 *isei*). For the same reason, it is not called a long vocal if a Japanese expression is combined with a foreign word (in *katakana*) and two vowels meet, e.g., in aluminium chloride: えんかアルミニウム (塩化アルミニウム) *enkaaruminiumu* (塩化 *enka* + アルミニウム) or in molecular ion: ぶんしイオン (分子イオン) *bunshiion* (分子 *bunshi* + イオン).

15) There are only few words with long a or long i and they are all of Japanese origin. There is no *kanji* including long a or i. In addition, there are very few words of Japanese origin with a long e.

Table 1.8 Expression of long vowels.

Vowel	Chinese origin *on*-reading	Japanese origin *kun*-reading	Western origin (only *katakana*)
a		ああ	アー
i		いい	イー
u	うう	うう	ウー
e	えい	ええ	エー
o	おう	おお	オー

reading), *kana* in the u- and o-columns are doubled by adding u; and *kana* in the e-column have their vowels lengthened by adding i (Table 1.8).

Examples: long u: cast iron: ちゅうてつ = 鋳鉄 *chuutetsu*
electric current: でんりゅう = 電流 *denryuu*
long e: protein biosynthesis: たんぱくせいごうせい = 蛋白生合成 *tanpakuseigousei* (Chinese origin)
long o: many: おおい = 多い *ooi* (Japanese origin)
quantum number: りょうしすう = 量子数 *ryoushisuu* (Chinese origin)

Long vowels in foreign words that are written in *katakana* are formed by attaching a horizontal or vertical (vowel extender mark, 長音 *chouon*) line behind the vowel[16] in the center of the text, with the width of one *kana* character. It is written vertically in vertical text and horizontally in horizontal text as in the following examples:

citral: シトラール *shitora-ru*
strychnine: ストリキニーネ *sutorikini-ne*
safrole: サフロール *safuro-ru*
desiccator: デシケーター *deshike-ta-*
Foucault's pendulum: フーコー振子 *fu-ko-furiko*
Ziegler-Natta catalyst: チーグラーナッタ触媒 *chi-gura-nattashokubai*

If the word in *katakana* is derived from an original Japanese term with an own *kanji*, a long vowel is also expressed with an additional vowel such as for *hiragana*. If Japanese words are written with *kana*, usually *hiragana* are used. However, in scientific publications, *katakana* are often applied, especially for the names of the elements and chemical compounds.

16) The vowel extender mark chouon used in *katakana* is rarely used for *hiragana*. One example of this non-standard use is らーめん, which is also often written in *katakana*. The elongation line always follows the direction of the text: horizontal in left-to-right-writing and vertical in up-to-down-writing. If a Japanese word is written in *katakana*, long vowels are usually written as they would be in *hiragana*, but there are a few exceptions, such as for candle: ローソク (蝋燭 *rousoku*).

Example for long "e": silicon: ケイ素 = けい素 = 珪素 *keiso*

Examples for long "o": iodine: ヨウ素 = よう素 = 沃素 *youso*
kojic acid: コウジ酸 = こうじ酸 = 麹酸 *koujisan*
sodium borate: ホウ酸ナトリウム = ほう酸ナトリウム = 硼酸ナトリウム *housannatoriumu*
uric acid: ニョウ酸 = にょう酸 = 尿酸 *nyousan*

Also for words written in *katakana*, an additional vowel may be used instead of a vowel extender mark. Sometimes, this is a sign of an intermission regarding content or a short break in the flow of words, e.g., because the word is composed of two independent parts (this might not be called a real long vowel, as described for *hiragana* above).

Examples: phenylurethane: フェニルウレタン *feniruuretan* (フェニル *feniru* + ウレタン *uretan*)
fluorescein: フルオレシイン *furuoreshiin*
isooctane: イソオクタン *isookutan* (イソ iso + オクタン okutan)

For other examples, there is no hint for this kind of composition, though no vowel extender mark is used but an additional vowel, e.g.

sphaerite: スフェエライト *sufeeraito*
squalene: スクウアレン *sukuuaren*
mendelejevite: メンデレエフ石 *mendereefuseki*

There is a variation that is applied in this book in contrast to the usually applied revised Hepburn system: To guarantee a clear, accurate conversion of scientific expressions it was necessary to change the transcription of long vowels: Long vowels are expressed in *hiragana* by adding an additional *kana* of the same or of another vowel after the affected vowel (あ after *a*; い after *i*; お after *o*; う after *u*; お or う after *o*; い or え after *e*). The Hepburn system takes long vowels into account with a macron on top of the vowel: ē, ā, ī, ō and ū. But with a long "o"-sound, an additional お or う may be added. Using the Hepburn system, it cannot be decided which vowel had been added, as both sounds are written with ō. Therefore, in this book, all vowels that operate as elongation vowels are also transferred into Latin characters and no macrons are used. This ensures both compatibility with the Japanese dictionary and distinction between おお (*oo*) and おう (*ou*). This is also important for most computerized systems to properly convert keystrokes on a Roman keyboard into *kana* (if no characters from outside the ASCII character set may be used).

Long vowels in *katakana* are indicated with an elongation line behind the vowel. For the same reason, i.e., to stay close to the Japanese typeface, long vowels will not be expressed with a macron but with an elongation line behind the vowel, similar to the Japanese origin. For the differences between this book and Hepburn see the examples in Table 1.9.

1.2.2.4 **Other Aspects**

- Doubled consonants (also called long consonants or long consonants) appear in Japanese in front of fricatives or short stops of reading within one word. They are indicated by a

Table 1.9 Different transcription in this book and by Hepburn.

English word	Japanese	In this book	Hepburn system
bromine	臭素	*shuuka*	*shūka*
chain compound	鎖状化合物	*sajoukagoubutsu*	*sajōkagōbutsu*
copper sulfide	硫化銅	*ryuukadou*	*ryūkadou*
protease	プロテアーゼ	*purotea-ze*	*puroteāze*
indole blue	インドールブルー	*indo-ruburu-*	*indōruburū*
coulometer	クーロメーター	*ku-rome-ta-*	*kūromētā*

small *kana* つ or ツ (called 促音 *sokuon*) and by doubling the following consonant in *ro-maji*, e.g.:

in *hiragana*:	platinic acid: はっきんさん (白金酸) *hakkinsan*
	dehydration: だっすいそ (脱水素) *dassuiso*
in *katakana*:	nickel chloride: 塩化ニッケル *enkanikkeru*
	ytterbium: イッテルビウム *itterubiumu*

Originally, doubled consonants occur only for unvoiced ones (k, s, t, p, n, m). Doubled voiced consonants (gg, dd, bb, jj) can only be found in words with foreign origin (*gairaigo*), such as for Bragg angle: ブラッグの角 *buraggunokaku*, hybrid: ハイブリッド *haiburiddo*, Abbé condenser: あっべ集光器 *abbeshuukouki* and Wheatstone bridge: オイートストーン・ブリッジ *oi-tosuto-nburijji*.

- The nasal sonorant ん, ン cannot be at the beginning of a word. If it is directly followed by a vowel within a word, notably, n may not be merged with the vowel to get a *kana* of the n-row. The Hepburn system (but not this book) uses an apostrophe between n and the vocal in case the "n" is originally ん or ン.[10] For example: crotonaldehyde: クロトンアルデヒド *kurotonarudehido* (Hepburn: *kuroton'arudehido*).
- There are three particles that are written by *hiragana* but pronounced differently: を (*wo*), へ (*he*) and は (*ha*), pronounced o, e and wa. As is common in Japanese language learning materials for foreigners, they are romanized in this book, using their pronunciation.
- A small *katakana ke* ヶ (pronounced "ka", a simplified version of the *kanji* 箇), is used to indicate quantity such as period of months (e.g., five months: 五ヶ月 *gogetsu*).

1.2.3 *kanji* 漢字

1.2.3.1 Introduction to *kanji*[17]

The Japanese originally did not possess characters to write down their spoken language. The development of the current Japanese writing system started with the introduction of Chinese

17) 漢字 *kanji*, literally "Han characters", is the Japanese term for Chinese characters (Hanzi).

characters in the 4th–6th century by Buddhist monks from China via the Korean peninsula. Initially, *kanji* were used as phonetic characters independent of their meaning, but to express similar sounding Japanese syllable sounds. By this, each Japanese word could be written down, but the longer the word, the more characters were necessary (with each character consisting of few to many stroke numbers). Later, *kanji* were also incorporated into the way of writing relating to their meaning and independent of their phonetic properties to express Japanese words with the same or a similar meaning. In this case, they were read with the originally Japanese pronunciation for the word. During the following centuries, the set of Chinese characters used in the Japanese language constantly changed: New characters were introduced, existing *kanji* changed their shapes, characters were simplified, others got lost and new characters were invented.

After the Meiji Restoration at the end of the 19th century, the government, for the first time, regulated the writing system. As part of activities to modernize the country, the writing was facilitated. Many characters were simplified, the total number of *kanji* in circulation was reduced, difficult *kanji* were replaced by easy ones, the number or readings as well as the number of *kanji* taught in school were limited and standardized rules for the way of writing established. The current set of *kanji* in use[18] is the result of some main orthographic reforms until the 1950s. Less important changes have followed since. The official guidelines from the government are recommendations, hence many characters outside the standards are still known and commonly used. A Japanese person with an average education will know about 3000 characters, but the number of *kanji* that are regularly used in publications (fiction and basic technical literature) is estimated as between 6 000 and 7 000.[19]

Because of the above-described ways *kanji* has been adopted into Japanese, a single *kanji* has one or more different readings and may be used to write different morphemes. The decision as to which reading has to be chosen depends on the context and its use in combination with other *kanji* as well as on the intended meaning. Readings are classified[20] as either Chinese-derived *on*-reading (also Sinojapanese reading, 音読み *onyomi*) or Japanese *kun*-reading (also native reading, 訓読み *kunyomi*).[21]

The *on*-reading is based on the original Chinese pronunciation of the *kanji* when it was introduced in Japan. Because some characters were introduced at different times or from different parts of China, they also have multiple *on*-readings, such as for 度: *do*, *taku* and *to*.[22] If

18) In 1946, the Japanese government identified 1850 *kanji* as "current-use characters" (当用漢字, *touyou kanji*). The current official governmental guideline comprehends the following number of *kanji* for teaching in school and for use in ministerial publications:
- 1006 characters that Japanese children learn in elementary school (教育漢字 *kyouiku kanji*),
- 1945 characters (including *kyouiku kanji*) taught in high school (常用漢字 *jouyou kanji*),
- 983 additional characters (人名用漢字 *jinmeiyou kanji*) for use in people's names.

19) The 大漢和辞典 *daikanwa jiten*, one of the largest dictionary of *kanji* ever compiled, has about 50 000 entries. The recently published *kanji* compilation *kou kanwa jiten* includes about 20 000 characters in modern Japanese.

20) To distinguish *on*- and *kun*-readings, some dictionaries use *hiragana* for *kun*-readings and *katakana* for *on*-readings. In other books, *on*-readings are given in capital and *kun*-readings in lower-case letters.

21) There are *kanji* without *kun*-reading. Other characters have a *kun*-reading only in combination with other *kanji*, e.g., 方 *kata* in combination with verbs (*kun*-reading) or 御 *o* as honorific prefix.

22) *on*-readings are classified into four types: 呉音 (*goon*) were introduced from Japan during the 5th and 6th centuries from the Wu region (now Shanghai), 漢音 (*kanon*) were originally used in the Chinese standard language of the Tang Dynasty (7th to 9th century), 唐音 (*touon*) is related to the pronunciations of later dynasties and 慣用音 (*kanyouon*) denotes mistaken readings that have become accepted.

a *kanji* is part of a multi-*kanji* compound word, usually the *on*-reading has to be applied, because, beside the *kanji*, these words were also adapted from the Chinese language. This covers words that either did not exist in Japanese or could not be articulated in exactly the same way with native words.

The *kun*-reading is similar to the pronunciation of the native Japanese word for which the Chinese character was chosen because of its close meaning. There might be more than one or, also, no *kun*-reading for one *kanji*. This reading is chosen mainly for isolated *kanji* that are not part of a combination of *kanji*. They often function as simple nouns or inflected adjectives and verbs.

As an aid for correct pronunciation, small *kana* (振り仮名 *furigana*) may be printed next to a *kanji*, e.g., in texts for children and foreign learners, or in newspapers for rare or unusual readings and if characters are not included in the official lists of essential *kanji*.

Example:

さんか かんげんでンい
oxidation-reduction potential: 酸化還元電位 *sankakangendeni*

Usually *hiragana* is used, but when it is necessary to distinguish between *kun*- and *on*-reading, the Japanese pronunciations are written in *hiragana*, and the Chinese ones are written in *katakana*.

1.2.3.2 Structure and Elements of *kanji*

Simple *kanji* may be single pictograms, ideograms or phonograms, but most of the characters consist of different elements that might be classified into:

- a phonetic element indicating the sound or reading of a *kanji*, which is usually in the right part of the *kanji*;
- a radical indicating the general area of meaning of the character and dominantly positioned in the left part of the *kanji*;
- further elements modifying the meaning of the radical and determining the overall sense of the character. These elements might also be radicals, but only one is taken for the identification of the character.

The phonetic element exists as an own *kanji*. In more complex characters, it can take every position, but is often in the right, upper right and lower right part of the *kanji*. Usually, it does not contribute to the meaning of the character and only determines its pronunciation. However, the presence of such an element does not necessarily mean the character is read the same, as the reading may also determined by other elements or be totally different. As an example, the *kanji* for five, 五 *go*, is also the phonetic element in the following characters that are all read "*go*": 語, 梧, 伍, 吾 and 悟. The *kanji* 工 *kou*, meaning "work, manufacturing", is contained in 紅, 江, 控, 紅, 肛, 腔, 紅 and 虹, and all characters can be pronounced *kou*, but may also have additional *on*- and *kun*-readings.

Radicals are a set of characters that are used to classify *kanji* in the Chinese and Japanese language. The historical Chinese system consisted of 214 radicals; modern Japanese dictionaries use only 79 radicals. In opposition to phonetic elements, radicals take the dominant function in determining the *kanji*'s meaning, which is further modified in complex characters with additional radicals and elements. For instance, the radical 金 appears in over 140

characters and the meaning of many of them has some connection to metal, gold, other metallic elements or metal products in older times, like 鉄 (*tetsu*, iron), 鉦 (*shou*, fermium), 鈷 (*ko*, cobalt), 鉛 (*namari*, lead), 鉱 (*kou*, ore), 銭 (*sen*, money), 銀 (*gin*, silver), 銑 (*sen*, pig iron), 銃 (*juu*, gun), 銅 (*dou*, copper), 鋳 (*chuu*, cast metal), 錐 (*sui*, gimlet), 錫 (*suzu*, tin), 錆 (*shou*, rust), 錚 (*sou*, metallic sound), 錨 (*byou*, anchor), 鍵 (*kagi*, key), 鋼 (*hagane*, steel), 鎖 (*kusari*, chain), 鐘 (*shou*, bell). Important radicals that can be found in *kanji* for chemical terms and methods to identify *kanji* by radicals are described in Section 2.6.2.

1.2.3.3 **Classification of *kanji***

From the above-described characteristics and possible elements of a *kanji*, four basic ways to systematically order Chinese characters are possible and realized in dictionaries or other publications: Order by category, by reading, with radicals or by stroke counting. To identify characters in dictionaries, mainly the order by radicals is useful. Dictionaries intended to be used by native speakers require a knowledge of the reading. For trained users, the order by stroke counting may also be helpful. Classification by reading, with radicals or by stroke counting, is described in more detail in Sections 2.6.1 and 2.6.2.

Classification of *kanji* by category: Chinese characters are traditionally classified by their structure and function. This classification is not useful for the identification of the meaning as most of the characters belongs to one, and some to more than one, group. There are the following six categories (六書 *rikusho*):

- Pictrographic or diagrammatic characters 象形文字 (*shoukeimoji*), which are simple pictures or sketches of the object they represent, e.g., tree: 木 *ki* or mountain 山 *yama*.
- Ideographic characters and symbols 指事文字 (*shijimoji*) representing an abstract idea of their meaning, e.g., up: 上 *ue*, three: 三 *san*.
- Ideograms 会意文字 (*kaiimoji*), which are combination of pictograms that contribute to the overall meaning of the *kanji*, e.g., wood 森 *mori* (three trees), coal 炭 *tan* (mountain + slope + fire).
- Phonetic-ideographic and radical-phonetic characters 形声文字 (*tenchuumoji*), which consist of a combination of some elements, typically two components, one radical indicating the general area of meaning (semantic context) and one phonetic element showing its sound or reading, e.g., powder 粉 *fun*. This is the largest category with about 85% of the characters.
- Derived characters with extended usage 転注文字 (*tenchuumoji*) – a vaguely defined group of characters, of which the meaning has become extended or the character was used in a meaning derived but different from its original one.
- Phonetic loan characters 仮借文字 (*kashamoji*) have no relationship between their semantic and structure rather a phonetic that is derived from a former meaning.

1.2.3.4 ***kanji* Combination**

When the Japanese adopted Chinese writing and introduced it to their language, they did not only take over the Chinese characters with their meanings, they also adapted the Chinese method of forming complex new words by joining several characters together. The existing number of *kanji* is a high but limited source for words, but with the method for combining

Table 1.10 Examples of *kanji* combination with two characters.

First character	Second character	*kanji* combination
transform, make into 化 *ka*	+ science, learning, study 学 *gaku*	→ chemistry 化学 *kagaku*
original, fundamental 原 *gen*	+ child 子 *shi*	→ atom 原子 *genshi*
dividing 分 *bun*	+ child 子 *shi*	→ molecule 分子 *bunshi*
positive 陽 *you*	+ child 子 *shi*	→ proton 陽子 *youshi*
odor 臭 *shuu*	+ element 素 *so*	→ bromine 臭素 *shuuso*
take away 脱 *datsu*	+ water 水 *sui*	→ dehydration 脱水 *dassui*
acid 酸 *san*	+ transform make into 化 *ka*	→ oxidation 酸化 *sanka*
firefly 蛍 *kei*	+ light 光 *kou*	→ fluorescence 蛍光 *keikou*
turn, change 転 *ten*	+ place 位 *i*	→ rearrangement 転位 *teni*
red 赤 *seki*	+ external 外 *gai*	→ infrared 赤外 *sekigai*
agriculture 農 *nou*	+ medicine 薬 *yaku*	→ agricultural chemicals 農薬 *nouyaku*
try out 試 *shi*	+ effect 験 *ken*	→ experiment 試験 *shiken*
egg 蛋 *tan*	+ white 白 *paku*	→ protein 蛋白 *tanpaku*
steam 蒸 *jou*	+ departure, emit 発 *hatsu*	→ evaporation 蒸発 *jouhatsu*
color 色 *shiki*	+ element 素 *so*	→ pigment, dye 色素 *shikiso*
many 多 *ta*	+ form, shape 形 *kei*	→ polymorph 多形 *takei*

kanji, Japanese can express all kinds of complex contents. If new words emerged, e.g., by technological developments, *kanji* combinations could be created.

Words formed by combining several *kanji* and pronounced with sounds adopted from Chinese are called 熟語 *jukugo*. Most combinations are 漢語 *kango*, which are read with their *on*-readings.[23] In many cases, the meaning of a *kanji* combination can be derived from the meaning of the single characters, such as for the examples given in Table 1.10. This also works for terms consisting of more than two *kanji* (Table 1.11).

kanji or *kanji* groups can not be arbitrarily combined but the *kanji* order is relevant for the meaning. Sometimes the combination works only in one order, in other cases different meanings result. For instance, two terms can be formed by combining "chemistry" 化学 and "industry" 工業: chemical industry 化学工業 *kagakukougyou* and industrial chemistry 工業化学 *kougyoukagaku*.

In some cases, a scientific term can be written with two different *kanji* (or, in other words, there are two *kanji* with the same pronunciation expressing the same content), such as for 形 and 型 in following examples:

23) Very few *kanji* combinations are read with the *kun*-readings of the individual characters contained in them. Also, mixed *on*- and *kun*-readings are rare. Some combinations have irregular readings that are not related to the readings of the individual characters. Occasionally, there are combinations that can be read in two ways.

reduced form: 還元形 and 還元型 *kangengata*
boat form, boat conformation: 舟形 and 舟型 *funegata*

With the *kanji* combination, specific syllables may come together, which complicates the reading of the composition. In certain cases phonetic modifications are applied, facilitating the reading, i.e., the deletion of syllables and the insertion of a double consonant with ッ (especially if the first *kanji* ends with i or u of a syllable with a voiceless consonant and the reading of the second *kanji* begins with the same voiceless consonant). In addition, changes within the consonants system occur from voiceless to voiced consonants, e.g., from h to b or p.

Examples:
脱 *datsu* + 水 *sui* → dehydration: 脱水 *dassui*
測 *soku* + 光 *kou* → photometry: 測光 *sokkou*
物 *butsu* + 体 *tai* → substance, object: 物体 *buttai*
石 *seki* + 灰 *kai* → lime: 石灰 *sekkai*
熱 *netsu* + 湯 *tou* → boiling water: 熱湯 *nettou*
接 *setsu* + 着 *chaku* → adhesion: 接着 *secchaku*
弗 *futsu* + 素 *so* → fluorine: 弗素 *fusso*
六 *roku* + 百 *hyaku* → six hundred: 六百 *roppyaku*
三 *san* + 千 *sen* → three thousand: 三千 *sanzen*

Table 1.11 Examples of *kanji* combination with more than two characters.

First part	Second part	*kanji* combination
chlorine 塩素 *enso*	+ treat, deal with 処理 *shori*	→ chlorination 塩素処理 *ensoshori*
tall 高 *kou*	+ molecule 分子 *bunshi*	→ macromolecule 高分子 *koubunshi*
research 研究 *kenkyuu*	+ room 室 *shitsu*	→ research laboratory 研究室 *kenkyuushitsu*
living creature 生物 *seibutsu*	+ engineering 工学 *kougaku*	→ biotechnology 生物工学 *seibutsukougaku*
atom 原子 *genshi*	+ nucleus 核 *kaku* + chemistry 化学 *kagaku*	→ nuclear chemistry 原子核化学 *genshikakukagaku*
add 加 *katsu*	+ water 水 *sui* + decomposition 分解 *bunkai*	→ hydrolysis 加水分解 *kasuibunkai*
hydrogen 水素 *suiso*	+ linkage 結合 *ketsugou*	→ hydrogen bond 水素結合 *suisoketsugou*

1.2.3.5 **Combination of *kanji and kana***

Nouns may not only be formed by combining several *kanji* but also by joining *kanji* and *kana*, especially with *katakana* in scientific terms. The *kanji* part can consist of a single character as well of a *kanji* combination. In more complex terms, several *katakana* may also occur between *kanji* or some *kanji* are placed between two *katakana* expressions.

Examples:
palmitic acid ($CH_3(CH_2)_{14}COOH$): パルミチン酸 *parumichinsan*
Raman effect: ラマン効果 *ramankouka*

magnesium chloride ($MgCl_2$):	塩化マグネシウム *enkamaguneshiumu*
hydrogen cyanide (HCN):	シアン化水素 *shiankasuiso*
Boltzmann constant:	ボルツマン定数 *borutsumanteisuu*
fluorescent screen:	螢光スクリーン *keikousukuri-n*
phenyl isocyanate (C_6H_5NCO):	イソシアン酸フェニル *isoshiansanfeniru*
phthalic anhydride ($C_8H_4O_3$):	無水フタル酸 *musuifutarusan*

1.2.4 Transcription of Foreign Words into Japanese Phonology

If terms from foreign languages are intended to be written with Japanese characters, they have to be expressed by the existing syllables. The sounds are transcribed with the syllable that is as close as possible to the phonology of the foreign sound. One of the most characteristic differences between western languages and Japanese is the missing Japanese equivalent for consecutive consonants. To solve this problem, a syllable of the u-row (sometimes also of i- or o-row) is used and the ending vowel is spoken weakly or not at all. Consonants at the end of a foreign word are transcribed in a similar way, mainly ending with a syllable of the u-row or, if the foreign expressions ends with "t" or "d", by ト or ド.

Examples:	magnesium:	マグネシウム *maguneshiumu*
	benzyl alcohol:	ベンジルアルコール *benjiruaruko-ru*
	dextrin:	デキストリン *dekisutorin*
	redox reaction:	レドックス反応 *redokkusuhannou*
	leucopterin:	ロイコプテリン *roikoputerin*
	lactose:	ラクトース *rakuto-su*
	methylate:	メチラート *mechira-to*
	polyamide:	ポリアミド *poriamido*

Especially within the scientific and technical language, many words have to be expressed with sounds that are not represented by the syllables in the 50-sound-matrix or the above-described variations (clouded sounds) and combinations (palatalized sounds). Because of this, and parallel to the increasing importance of literature from abroad during the last few decades, new combinations of syllables have been developed. They are written like the palatalized sounds with small characters of vowels, such as ディ in ディアステレオメル *diasutereomeru* (diastereomer), フォ in フォスゲン *fosugen* (phosgene, $COCl_2$) or ウェ in カルウェオール *karuweo-ru* (carveol, $C_{10}H_{16}O$), or with small characters of the y-row, such as デュ in デュロキノン *dyurokinon* (duroquinone, $C_{10}H_{12}O_2$). In this way, some gaps in the sound system concerning existing combinations of consonants and vowels were also closed. For instance, "tsu" is written as ツ, but "tsa", "tsi", "tse" and "tso" could not be expressed. The same applies with "wa", which is written as ワ, and the missing characters for "wi", "wu", "we" and "wo". For the sounds in the t-row, タ, テ and ト exist, but there was no way to write "ti" and "tu" because the two other characters in the row (チ and ツ) were read differently.

Even a new clouded character ヴ was introduced for foreign sounds starting with "v". ヴ can be combined with small characters of vowels, e.g., ヴァ in vanadium: ヴァナジウム *vanajiumu* and ヴォ in flavone フラヴォン *furavon*. As all new characters and character combinations are only used to support the transcription of foreign words, they can only be found for *katakana* (Fig. 1.4). Because there are no strict rules regarding the use of *kana* to express foreign sounds, other combinations can also be found.

	new a-sounds	new i-sounds	new u-sounds	new e-sounds	new o-sounds
combinations with the character ヴ	ヴァ *va*	ヴィ *vi*	ヴ *vu*	ヴェ *ve*	ヴォ *vo*
	ヴャ *vya*		ヴュ *vyu*		ヴョ *vyo*
new combinations in the vowel-row				イェ *ye*	
		ウィ *wi*	ウゥ *wu**	ウェ *we*	ウォ *wo*
new combinations in the k-row	クァ *kwa*	クィ *kwi*	クゥ *kwu**	クェ *kwe*	クォ *kwo*
	グァ *gwa*	グィ *gwi*	グゥ *gwu**	グェ *gwe**	グォ *gwo**
new combinations in the s-row				シェ *she*	
				ジェ *je*	
new combinations in the t-row		ティ *ti*	テゥ *tu** トゥ *tu* テュ *tyu*		
	ツァ *tsa*	ツィ *tsi*		ツェ *tse*	ツォ *tso*
				チェ *che*	
	デャ *dya*	ディ *di*	デゥ *du** ドゥ *du* デュ *dyu*		デョ *dyo*
new combinations in the h-row	ファ *fa*	フィ *fi*		フェ *fe*	フォ *fo*
	フャ *fya*	ヒィ *hyi**	フュ *fyu*	ヒェ *hye*	フョ *fyo*

Fig. 1.4 Expression of foreign sounds with new *katakana* and *katakana* combinations. New combinations marked with an asterisk are basically possible but not commonly accepted. More new combinations can be found on the internet (e.g., at http://www.roomazi.org and http://www.wul.waseda.ac.jp/opac/aboutw/roman/).

The small *tsu*, which is used in Japanese words to indicate double consonants, may be used in places that have no equivalent in native sounds, e.g., to express "x", such as in redox potential: レドックス電位 *redokkusudeni*. It is often used for the sound "ch", which is common in German names (e.g., Esbach's reagent: エスバッハ試薬 *esubahhashiyaku*).

The sounds represented by "r" and "l" in English are unknown in the Japanese language. The Japanese sounds expressed by *kana* of the r-row (ラリルレロ) start with a short roll of a trilled "r" which is a quick flap of the tongue against the gum. However, these *kana* are usually used to transcribe both, r- and l-sounds of foreign terms.

It has to be kept in mind that there is no standardized or even generally accepted form of romanization for the new *kana* combinations and the use of the small ッ. Even with the increased number of sounds that can be expressed by using *katakana*, it is still not always easy to carry out a proper transcription. In the end, it is the understanding of the author and his personal phonetic perception of a word. This leads to different possibilities for its transformation into the Japanese syllable system. Table 1.12 gives some ideas of possibilities for expressing foreign sounds for which no traditional Japanese syllable in the 50-sound-matrix exists, either by known *katakana* or with the above-described new *katakana* combinations. Because the transcription is based on the sounds and not on the writing, the chosen *katakana* syllable can not always be easily foreseen by the isolated letter in the English word, and the sounds before and behind have to be taken into account.

As can be seen, for many sounds there is more than one possibility for transferring them into Japanese writing. Because many scientific words are not often used, they do not have a

Table 1.12 Examples for the expression of foreign sounds with *katakana* syllables.

Foreign sound		Transcription	Examples
a-sounds	ca	カ, キャ	carrier: キャリヤー *kyariya-*
i-sounds	shi, schi, dschi, si, sy, ci, cy, zi, zy, thi, thy, ty	シ, チ, ジ	shikimic acid: シキミ酸 *shikimisan*; cresyl: クレシル其 *kureshiruki*
	ci, ti, ty	チ, ティ	mesitylene: メシチレン *meshichiren*; myristic acid: ミリスティン酸 *mirisutinsan*
e-sounds	je, ye	イエ	meyerhofferite: マイエルホッフェル石 *maieruhofferuseki*
	she	セ, シェ	shellac: セラック *serakku;* echellite: エシェル石 *esheruseki;* shaker: シェーカー *she-ka-*
	eu	syllable o-column + イ	leucine: ロイシン *roishin*

Table 1.12 *(continued)*

Foreign sound		Transcription	Examples
German umlaute	ä	syllable from e-column	jäneckite: エーネカイト *e-nekaito;* Gräbe-Ullmann synthesis: グレーベウールマン合成 *gurebeu-rumangousei*
	ö	syllable from e-column	Mössbauer spectrum: メスバウアースペクトル *mesubaua-supekutoru;* trögerite: トレゲル石 *toregeruseki;* Brönsted acid: ブレーンステズ酸 *bure-nsutezusan*
	ü	syllable from i-column with small ユ*;* syllable from u-column	hüttenbergite: ヒュッテンベルグ石 *hyuttenberuguseki;* Geiger–Müller counter: ガイガーミュラー計数管 *gaiga-myura-keisuukan;* Büchner funnel: ブッヒナー吸引漏斗 *buhhina-kyuuinrouto*
d-sounds	di	ディ, ジ	diastereomer: ディアステレオメル *diasutereomeru;* acridine: アクリジン *akurijin*
	du	ズ, シュ, ジュ, ヂュ	dulcin: ズルチン *zuruchin;* duralumin: ジュラルミン *jurarumin;* isodurene: イソヂュロール *isodyuro-ru*
hu		フ	humic acid: フミン酸 *huminsan*
l-sounds	la	ラ, ロ, レ	riboflavine: リボフラビン *ribofurabin*; laser: レーザー *re-za-*; lawsonite: ローソン石 *ro-sonseki*
	le	レ, ラ	lens: レンズ *renzu*; roller mill: ローラーミル *ro-ra-miru*
	li	リ	linolenic acid: リノレン酸 *rinorensan*
	lo	ロ	linalool: リナロール *rinaro-ru*
	lu	ル	luminol: ルミノール *rumino-ru*
f- and ph-sounds	fa, pha	ファ, ハ	farnesol: ファルネゾール *farunezo-ru*; rhodophane: ロドファン *rodofan*
	fi, phi	フィ, ヒ, ファ	olefin: オレフィン *orefin;* fiber: ファイバ *faiba*
	fe, phe	フェ, ヘ	phenyl: フェニル *feniru*
	fo, pho	フォ, ホ	iodoform: ヨードフォルム *yo-doforumu;* foil: ホイル *hoiru*

Table 1.12 *(continued)*

Foreign sound		Transcription	Examples
pf-sounds	pfe	ペ, フェ	cupferron: クペロン *kuperon* or クッフェロン *kufferon;* kaempferol: ケンフェロール *kenfero-ru;*
	pfu, pf + consonant	プ, フ	Schoellkopf's acid: シェールコップの酸 *she-rukoppunosan;* hoepfnerite: フェフナー石 *fefuna-seki*
q-sounds	qua	クァ	equatorial bond: エクアトリアル結合 *ekuatoriaruketsugou;* squalane: スクアラン *sukuaran*
	que	クェ, クエ, クウェ, ケ	sequencing: シークエンシング *shi-kuenshingu;* quebrachite: クウェブラキト *kuweburakito;* quercitol: ケルシット *kerushitto*
	qui	クィ, クイ, キ	equilenine: エクイレニン *ekuirenin;* orthoquinone: オルトキノン *orutokinon*
	quo	クォ, クオ, コ	aliquot: アリコート *ariko-to*
ch at word end	-ach	ッハ	Wallach reaction: ヴァラッハの反応 *varahhanohannou;* weisbachite: ワイスバッハ石 *waisubahhaseki*
	-ich	ッヒ	Mannich reaction: マンニッヒ反応 *mannihhihannou;* Ehrlich's reagent: エールリッヒ試薬 *e-rurihhishiyaku*
	-och	ッホ	Koch's acid: コッホ酸 *kohhosan*
t-sounds	ti	ティ, チ	antimony: アンチモン *anchimon;* elastin: エラスティン *erasutin*
	tu	ツ, チュ	galacturonic acid: ガラクツロン酸 *garakutsuronsan;* spatula: スパチュラ *supachura*
	voiceless th	s- and t-rows	methyl: メチル *mechiru;* threonine: スレオニン *sureonin;* ether: エーテル *e-teru*
	voiced th	z-row	rutherfordium: ラザホージウム *razaho-jiumu*
v-sound	va	ワ, バ, ヴァ, ウア	vaseline: ワゼリン *wazerin*; mevalonic acid: メバロン酸 *mebaronsan*; rivanol: リヴァノール *rivano-ru*
	ve	ベ, ヴェ, ウエ, バ	veratrole: ベラトロール *beratoro-ru*; flaveanic acid: フラヴェアン酸 *furaveansan*; receiver: レシーバー *reshi-ba-*

Table 1.12 *(continued)*

Foreign sound		Transcription	Examples
	vi	ビ, ヴィ, ウイ	flavine: フラビン *furabin*; pyruvic acid: ピルヴィン酸 *piruvinsan*; virus: ウイルス *uirusu*
	vo	ボ, ヴォ, ウオ	flavone: フラボン *furabon;* volt: ヴォルト *voruto*
	vu	ブ, ヴ	levulinic acid: レブリン酸 *reburinsan;* levuline: レヴリン *revurin*
w-sounds	we	ベ, ウェ, ウエ, ワエ	veronal: ヴェロナール *verona-ru;* websterite: ウエブスター石 *uebusuta-seki*
	wi	ビ, ウィ, ヴィ, ワイ	wittichenite: ウィチヘン鉱 *wichihenkou;* Neuwied green: ノイヴィードグリーン *noivi-doguri-n;* wine yeast: ワイン酵母 *wainkoubo*
	wo	ボ, ウォ, ウ, ワオ	wolfram: ウォルフラム *worufuramu;* Wood's metal: ウッド金 *uddokin*
	wu	ブ, ヴュ, フ, ウ, ウゥ, ワウ	wurtzite: ウルツ鉱 *urutsukou;* Wurtz synthesis: ヴュルツの合成法 *vyurutsunogouseihou*
x-sounds	xa	クサ, キサ	siloxane: シロクサン *shirokusan;* rhodoxanthin: ロドキサンチン *rodokisanchin*
	xe	クセ, キセ	hexene: ヘキセン *hekisen;* siloxene: シロクセン *shirokusen*
	xi, xy	クシ, キシ	lipoxygenase: リポキシゲナーゼ *ripokishigena-ze;* aloxite: アロクシット *arokushitto*
	xo	クソ, キソ	lyxose: リキソーゼ *rikiso-ze;* hexose: ヘクソーゼ *hekuso-ze*
	xu, -x	クス, キス	dextrin: デキストリン *dekisutorin*; redox reaction: レドックス反応 *redokkusuhannou*

commonly accepted way of being written and the choice of the *katakana* syllables depends on the opinion of the author. Consequently, different spellings for many foreign scientific and technical terms can be found in different publications. The number of different spellings is even increased because, in English, different expressions may, sometimes, also be used and terms are also adopted from other languages, in particular from German, such many element names, e.g., sodium: ナトリウム (from the German "Natrium"), potassium: カリウム (from "Kalium") and chromium: クロム (from "Chrom"). The following examples demonstrate the variety of possible translations.

benzene:	ベンゼン, ベンゾール
virus:	ヴァイラス, ヴィールス, ウイルス, ビールス
spectrum:	スペクトル, スペクトラム
molar:	モーラル, モル
millimeter:	ミリメーター, ミリメートル
Cannizzaro reaction:	カニザロー反応 *kanizaro-hannou* カニッツァーロ反応 *kanissha-rohannou* カニシャロ反応 *kanisharohannou* カニッシャロ反応 *kanissharohannou*

The following examples show the critical areas that cause most of the different transcriptions that can be found for chemical terms:

- Sounds that begin with "f …" or "v …" in English can be expressed with the new characters ヴ, ファ, フィ, フェ and フォ but, usually, the written form with an alternative transcription, i.e., with syllables of the h- and b-rows, can also be found in the literature, such as for:

"va"	valine:	ヴァリン or バリン
	ovalbumin:	オヴァルブミン or オボアルブミン
"vi"	vinyl:	ヴィニル or ビニル
	flavine:	フラヴィン or フラビン
"ve"	biliverdin:	ビリヴェルヂン or ビリベルジン
"vo"	sulfonic acid:	スルフォン酸 *surufonsan* or スルホン酸 *suruhonsan*
	Avogadro's number	アヴォガドロ数 *avogadorosuu* or アボガドロ数 *abogadorosuu*
	flavone:	フラヴォン or フラボン
	formaldehyde:	フォルムアルデヒド or ホルムアルデヒド
	phospholipase:	フォスフォリパーゼ or ホスフォリパーゼ
	chloroform:	クロロフォルム or クロロホルム

- If the names of chemical compounds end with -ose, e.g., sugars or some plastics, the written form may end with ゼ or by ス, e.g.:

arabinose:	アラビノーゼ or アラビノース
hexose:	ヘキソーゼ or ヘキソース
viscose:	ビスコース or ビスコーゼ
cellulose:	セルロース or セルローゼ

- For the sounds "lo" and "ro", in some cases, the two transcription possibilities ロ or ル are used equivalently, e.g.:

acrylonitrile	アクリルニトリル or アクリロニトリル
chlorobenzene:	クロロベンゾール or クロルベンゾール

fluorosilicic acid: フルオルケイ酸 *furuorukeisan* or フルオロケイ酸 *furuorokeisan*

- English terms having an e-sound at the beginning may be translated with a *kana* of the a- or e-column, e.g., for berkelium: バーケリウム or ベーケリウム.
- It is not always clear if a vowel is long or short; therefore, some words can be found with or without a vowel extender mark (長音 *chouon*) or with an additional character for the same vowel:

Examples:
austenite: オーステナイト or オウステナイト
iodal: ヨーダール or ヨーダル
lipoxygenase: リポオキシゲナーゼ or リポキシゲナーゼ
isoxazole: イソオキサゾール or イソキサゾール

- A consonant and a following vowel in a foreign term may be phonetically combined to one syllable, e.g., s + a = サ. Alternatively, the consonant is expressed by a syllable of the u-row and the vowel stays independent (e.g., s + a = スア). The second way is used if the term is a word composition and the border is just between the consonant and the syllable. For instance, the term "propyl alcohol", which consists of two parts, could not reasonably be transcribed as "プロピラルコール" because the word "alcohol" can hardly be recognized. Instead, プロピルアルコール is used. As the pronunciation of both transcriptions is different, it is usually clear which method has to be applied. However, for some English terms two Japanese expressions can be found, even if one, for the reason described above, does not properly reflect the English reading (Table 1.13).
- For foreign words that contain "xa" or "xo", often, two Japanese forms can be seen: one in which the "x ..." is transcribed with キ and another with ク, as in following examples:

cyclohexane: シクロヘキサン or シクロヘクサン
oxonium salt: オキソニウム塩 or オクソニウム塩
exopeptidase: エキソペプチダーゼ or エクソペプチダーゼ
oxaminic acid: オキサミド酸 *okisamidosan* or オクザミド酸 *okuzamidosan*
dioxan: ジオキサン or ジオクザン
hexanol: ヘキサノール or ヘクサノール

Table 1.13 Examples of different transcriptions.

	Combined syllable	Consonant and vowel separated
chloramine:	クロラミン *kuroramin*	クロルアミン *kuroruamin*
rosaniline:	ローザニリン *ro-zanirin*	ローズアニリン *ro-zuanirin*
butaldehyde:	ブチラルデヒド *buchirarudehido*	ブチルアルデヒド *buchiruarudehido*
benzamide:	ベンザミド *benzamido*	ベンズアミド *benzuamido*

- As the pronunciation of a foreign word may not be always clear, voiceless and voiced syllables can be found in same expressions, e.g.:

sarcosine:	サルコシン or ザルコシン
farnesol:	ファルネソール or ファルネゾール
oxalacetic acid:	オキサロ酢酸 *okisarosakusan* or オキザロ酢酸 *okizarosakusan*
resorcinol:	レソルシノール or レゾルシノール

- The transformation of i- and similar sounds is the source of most of the non-uniform appearance of scientific terms, because there are many i-sounds in chemical expressions and also many similar possibilities to transcribe. Typical similarities that occur are ディ vs. ジ, ティ vs. チ, ジ vs. チ, ジ vs. ギ or シャ vs. ジヤ to give some examples. They are used, for instance, in the following words:

stigmasterol:	スチグマステロール or スティグマステロール
benzidine:	ベンジジン or ベンチジン
abscisic acid:	アブシシン酸 *abushishinsan* or アブシジン酸 *abushijinsan*
butyne:	ブチン or ブテイン
dysprosium:	ジスプロシウム or ディスプロシウム
elastin:	エラスチン or エラスティン
brucine:	ブルシン or ブルチン
fluorescein:	フルオレシイン or フルオレセイン
gibberellin:	ギベレリン or ジベレリン
anthraquinone:	アントラキノン or アントラヒノン
potential:	ポテンシャル or ポテンジヤル
amidine:	アミジン or アミディン

In addition, other vowels or consonants and whole syllables may be transcribed with different characters. As with most of the scientific terms, there is no clear spelling in the Japanese language – it is up to the authors to find a proper transformation of foreign expressions into Japanese.

Examples of different vowels:

leucoaniline:	リュコアニリン or ロイコアニリン
alkylate:	アルキラート or アルキレート
phenetidine:	フェニチジン or フェネチジン
burette:	ビュレット or ブレット

Examples of different consonants or complete syllables:

benzhydrol	ベンズヒドロール or ベンツヒドロール
Brönsted acid:	ブレンステット酸 *burensutettosan* or ブレーンステズ酸 *bure-nsutezusan*

proinsulin:	プロインスリン or プロインシュリン
cellulose:	セルロース or シェルロース
sodium amalgam:	ナトリウムアマルガム or ナトリウムアムルガム
cupferron:	クッフェロン or クペロン
duralumin:	ジュラルミン or デュラルミン
carbene:	カルベン or カーベン

In some cases, the transcription of different foreign terms leads to the same Japanese word and it has to be decided by context which expression is intended by the author. Examples of this problem are:

ベンジル *benjiru*	benzyl (-$CH_2C_6H_5$) or benzil ($C_6H_5COCOC_6H_5$)
アスタチン *asutachin*	astatine (At, element 85) or astacine ($C_{40}H_{48}O_4$)
フレーム *fure-mu*	flame or frame
カプリン酸 *kapurinsan* and カプリル酸 *kapurirusan*	capric acid [$CH_3(CH_2)_8COOH$] or caprylic acid [$CH_3(CH_2)_6COOH$]
コラミン *koramin*	colamine ($H_2NCH_2CH_2OH$) or coramin ($C_{10}H_{14}ON_2$)