1

Introduction

Today the history of science is becoming recognised as an integral part of the whole history of human civilisation; an essential ingredient in the development of human culture. Tracing its growth has occupied a host of scholars who, almost without exception, have worked backward from the science and technology of today to its cradle in the thought and practice of Mediterranean antiquity. They have uncovered an evolution starting from the Sumerians, Babylonians and Egyptians, an evolution that led to the growth of scientific thought and observation of the natural world among the Greeks and in the Roman Empire. From here they have tracked its transmission to mediaeval Europe by way of Islam, and seen how its arrival led to the revolutionary changes that occurred in the wake of the Renaissance.

To a great extent, all this is something new. A century and a half ago, the scientific contributions of the Sumerians and Babylonians, for instance, were quite unsuspected. In 1837, when William Whewell wrote his memorable *History of the Inductive Sciences*, he could display a bland unconsciousness of any contributions by other civilisations to the scientific culture of the modern West, and do so without criticism. Yet now the situation is somewhat different; not only are the Babylonians and Sumerians recognised, but there is also some appreciation of the legacy we owe to India. All the same, there is still one vast gap in our understanding of our debts to other civilisations – the contribution from Asia, and especially the northernmost of its two oldest civilisations, the Chinese. This scientific heritage is the theme of this book.

Precisely what the Chinese contributed to science and technology as well as to scientific thought depended, as will become clear, on the historical period being considered. In ancient and mediaeval times it was of immense importance, but its character changed after the visit of Jesuit missionaries to Peking early in the seventeenth century, and it gradually fused into the universal science that has continuously

developed over the last three hundred years. Before the Jesuit arrival Chinese science was quasi-empirical – based on observation and experience, with theory in a comparatively undeveloped state. Yet, even so, the Chinese succeeded in anticipating many scientific and technical discoveries of the Greeks; they managed to keep pace with the Arabs who had all Greek knowledge at their disposal; and between the first and thirteenth centuries A.D. reached a level of scientific knowledge unapproached in the West.

To those of us brought up in a culture which has the classical world as its foundation, the Chinese achievement may well seem nothing less than astonishing. Certainly there was no rise of modern science in sixteenth-century China as occurred in Europe from this time onwards, while it is also true that the Chinese suffered from a weakness in theoretical ideas and a lack of deductive geometry – the very essence of precision in Greek science. Yet in spite of all this we see in ancient China a society more amenable to the application of science than was the case in Greece, in Rome, or even in mediaeval Europe. What is more, in China there developed an organic philosophy of Nature that closely resembles that which modern science has been obliged to adopt after three centuries of scientific materialism. How this could be under the circumstances is one of the questions that will be discussed.

To appreciate what the Chinese accomplished can be difficult, even today, because unfortunately many misconceptions about Chinese discoveries and scientific development still exist. The old legendary chronology relayed by the seventeenth-century Jesuits lives on, with the result that either too much or too little is ascribed to East Asian origin, and Chinese as well as Western scholars have sometimes been known to ignore, or at least pay scant attention to, achievements made early on in China. Frequently, too, legends themselves are unrecognised as such, with the result that worthwhile evidence is glossed over. Nevertheless, most Europeans are at least dimly aware of a vast and complex civilisation no less intricate and rich than their own, at the other end of the huge Euro-Asian land mass. The main barrier to a more intimate understanding, especially when it comes to Chinese science and technology, has been the Chinese use of ideographic characters. Inevitably most sinologists have been of literary tastes and training and, in consequence, there is a vast amount of scattered literature that has hardly been surveyed, let alone studied in detail.

In one sense, then, this book can be no more than a reconnaissance, and a brief reconnaissance at that, but at least it is based on a detailed approach to some sources made by Joseph Needham and his collaborators. Uniquely qualified as a research scientist and historian of science familiar with the country and its language, and in contact with many

Chinese scientists and scholars, he has been able to study the original Chinese texts from which translations have been made as well as those for which no translations have so far been available. This has enabled him to correct mis-translations and misconceptions. For example, in the only complete translation of the important *Mo Tzu* (Book of Master Mo Ti) from the fourth century B.C., there is a reference to textile manufacture. The accepted translation runs: 'Women work at variegated embroidery: men work at the weaving of stuffs with inserted patterns.' Taken at its face value this looks like a reference to the drawloom; only a careful study of the text shows that nothing is said of inwoven figured patterns. The author is, in fact, referring to 'cut and engraved' work; in other words to a kind of brocade made by stitching coloured threads into an already woven fabric. Thus the drawloom is not concerned and one cannot, therefore, claim evidence for its invention in the fourth century B.C. on this ground. But other evidence does date back some form of it to that time. Plenty of other examples could be quoted but this alone may serve to underline the dangers that face anyone unfamiliar either with the language or with the techniques involved.

Here it should be emphasised that although ninety per cent of the work as published has been written by Joseph Needham, the project, he tells me, would have been absolutely impossible without the partnership of a number of colleagues. From 1948 to 1958 his chief collaborator was Wang Ching-Ning (Wang Ling), now professor at Canberra in Australia, a historian and mathematician; and since 1958 an even older friend, Lu Gwei-Djen, a specialist on the history of medicine and biology. Several other Chinese scholars have also collaborated, notably Ho Ping-Yü of Brisbane, historian of astronomy, alchemy and early chemistry, Lo Jung-Pang in California who contributes, for instance, the chapter on the salt industry and the epic of deep borehole drilling, Chhien Tshun-Hsün at Chicago, one of the best authorities in the world on the history of paper and printing, and Li Li-Shêng, studying the traditional chemical industries. As time has gone on it has been necessary to enlarge more and more the circle, so that textile technology, for example, is now in the charge of Ohta Eizō in Kyoto, and ceramics undertaken by Chhü Chih-Jen in Hong Kong. Western collaborators have also participated in the project, notably Kenneth Robinson, who drafted the physical acoustics section, Derk Bodde, who is surveying the world-outlook of the traditional Chinese literati, and Janusz Chmielewski who is writing the important study of Chinese logic. This is by no means a full list of all collaborators and participators, but it may give some idea of the scope of the team-work that has been involved.

Like the full seven-volume study in perhaps twenty separate parts that

Needham and his collaborators are writing and of which ten parts have now appeared, this abridgement may be, it is hoped, a contribution to international understanding. The genius of the Chinese people has so often been represented to the West as primarily artistic and agricultural: the long succession of technical discoveries taken over from China during the first thirteen centuries of our era has been almost entirely overlooked. How much this genius may have influenced the seventeenth-century scientific revolution in the West has yet to be fully assessed. Even so, one must recognise that all the foundations of our knowledge of electromagnetics were laid in China, and Europe at the turning-point was greatly affected by the Chinese conviction of the infinity of the universe. Whatever the final answer may be, a knowledge and appreciation of the achievements of the scholars and craftsmen of other cultures can only lead to a growth of mutual comprehension. After all, we must be on our guard against the temptation of thinking that the whole of modern civilisation began with Renaissance figures like Galileo and Vesalius in the sixteenth and seventeenth centuries, and the conclusion that 'Wisdom was born with us'. There was a Chinese contribution to Man's understanding of Nature and his control over it, and it was a great one. No single people or group of peoples has had a monopoly in contributing to the development of science. All achievements should be recognised, and celebrated, if we are to move on our way to a universal brotherhood of Man.

2

The Chinese language

Before describing any of the achievements of Chinese science and technology, it is necessary to have some kind of cultural background against which they can be set. That is the purpose of this volume – to provide a backcloth for the scientific details that the remaining volumes will contain. To form this background it will be best if we glance first at the geography of China, then at its history, and next consider what opportunities there were for an interchange of ideas between Eastern Asia and the West. We shall then be in a position to trace the origin and development of scientific thought in Chinese philosophy – something that is vital if we are to see the inventive genius of China in anything like a proper perspective.

Throughout this volume we shall, of course, have occasion to use Chinese names and refer to Chinese words, so as a preliminary to our background reconnaissance, it is desirable to spend a few moments on the Chinese language itself. To begin with we shall need to be able to transform Chinese words into our own romanised script so that we can write them and, at the same time, get some idea of their pronunciation. Since Chinese is a tonal language where the tone can give different meanings to a single word, any system we adopt is bound to be at best only approximate, and there has been, and still is, controversy about how romanisation should be done. A large number of competing systems grew up, some stemming from a romanisation of the Cantonese dialect once used by the Chinese Post Office, others based on phonetic and linguistic studies. Sir Thomas Wade in 1867 tried to formulate an internationally acceptable system, but French and German sinologists evolved methods based on their own way of pronouncing the Latin alphabet. Nevertheless the Wade–Giles system, so called because it was modified and adopted by H. A. Giles in the 1890s, is that most widely used in the Western world today. Its chief rival perhaps is the Phin-yin system, an alternative introduced officially by the Chinese Government

Table 1. *Romanisation of Chinese sounds*

The 24 Consonantal Initials

Wade–Giles system	Phin-yin system	System adopted in this book	Pronunciation
ch-	*zh-* or *j-*	*ch-*	between *chair* and *jar*
ch'-	*ch-* or *q-*	*chh-*	as in *much harm*; strongly aspirated
f-	*f-*	*f-*	as in *farm*
h-	*h-*	*h-*	Gaelic *-ch*, as in *loch*
hs-	*x-*	*hs-*	a slight aspirate preceding and modifying the sibilant, the latter being the stronger. Try dropping the first *i* in *hissing*
j-	*r-*	*j-*	French *j-* as in *je* or *jaune*. A *j-* pronounced at the front of the mouth gives an impression of *r-* (cf. Polish *rz-*)
k-	*g-*	*k-*	between *k* and *g*
k'-	*k-*	*kh-*	*k* strongly aspirated, as in *kick hard*
l-	*l-*	*l-*	as in English
m-	*m-*	*m-*	as in English
n-	*n-*	*n-*	as in English
p-	*b-*	*p-*	like *b* in *lobster*, or Fr. *peu*
p'-	*p-*	*ph-*	as in Irish dialectal pronunciation of *party* or *parliament*, more strongly aspirated than anything in French, German or English
s-	*s-*	*s-*	as in English
sh-	*sh-*	*sh-*	as in English
ss-	*s-*	*ss-*	only occurs with *-ŭ*, q.v.
t-	*d-*	*t-*	nearer *d-* than *t-* in English but not quite *d-*
t'-	*t-*	*th-*	strongly aspirated *t-*, as in Irish dialectal pronunciation of *torment*
ts-	*c-*	*ts-*	as in *jetsam*, *catsup*
ts'-	*z-*	*tsh-*	*ts-* strongly aspirated, as in *bets hard*
tz-	*c-*	*tz-* \	only occur with *-ŭ*, q.v. Sounds near to *ts'*
tz'-	z-	tzh-/	
w-	*w-*	*w-*	as in English, but faint
y-	*y-*	*y-*	as in English, but faint

The 42 Vowel, Diphthong and Consonant Finals

-a or *a*	*as in father*, the 'broad' *a*
-ai	as in *aye*, or better Italian *hai*, *amai*. English *why*
-an	somewhat like Dutch *Arnhem* pronounced by an Englishman, the *r* being unsounded. Or German *ahnung*
-ang	the *-ng* has a partly nasalising and partly gutturalising influence on the vowel. Something like German *angst*
-ao	as in Italian *Aosta*, *Aorno*. Not so fused as in English *how*

Table 1. *Romanisation of Chinese sounds (continued)*

-ê	nearest approached by English vowel-sound in *earth*, *perch*, or *lurk*
-êi	the foregoing, says Wade, followed enclitically by *-y*. English *money* omitting the *-on-*. Generally sounded as *-ei* or *-ui* (see below)
-ei	generally indistinguishable from English *may*, *play*, *grey*, *whey*
-en	as in English *yet*, *lens*, *ten*
-ên	as in English *bun*
-êng	as in English *unctuous*, *flung*
-erh	as in English *burr*, *purr*
-i	vowel-sound as in English *ease*, *tree*
-ia	not like *yah* but with the vowels more distinct, though not so much so as in Italian *Maria*, *piazza*, and not separately accented
-iai	as in Italian *vecchiaja*
-iang	like *-ang* above, with the additional vowel
-iao	like *-ao* above, with the additional vowel
-ieh	as in French *estropié*
-ien	with vowels distinct, as in Italian *niente*
-ih	short vowel, as in *cheroot*
-in	short vowel, as in English *chin*
-ing	short vowel, as in English *thing*
-io	short vowel, as in French *pioche*
-iu	always longer than English termination *-ew*, e.g. 'chyew' in lead of *chew*. *Mew* of cat, as onomatopoeically pronounced
-iung	like *-ung* below, with the additional vowel
-o	something between the vowel-sounds in English *awe*, *paw* and *roll*, *toll*
ong	as in English *dong* cut short
-ou	really *-eo*, English *Joe*
-u	as in English *too*
-ü	as in French *eût*, *tu*
-ŭ	between the *i* in English *bit* and the *u* in *shut*. Only occurs with *ss-*, *tz-* and *tzh-*, 'which it follows from the throat' says Wade 'as if the speaker were guilty of a slight eructation'.
-ua	as in Spanish *Juan*; may contract almost to *wa*
-uai	as in Italian *guai*
-uan	like *-an* above, with the additional vowel
-üan	the *ü* as above, the *-an* as in English *antic*
-uang	like *-ang* above, with the additional vowel
-üeh	as in French *tu es*
-uei	the *-u* as above, the *-ei* as above; cf. French *jouer*
-ui	as in Italian (not French) *lui*
-un	as in Italian *punto*, *lungo*
-ün	as in German *München*
-ung	as in Lancashire dialectal pronunciation of English *bung*, *sung*; not so broad as *-oong*
-uo	the *o* as in English *lone*; the whole as in Italian *fuori*

It should be mentioned that the Wade–Giles system took the sounds of the Peking dialect of 'mandarin' as standard. But the *pu thing hua* pronunciation of today is not quite the same, and we have modified the transcriptions of the present book in a desire to concord with it. Thus we find the circumflex accent essential in words such as *pên* (origin) and *Chêng* (family name), but not in *jen* (a person), *chen* (true) or *Chhen* (family name). Similarly, we retain the diaeresis in *hsü* and *hüan* but we do not write it in *yuan*. The sound represented by the inverted circumflex *ŭ* can always be recognised from the consonants which invariably accompany it; we therefore dispense with this diacritical mark.

in 1962. In the previous table both systems are given, together with the scheme adopted by Joseph Needham and collaborators, which is the one in these volumes. It avoids the apostrophes that Wade and Giles used for aspiration, and replaces them by *h*, thus permitting direct comparison with the sounds of Indian languages where, for instance, 'Buddha' and 'Buddhism' are common romanisations.

As a language Chinese is unique: it is the main one which has remained faithful to the ideographic form of writing. Why it has done so is uncertain; perhaps it refused to move to an alphabetical system because it may originally have been monosyllabic. Whatever the reason, it has retained the ideographic script, unlike what happened, for instance, in ancient Egypt and Sumeria.

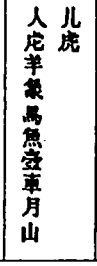
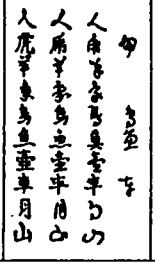
The most primitive elements of Chinese are pictographs – drawings reduced to the bare essentials, conventionalised and, in due course, highly stylised. Natural objects, such as celestial bodies, animals, plants, tools and implements, lend themselves most easily to such drawings, and a number of them are shown in Table 2. The ancient forms of characters are often of considerable interest from the standpoint of Chinese science and technology, as will become evident in later volumes. As the language developed, other written characters were adopted. *Indirect symbols* were introduced, being derived by using gestures for actions, effects for causes and so on. Thus, as Table 2 shows, *chih*, to mount, originated from a picture of two footprints pointing upwards, and *fu*, meaning full or blest, is derived from an ancient picture of a jar. There were also *associative compounds*: *fu*, father, consists of ancient signs for hand and stick; *fu*, wife, signs for woman and broom, while the ideograph *nan*, for male or man, comes from the radicals for plough (or strength) and field.

Besides indirect symbols and associative compounds, some sinologists recognise what may be called *mutually interpretative compounds*. Here one sign is derived from another, although originally they both meant the same thing; only later becoming interpreted differently. For instance, *khao*, meaning examination, is said to be derived from *lao*, old, because it is the old who examine the young, yet originally the two characters meant the same.

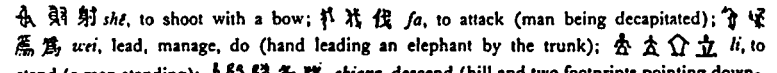
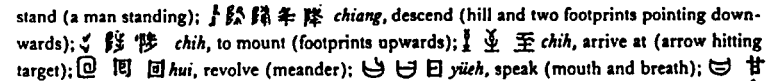
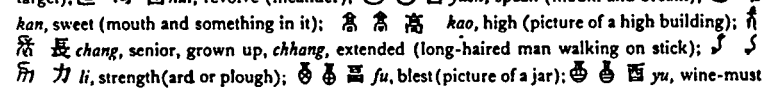
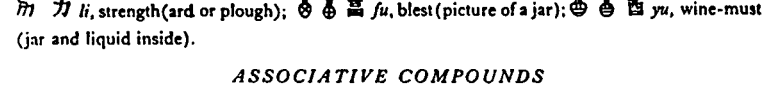
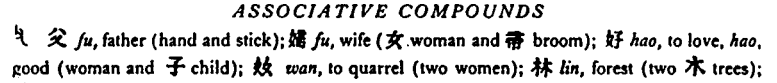
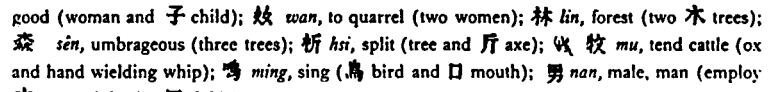
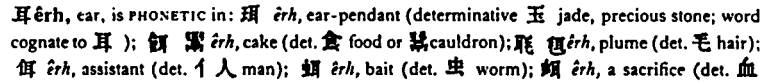
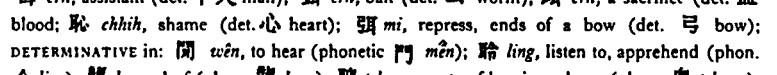
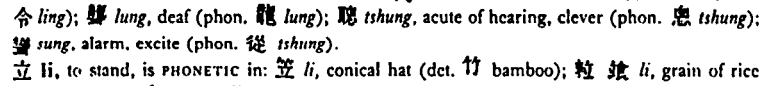
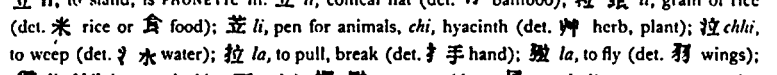
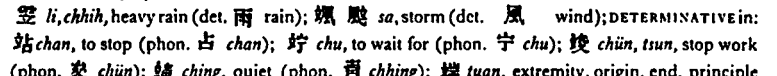
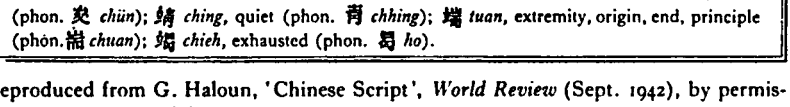
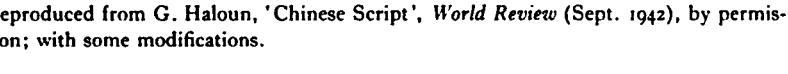
At the present time there are about 2000 pictographs, indirect symbols, associative compounds and mutually interpretative compounds. Yet these do not exhaust the Chinese characters that may be used. Chinese is also very rich in homophones – words having different meanings but sounding the same (like the English words sew, sow, so). Because of this there was always a tendency to use one ideograph with the sense that properly belonged to another that looked different but sounded the

Table 2. *The development of Chinese script*

PICTOGRAPHS

Archaic script	Small seal	Modern script	Forms in writing	Meaning		Rad. no.
				*jên,*	man	9
				hu,	tiger	141
				yang,	sheep	123
				hsiang,	elephant	—
				niao,	bird	196
				yü,	fish	195
				hu,	wine-vessel	—
				chhê,	chariot, car	159
				yüeh,	moon	74
				shan,	mountain	46

INDIRECT SYMBOLS

 *shê*, to shoot with a bow;  *fa*, to attack (man being decapitated);  *wei*, lead, manage, do (hand leading an elephant by the trunk);  *li*, to stand (a man standing);  *chiang*, descend (hill and two footprints pointing downwards);  *chih*, to mount (footprints upwards);  *chih*, arrive at (arrow hitting target);  *hui*, revolve (meander);  *yüeh*, speak (mouth and breath);  *kan*, sweet (mouth and something in it);  *kao*, high (picture of a high building);  *chang*, senior, grown up, *chhang*, extended (long-haired man walking on stick);  *li*, strength (ard or plough);  *fu*, blest (picture of a jar); *yu*, wine-must (jar and liquid inside).

ASSOCIATIVE COMPOUNDS

 *fu*, father (hand and stick);  *fu*, wife (女 woman and 帚 broom); 好 *hao*, to love, *hao*, good (woman and 子 child); 妧 *wan*, to quarrel (two women); 林 *lin*, forest (two 木 trees); 森 *sên*, umbrageous (three trees); 析 *hsi*, split (tree and 斤 axe); 牧 *mu*, tend cattle (ox and hand wielding whip); 鳴 *ming*, sing (鳥 bird and 口 mouth); 男 *nan*, male, man (employ 力 strength in the 田 fields).

DETERMINATIVE-PHONETIC CHARACTERS

耳 **êrh**, ear, is PHONETIC in: 珥 *êrh*, ear-pendant (determinative 玉 jade, precious stone; word cognate to 耳); 餌 *êrh*, cake (det. 食 food or 鬻 cauldron); 毦 *êrh*, plume (det. 毛 hair); 佴 *êrh*, assistant (det. 亻人 man); 鉺 *êrh*, bait (det. 虫 worm); 衈 *êrh*, a sacrifice (det. 血 blood; 恥 *chhih*, shame (det. 心 heart); 弭 *mi*, repress, ends of a bow (det. 弓 bow); DETERMINATIVE in: 聞 *wên*, to hear (phonetic 門 *mên*); 聆 *ling*, listen to, apprehend (phon. 令 *ling*); 聾 *lung*, deaf (phon. 龍 *lung*); 聰 *tshung*, acute of hearing, clever (phon. 悤 *tshung*); 慫 *sung*, alarm, excite (phon. 從 *tshung*).

立 **li**, to stand, is PHONETIC in: 笠 *li*, conical hat (det. 竹 bamboo); 粒 *li*, grain of rice (det. 米 rice or 食 food); 苙 *li*, pen for animals, *chi*, hyacinth (det. 艸 herb, plant); 泣 *chhi*, to weep (det. 氵水 water); 拉 *la*, to pull, break (det. 扌手 hand); 翍 *la*, to fly (det. 羽 wings); 霖 *li*, *chhih*, heavy rain (det. 雨 rain); 颯 *sa*, storm (det. 風 wind); DETERMINATIVE in: 站 *chan*, to stop (phon. 占 *chan*); 竚 *chu*, to wait for (phon. 宁 *chu*); 竣 *chün*, *tsun*, stop work (phon. 夋 *chün*); 竫 *ching*, quiet (phon. 靑 *chhing*); 端 *tuan*, extremity, origin, end, principle (phon. 耑 *chuan*); 竭 *chieh*, exhausted (phon. 曷 *ho*).

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same. Due to a strong inclination of the Chinese to pun, it led some characters which had ceased to have their original function being used for other purposes. Thus *lai*, meaning to come (來), originally meant a cereal plant, as its ancient ideograph () shows, and *wan*, ten thousand (萬), was originally a scorpion (). The changes happened because the words are homophones, and the new phonetic characters are called *loan characters*.

The greatest invention in the development of Chinese was that of the *determinative-phonetic* characters. A determinative is a basic element (a radical) that is added to a phonetic word to indicate the category in which the meaning of the word is to be sought. Thus a whole series of words with the same, or approximately the same, sound can be written down without any possibility of confusion. Some examples will make this clear. The word *thung*, a phonetic meaning with, together, is combined with various radicals to provide a new series of words:

chin (金) (metal) + *thung* (同) = *thung* (銅) copper, bronze.
chu (竹) (bamboo) + *thung* (同) = *thung* (筒) pipe, flute.
hsing (行) (to go) + *thung* (同) = *thung* (衕) side street.

On the other hand the radical *shui*, water, can be used in combination with another word to show that the word in question has something to do with water. Thus:

shui (水) (water) + *mo* (末) (branches) = *mo* (沫) (froth, foam).
shui (水) (water) + *chha* (叉) (fork) = *chha* (汊) (branching streams).
shui (水) (water) + *mei* (每) (each, every) = *mei* (海) (the sea).

How far combinations like these were the result of ingenuity by scribes in the tenth to seventh centuries B.C. we cannot tell, but many certainly reveal appropriate, even poetical, contexts of thought. Some ideographs can be both phonetic and radical-determinative, like *erh* (ear) (耳) and *li* (to stand up) (竹), as can be seen in Table 2.

Any one of the pictographs or symbols of the classes mentioned could be used as a phonetic, and so render words that sounded the same or, at least, closely similar. But the number of determinatives was not unlimited, since the number of categories required in the primitive stages of a civilisation was not great. As a result the radical-determinative came to be adopted as a convenient way of forming characters; it was already in full use in the ninth century B.C., and codified in 213 B.C. The first great dictionary appeared in A.D. 121, containing 541 radicals. This large number remained in use for some 1200 years, then it was reduced to 360 and finally to 214, the figure in use today.

To anyone with scientific interests approaching Chinese, a helpful analogy is possible if we consider Chinese characters as molecules