Early Chinese Work in Natural Science

A Re-examination of the Physics of Motion, Acoustics, Astronomy and Scientific Thoughts

Chen Cheng-Yih

Hong Kong University Press
香港大學出版社

Hong Kong University Press
139 Pokfulam Road, Hong Kong

ISBN 962 209 385 X

Hong Kong University Press wishes to acknowledge with appreciation the generous support from the East Asian History of Science Foundation (Hong Kong) for the publication cost of Professor Chen's book: Early Chinese Work in Natural Science.

Printed in Hong Kong by Liang Yu Printing Factory Ltd.

Contents

List of Illustrations

List of Tables

1 Early Chinese Work on the Physics of Motion

無動而不變, 無時而不移.
Zhuāng Zǐ · Qiū Shuǐ 《莊子 · 秋水》
(*The Book of Master Zhuāng*)

The direct physical experience of man in his immediate environment is predominantly mechanical. Ever since the dawn of civilization, humanity has been fascinated by the phenomenon of motion. They not only studied it but made ingenious use of it. But not until the phenomenon of motion was analyzed in terms of its general features and its relationship to force did the study of motion begin to take shape as a branch of physical science known as mechanics.

1.1 The Conceptualizations of Space and Time

To describe motion, it is necessary to have an understanding of space and time. The early Chinese conceptualization of space and time is best stated in the *Mò Jīng* 《墨經》 (*The Mòhist Canon*).[10] We have:

> 宇, 彌異所也.
> 久, 彌異時也.
> Space is that which extends to different positions.
> Time is that which extends to different moments.[11]

10. The *Mò-Jīng* which contains two canon sections and two sections on canon exposition was compiled in the early −4th century. The canon section contains a number of Mò Zǐ's own teaching of the −5th century. The book, as we now have it, also contains the work of later Mòhists down to the −3rd century.
11. The translations in this work are made in consultation with earlier translations whenever they are available. Every effort has been made to retain their original

The space and time as defined by these statements are the general continuum space and continuum time extending without bounds. These concepts are theoretical abstractions of bounded space and finite time intervals.

The Mòhists, Mò Jiā 墨家, were well aware of the fact that time cannot be perceived directly through our five senses. In the *Mò-Jīng*, it is stated:

> 知而不以五路, 說在久.
> There are things that we know but cannot be perceived by the five paths (i.e. our five senses). An example is time.

The Mòhists must have also deduced this concept of time from observations of changes. This is obvious from the word *jiŭ* 久 adopted to represent time, since it is a borrowed term which, according to the *Shuō-Wén Jiĕ-Zì* 《說文解字》 (*Analytical Dictionary of Characters*) of 121, means originally 'blocking' and, in the course of time, took on the connotation 'long duration' associated with the length of the blocking action. It was through such connections that the word was borrowed to represent the abstract concept of time.

In the *Mò-Jīng*, we find also discussions on the concept of a point in space and an instant in time. As a specific example of an instant in time, the Mòhists considered the instant of onset by defining the term *shĭ* 始:

> 始, 當時也.
> 始, 時或有久, 或無久, 始當無久.
> The onset-instant is an instantaneous moment in time.
> Time sometimes has duration and sometimes not,
> the onset-instant has no duration.

Here we see that the concept of an instant in time is visualized as an instantaneous moment (*dāng shí* 當時) with no duration.

Further insights on Mòhist interpretations of space and time can be found in the 'exposition' section of the *Mò-Jīng*. We have the following elucidation of the definitions of space and time:

> 宇, 東西家南北.
> 久, 古今旦莫.
> Space extends to the east, west, south and north [from] a *jiā* 家 (center).
> Time extends to the past, the present, the morning and the evening.

meaning and writing style. For the convenience of the reader, the Chinese writings are reproduced with their English translations, with supplied interpretations given in square brackets [ ] and explanations given in parentheses. The reader is urged to also consult translations by Joseph Needham and his collaborators in the *Science and Civilisation in China*.

Here space is illustrated in terms of directions and time in terms of durations. It is significant that the concept of direction is introduced in the exposition of space. The character *jiā* 家, adopted to represent the centre from which the directions are specified, means literally 'home' and is defined only with respect to an individual and thus, its location can be arbitrarily chosen. This is indeed a remarkable anticipation of the concept of coordinates (see Fig. 1).

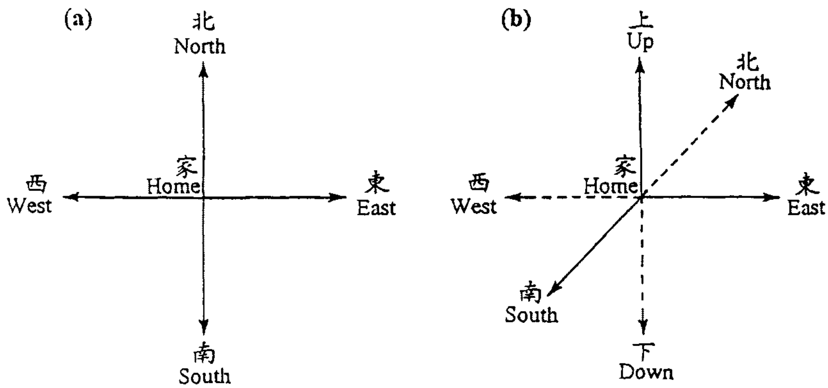

Figure 1. An illustration of space as described in (a) the 'exposition' section of the Mò-Jīng《墨經》and (b) the *Shī Zǐ*《尸子》.

The Mòhist exposition of space and time is obviously not in the most general terms since the given four directions subtend only a two-dimensional space (see Fig. 1a). This limitation was soon removed by the work of Shī Jiǎo 尸佼 (fl. –4th century). We have from the *Shī Zǐ*《尸子》(*The Book of Master Shī*):

> 宇, 四方上下.
> 宙, 往古來今.
> Space extends to the four cardinal directions
> [as well as] the up and down directions.
> Time extends to the past and the coming of the present.

By the inclusion of the up and down directions in the exposition of space, Shī Jiǎo succeeded in describing a three-dimensional space consistent with the Mòhist definitions of space and time given above (see Fig. 1b).

The coinage of the character *zhòu* 宙 to replace *jiǔ* 久 for denoting the general concept of time in this context is of significance. It was in terms of *yǔ* 宇 and *zhòu* 宙 that the concept of the four-dimensional space-time continuum began to emerge early in Chinese civilization as the characters *yǔ* and *zhòu* were later joined together to form the compound word *yǔ-zhòu* 宇宙 to denote the concept of the universe (see p.156 to p.158).

1.2 Motion in Space

Having examined the early Chinese conceptualization of space and time, we are now in a position to consider their view of motion in space. In describing motion, the basic physical quantities that are of concern are the displacement in position and the duration in time from which other physical quantities of motion, such as velocity and acceleration, may be derived. We find in the *Mò-Jīng* a description of motion in terms of these basic quantities:

> 行，脩以久，說在先後.
> 行，行者必先近而後遠.
> 遠近脩也，先後久也.
> 民行脩必以久也.
> During motion, displacement is measured in terms of duration,
> for in motion there is 'earlier and later'.
> In motion, a moving object must first be at a near position and later at a distant position.
> The near and the distant constitute the displacement.
> The earlier and the later constitute the duration.
> The displacement of a person in motion must therefore be measured in terms of duration.

This description of displacement in terms of time duration is of interest since it appears to venture, in non-mathematical terms, toward the concept of 'velocity'. Although the character *xiū* 脩 is defined to be the change in position, it is not clear whether the directional property of displacement was appreciated and implied in the above definitions. Consequently, the term 'velocity' should be interpreted with caution. One thing, however, is certain; the concept of directions was used in the description of space (as mentioned on p.1 to p.3 and Fig. 1).

Mòhists viewed continuous change in location of an object as motion. This is discussed in the *Mò-Jīng*:

> 動，域從也.
> 動，偏際從，若戶樞免瑟.
> Motion is change in location (*yù* 域).
> If the door-pivot is free from [the action of] the bolt, the open-edge [of the door] would yield to [swinging] motion.

It is of interest to note that the example of motion chosen in the 'exposition' section of the *Mò-Jīng* is the motion of a swinging door. This is not an example of pure translational motion, but an example of rotational motion of an extended body.

Motion is also a topic of quantitative study in mathematical treatises. In Chapter 6 of the *Jiŭ-Zhāng Suàn-Shù* 《九章算術》 (*Mathematics in Nine Chapters*), for example, there are a number of problems designed to study constant motion. Reproduced below as an illustration is Problem 16:

今有客馬, 日行三百里. 客去忘持衣, 日已三分之一,
主人乃覺. 持衣追及與之而還, 至家視日四分之三.
問主人馬不休日行幾何?
Given a host, a visitor, and a visitor's horse which travels at a speed of 300 *lǐ* 里 / day. The visitor forgot to bring his clothes which was not discovered by the host until one third of the day has gone by. The host chased and brought the clothes to the visitor, but when he returned home the day was three quarters gone. What would be the distance travelled by the host's horse in a day without resting?

Such problems are designed to study the interrelationships among speed, time, and distance in motions with constant speed. Both the method and the answer for problem 16 are given in the book; the distance travelled is found to be 780 *lǐ* 里.

In the early Chinese conceptualization of motion, the problem with reference was an important issue. This issue is best illustrated by a dialectical proposition found in the *Mò-Jīng*:

宇進無近説在敷.
傴宇不可偏舉宇也
進行者先敷近後敷遠.
Moving in space, there is nothing to indicate whether it is coming nearer [or going further away].
The explanation lies in the reference.
Space cannot, in general, be represented by certain selected districts;
[but only with respect to such districts can] a traveller first make reference as near and later make reference as far.

Contained in this proposition is the important physical insight of the relativeness of reference. The space-time continuum visualized by the early Chinese scholars is isotropic and homogeneous. The direction and position of a moving object in space are defined only with respect to a chosen reference.

The physical insights provided by the proposition undoubtedly helped the scholars of the Han period to first offer an explanation as to why the motion of the earth cannot be directly observed by an observer on earth. We have, from the 'Kǎo Líng Yào' 〈考靈曜〉 section of the *Shàng-Shū Wěi* 《尚書緯》 (*Treatise on the Book of Documents*) of the *c.*−1st century, the explanation:

地恒動不止而人不知.
譬如人在大舟中,
閉牖而坐, 舟行不覺也.
The earth is constantly in motion, without stop,
but one does not know about it.
Just as if one sat in a large boat with all the windows
[and doors] closed,
one would not sense the travelling of the boat.

In view of its time period, this is indeed a remarkable passage. Although the account provides no explanation as to how one knows that the earth is in motion, it certainly provides the first correct explanation as to why an observer on earth cannot directly observe the motion of the earth. The explanation is based on the realization that the state of motion and the state of rest are a matter of reference frames in which the observations of the object are made. This, in fact, is one of the theoretical foundations of Newtonian mechanics.

It should be noted that a two-dimensional rectangular coordinate system was certainly developed by the time of the Han period. This is evident from maps of the −2nd century unearthed from Han tombs. These maps are drawn on the scale of 1 *cùn* 寸 (Chinese inch) to 10 *lǐ* 里 (Chinese mile).[12] There is also evidence that, by the −4th century, a celestial equatorial coordinate system was developed to specify the positions of stars (see p.119 to p.125). There are, however, no extant records to indicate that coordinates were ever used to provide a quantitative description of an object in motion.

1.3 A Dynamical Consideration of Motion

In the study of motion, it is natural to ask questions such as why a moving object stops or what causes an object to move. In the past, inquiries of this type gradually led to the recognition of the role of force in motion. We have from the *Mò-Jīng*, an analysis on the cessation of motion:

> 止, 以久也.
> 止, 無久之不止, 當牛非馬, 若矢過楹.
> 有久之不止, 當馬非馬, 若人過梁.
> The cessation of motion (*zhǐ* 止) is due to blocking.
> [That the motion will] not stop in the absence of blocking
> is as [true as that] an ox is not a horse,
> like an arrow passing through between pillars.
> [That the motion would] not stop in the presence of blocking
> is like something being a horse and yet not a horse,
> like people passing over a bridge.

This is an interesting but difficult passage that requires careful analysis.

12. See the *Gǔ Dì-Tú*《古地圖》(*The Ancient Maps*) and the accompanying book entitled *Gǔ Dì-Tú Lùn-Wén Jí*《古地圖論文集》(*A Collection of Research Papers on Ancient Maps*) (Wén-wù, 1977), p. 6.

Before discussing the physical content of this analysis, some remarks on the interpretation of the character *jiŭ* 久 are in order. Reproduced below is the entry for the character *jiŭ* 久 in the *Cí Hăi* 《辭海》 (*Word Encyclopedia*):

〔久〕紀有切，音九，有韻．俗作乆．㊀永久也．易恆：『久而不已也．』㊁舊也．詳久要條．㊂待也．左傳昭二十四年：『寡君以爲盟主之故，是以久子．』㊃塞也．儀禮士喪禮：『冪用疏布久之．』注：『久讀爲灸，謂以蓋塞鬲口也．』按說文久字段注引士喪禮此文，云：『久字不必改讀，蓋久本義訓從後歫之，引伸之則凡歫塞皆曰久．』

It is seen that this character has a number of meanings, namely (1) for a long time, forever; (2) old, worn out, formerly; (3) wait for, stop over; and (4) blocking. As mentioned earlier, the original meaning of *jiŭ* is 'blocking'. In the course of time, it began to be associated with the length of the blocking action. It was through such a connotation that this character gradually acquired its other meanings. In the context of the above analysis on cessation of motion, the character *jiŭ* 久 is used in its original meaning, 'blocking'.

The use of 'blocking' without the mention of force to explain the cessation of motion is somewhat ambiguous since it seems to suggest that the action of 'blocking', rather than the opposing force produced by the action, is responsible for the cessations. The analysis, nevertheless, provides valuable physical insights. After stating that the cessation of motion is caused by blocking, it attempts to differentiate the varying degrees in the influence of blocking on motion. It begins with the assertion that in the absence of blocking, the motion will not stop. It then points out that even in the presence of blocking, the motion may not necessarily stop. Hence, three cases are recognized here, namely (1) with blocking, motion stops; (2) without blocking, motion never stops; and (3) with blocking, motion continues. These are cases related obviously to the strength of the blocking. Here, one sees the possibility of developing a quantitative understanding of the process had mathematization of physical concepts become available. Without mathematization, the Mòhists were only able to classify the third case as 'something being a horse and yet not a horse, like people passing over a bridge.' The implied comparison of the metaphor is the case of being in between. What the Mòhists did was to classify all possible cases involving situations in which the blocking is present but is not sufficient to stop the motion as in between cases.

The importance of this analysis, however, lies in its assertion that in the absence of blocking a moving object would not stop. This assertion is not at all self-evident. In fact, it is often stated in college physics textbooks[13] that 'before Galileo's time most philosophers thought that some influence or 'force' was needed to keep a body moving.' The physical insights of the Mòhist analysis were probably derived in part from their concern with the issue of reference as discussed earlier. There are also extant early records of observations of such physical phenomena of motion. For example, in the *Kǎo Gōng Jì* 《考工記》 (*The Artificer's Record*),[14] we have:

> 馬力既竭, 輈猶能一取焉.
> Although the pulling force of a horse has ceased,
> the cart shaft can still make a gain [in distance].

These types of observations undoubtedly were also helpful in realizing the existence of the physical property known later as 'inertia' related to the mass of the object.

The existence of such a physical property in rotational motion was later postulated by Zhāng Zài 張載 (1020–76) of the Northern Sòng 宋 in explaining the constant rotational motion of objects. He stated:

> 凡圓轉之物, 動必有機.
> 既謂之機, 則動非自外也.
> All objects engaged in rotational (and/or spinning) motion
> must have an (internal) 'mechanism' to sustain their motion.
> It is due to the existence of such a 'mechanism'
> that their motion is not caused by an outside agent.[15]

13. See for example, D. Halliday and R. Resnick (1974), p. 61.
14. The *Kǎo Gōng Jì* was a Qí 齊 document compiled probably in the −5th century or earlier. It was incorporated in the *Zhōu Lǐ* 《周禮》 (*The Book of Zhōu Institutions*) in the −2nd century.
15. See p. 6b of vol. II of the *Zhāng-Zǐ Quán-Shū* 《張子全書》 (*The Complete Work of Master Zhāng*).

The existence of an internal 'mechanism' to sustain rotational motion advocated by Zhāng Zài can, of course, now be confirmed and the mechanism can be identified with 'rotational inertia' (or 'moment of inertia') which depends not only on the mass but also on the configuration of the object.

The role of force in motion is best summarized in the *Mò-Jīng*:

> 力, 形之所以奮也.
> 力, 重之謂, 下與重奮也.
> Force is that which causes the status (of things) to hasten.
> Weight is a force.
> It is the downwardness with weight that gives rise to the hastening.

Here force is visualized to be that which causes things to undergo hastened motion. The key word used to denote this phenomenon is the character *fèn* 奮 which means 'rush', 'hasten' or 'rouse'. According to the *Shuō-Wén Jiě-Zì*, *fèn* originally was a pictogram describing the process of a large bird taking off from a field. Thus, the coinage of this character to describe the phenomenon of changing states in motion is particularly revealing, since such taking-off processes necessitate acceleration to give rise to velocity changes. The Mòhist analysis not only recognizes weight as a force but also states its directional property. It further recognizes that the phenomenon *fèn* (i.e. the increase in 'velocity') during a fall is due to the downward force of weight.

This is indeed a remarkable physical analysis of the role of force in motion. It comes extremely close to the concept of acceleration. Without the aid of mathematics, a precise quantitative definition of acceleration is not possible. This undoubtedly impeded the Mòhists' ability, despite their remarkable physical insights, to analyse quantitatively the role of force in motion. As a result, their experiments with motion on inclined planes and with the motion of spheres did not yield a quantitative understanding of motion. And yet one must acknowledge that natural science had to wait more than 2,000 years before a quantitative understanding of the concept of acceleration was made possible through the work of Galileo and Newton in the seventeenth century.

Quantitative studies of motion with changing speeds are also found in mathematical treaties. Reproduced below is Problem 19 of Chapter 7 of the *Jiǔ-Zhāng Suàn-Shù* 《九章算術》:

> 今有良馬與駑馬發長安至齊, 齊去長安三千里.
> 良馬初日行一百九十三里, 日增十三里; 駑馬初
> 日行九十七里, 日減半里. 良馬先至齊, 復還迎駑馬.
> 問幾何日相逢及各行幾何?
> Given a good horse and an old horse to be dispatched from Chángān 長安 to Qí 齊, a distance of 3,000 *lǐ* 里. The good horse travels with an

> initial speed of 193 *lǐ* 里 / day and an increase of 13 *lǐ* 里 / day; the old horse travels with an initial speed of 97 *lǐ* 里 / day and a decrease of 0.5 *lǐ* 里 / day. The good horse reached Qǐ 齊 first and then returned to meet the old horse. At which day will the two horses meet and by then what is the distances travelled by each horse?

The method used to solve this problem is the method of *yíng-bù-zú* 盈不足 a linear interpolation procedure devised primarily for interpolating apparent motion of planets (see p.159).

1.4 The Mechanization Movement

There are scholars who dismiss the significance of the Mòhist work as being an isolated case which had little, if any, impact on the general scientific development in Chinese civilization. This view is based not only on incorrect perceptions about the impact of the Mòhist work, but also on a faulty basis for evaluation since the significance of a scientific work should be measured in terms of its scientific merits. The conceptual framework formulated by Mòhists for the analysis of motion was revolutionary, though the revolutionary nature is less obvious now than it was then, more than 2,000 years ago. The activities of the Mòhist school actually spanned more than two centuries, from the middle of the –5th century to the second half of the –3rd century.

The work of Mòhists had a profound influence, not only on their contemporaries, but also on the subsequent development of science and technology in Chinese civilization. In the previous sections, I have mentioned the possibility of Mòhist influence on the work of Hàn and Sòng scholars on the physics of motion, including the brilliant explanation by Hàn scholars as to why the motion of the earth cannot be directly observed by an observer on earth. The influence of Mòhist work on the concept of time and space in the cosmological models is discussed on p.156 to p.165. In this section, I suggest that the Mòhist work on mechanics, in general, was responsible for initiating the 'mechanization movement' that began in China sometime in the –4th century.

It was certainly not a coincidence that a variety of mechanical contrivances began to appear in China parallel to the Mòhist formulation of a conceptual framework for the analysis of motion. We read, for example, of the invention of the *shuàn chē* 輴車, a mobile scaling-ladder with pulley and counterweight.[16] The prestige acquired from mechanical

16. See the second exposition section of the Mò Jīng. Needham has constructed, based on the description from Mò Jīng, an illustration of the counterweighted scaling-ladder, see *Science and Civilisation in China* (1962), vol. 4, sec. 26(c), p. 21.

inventions at that time is best illustrated by the attempts of the Dàoists (Dào Jiā 道家) to concoct the story of an ultimate machine. This is cast typically in the form of a Dàoist parable. We find in Chapter 5 of the *Liè Zǐ*《列子》(*The Book of Master Liè*):[17]

> King Mù of Zhōu 周穆公 made an inspection tour in the west, crossing the Kūnlún 崑崙 Mountains to the Yǎn-shān 弇山. While on his return journey, before reaching his central kingdom, a certain artificer by the name of Yǎn Shī 偃師 was presented to him. The king received him and asked him what he could do. He replied that he would do anything which the king commanded, but that he had a piece of work already finished which he would like to show him. 'Bring it with you tomorrow,' said the king, 'and we will look at it together.' So the next day, Yǎn Shī appeared again and was admitted into the presence of the king. 'Who is that man accompanying you?' asked the king. 'That, Sir,' replied Yǎn Shī, 'is my own handiwork. He can sing and he can act.' The king stared at the figure in astonishment. It walked with rapid strides, moving its head up and down, so that anyone would have taken it for a living human being. The artificer touched its chin, and it began singing, perfect in tone. He touched its hand, and it began posturing, keeping perfect time. It went through any number of movements that his fancy might happen to dictate. The king, looking on with Shèng Jī 盛姬 and his personal assistants, could hardly persuade himself that it was not real. As the performance was drawing to an end, the robot winked its eye and made advances to the concubines sitting by the king, whereupon the king became incensed and would have had Yǎn Shī executed on the spot had not the latter, in mortal fear, instantly taken the robot to pieces to let him see what it really was. And, indeed, it turned out to be only a construction of leather, wood, glue and lacquer, variously coloured white, black, red and blue. Examining it closely, the king found all the internal organs complete—liver, gall bladder, heart, lungs, spleen, kidneys, stomach and intestines; and over these, muscles, bones, and limbs with their joints, skin, teeth and hair, all artificial. Every part was fashioned with the utmost nicety and skill, and when it was put together again, the figure presented the same appearance as when first brought in. The king tested the effect of taking away the heart and found that the mouth could no longer speak; he took away the liver and the eyes could no longer see; he took away the kidneys and the legs lost their power of locomotion. The king was delighted. Drawing a deep breath, he exclaimed, 'Can it be that human skill is on a par with that of the "author of nature" (*zào huà zhě* 造化者)?' And forthwith, he gave an order for the spare chariot, in which he took home with him the artificer and his handiwork.[18]

17. The book attributed to Liè Yù-Kòu 列禦寇 (c. –5th century) was probably first compiled in the –4th century. The book was then edited by Liú Xiàng 劉向 in the fourth century with much Dàoist materials added.
18. This translation is from L. Giles (1912). I have made some minor changes here.

The motivation of the Dàoists in concocting a robot as the ultimate mechanical invention was to upstage the Mòhists who were enjoying prestige from their mechanical inventions. This motivation is revealed in their own words following the robot parable in Chapter 5:

> As for the cloud-scaling ladder (*yún tī* 雲梯) of Bān Shū 班輸 and the flying wooden kite (*mù yuān* 木鳶) of Mò Dí 墨翟, their masters probably thought that they had reached the limit of human achievement. But when Yǎn Shī's remarkable skill was brought to their knowledge by their pupils, Dōng Mén-Jiǎ 東門賈 and Qín Huá-Lí 禽滑釐, respectively, the two masters no longer dared to talk of their mechanical skill and hesitated often when they had the compass and the right-angled ruler in hand.

Of course, no robot was ever built at that time. The interest in the parable lies in the fact that it provides a measure of the impact of the 'mechanization movement' at that time.

In retrospect, it is not difficult to see that one of the difficulties with the early 'mechanization movement' was the inability to make use of mathematical knowledge in the conversion of mechanical knowledge into practical technology. Consequently, the movement, in comparison with that following the 'scientific revolution', was rather limited in scope and slow in rate. The early 'mechanization movement' had, however, a profound impact on Chinese civilization. The Chinese mechanical practice as seen in vehicles, projectiles and engines of various kinds was, if not often ahead, at least comparable to the European practice until the onset of the 'scientific revolution'.[19]

The 'mechanization movement' in China was not without resistance. We read in the *Zhuāng Zǐ* 《莊子》 (*The Book of Master Zhuāng*), of the late −4th century, the concern with the mechanical device for raising water, a counterbalanced bailing bucket known as the *gāo* 槔 (a type of swape). The setting of this Dàoist parable is between the Dàoists and the Confucians instead of the Mòhists. We have:

> Zǐ Gòng 子貢 had been touring in the south of Chǔ 楚 and was returning to Jìn 晉. As he passed Hànyīn 漢陰, he saw an old man working in a vegetable garden. Having dug his channels, he kept on going down into a well, carrying a large jar and returning with water for irrigation. This caused him much expenditure of strength for meagre results. Zǐ Gòng said to him, 'There is a mechanical contrivance (*xiè* 械) by means of which a hundred plots of ground may be irrigated in one day. Little effort will thus accomplish much. Would you, sir, not like to

19. See the volumes of documentation collected by Joseph Needham and his collaborators in *Science and Civilisation in China* (University Press, Cambridge, 1954–1988), in particular secs. 27–30.

> try it?' The farmer looked up at him and said, 'How does it work?' Zǐ Gòng said, 'It is a lever made of wood, heavy behind and light in front. It raises water quickly as if being drawn out and with such a quantity that it flows in a steady stream. Its name is gāo 槔 (swape).' The vegetable farmer suddenly changed his face and laughed, saying, 'I have heard about this device from my master. But he said, 'those who have cunning devices use cunning in their dealings' and 'those who use cunning in their dealings have cunning intentions'. Furthermore, with cunning intentions in one's heart one can no longer possess purity and simplicity and without purity and simplicity one cannot spiritually be at peace. Those who lose spiritual peace possess no longer the *dào* 道. It is not that I know not of the device; I would be ashamed to use such a device.'[20]

Despite the opposition of the Dàoists, mechanical knowledge was well integrated into the practical technology of the Chinese civilization.

1.5 Comments and Evaluations

The early Chinese work on motion has not been seriously studied among sinologists and historians of science. With very few exceptions, most scholars are of the impression that in Chinese civilization there was hardly any theoretical interest in motion. Even the basic concepts of space and time as given in the *Mò-Jīng* were misinterpreted. We have, for example, from the eminent sinologist, Marcel Granet, the following comments:

> For the ancient Chinese, time was not an abstract parameter, a succession of homogeneous moments, but was divided into concrete separate seasons and their subdivisions.
> Space was not abstractly uniform and extended in all directions, but was divided into the regions, south, north, east, west and centre.[21]

These comments certainly are contradictory with the definitions of space and time (see p.1 to p.3) given in the *Mò-Jīng*: 'Space is that which extends to different positions. Time is that which extends to different moments.' In the 'exposition' section of the *Mò-Jīng*, concepts of directions and durations are indeed introduced for the purpose of elucidating, respectively, the concepts of space and time. But these elucidations are appropriate and insightful and nowhere were suggestions made that 'time was not an abstract parameter' and 'space was not abstractly uniform and extended in all directions'.

20. This translation is a modified version of earlier translations by J. Legge (1891) and by Lin Yü-T'ang 林語堂 (1948)
21. Marcel Granet (1934), pp. 88, 96.

The accounts of Chinese work on motion found among the work of sinologists consist usually of discussions of the *mìng-tí* 命題 on motion, devised by dialecticians such as Huì Shī 惠施 (c. –380 to c. –305) and Gōng Sūn Lóng 公孫龍 (c. –320 to c. –250) of the Warring States period of the Zhōu dynasty. Such *mìng-tí* are mostly found in the *Zhuāng Zǐ*. Let us re-examine the following *mìng-tí* on motion:

> 飛鳥之景未嘗動也.
> The shadow of a flying bird never was in motion.
>
> 鏃矢之疾而有不行不止之時.
> The rapid motion of a flying arrow consists of moments
> at which [the arrow] is not in motion and not at rest.

These *mìng-tí* are inevitably compared with the arrow paradox of Zeno recorded in the work of Aristotle:

> The arrow in flight is at rest.
> For if everything is at rest
> when it occupies a space equal to itself and
> what is in flight always occupies a space equal to itself.[22]

(where the explanation was probably provided by Aristotle himself). Such comparisons are usually made, however, only at a level of marvelling at their superficial similarities without examining their difference in content.

The analysis of an arrow in flight given in the arrow *mìng-tí*, unlike that of Zeno's paradox, is not fallacious. It describes the instantaneous aspects of the motion. We now know that, at any instance during its flight, the arrow would have simultaneously an instantaneous position and an instantaneous velocity. To the dialecticians who debated the *mìng-tí*, the fact that the arrow is located at a specific position at a given instant implies that, at that instant, it is not in motion. Yet, in the meantime, the arrow has a velocity so that, at that same instant, it is not at rest. As discussed earlier, an instant in time is defined by the Mòhists as an instantaneous moment with no duration. Thus, the arrow *mìng-tí* deals with the instantaneous aspects of the motion anticipating the concept of instantaneous position and velocity. This is probably one of the earliest adumbrations of the instantaneous behaviour of an object in flight without the help of a mathematical apparatus in taking the limit to infinitesimal time intervals.

The shadow *mìng-tí* may superficially appear to be similar to Zeno's arrow paradox since it considers that the shadow of a flying bird, like an arrow in flight, is not in motion. But there is a subtle difference between

22. Aristotle, Physics, 239b, 5–33. The translation is from J. Burnet (1908), p. 367.

the motion of an arrow in flight and the shadow of a flying bird. The difference lies in the dynamics of the motion. Unlike the flying arrow, the moving shadow can neither possess inertia nor have forces acting directly upon it. Notice that the *mìng-tí* specifically depicts the motion of the shadow, not the motion of the flying bird itself. Based on the dynamic analysis of motion advanced by the Mòhists, the dialecticians can successfully argue that a shadow cannot by itself engage in motion dynamically. It derives its apparent motion from the flying bird.

Needham was much better informed of early Chinese work on motion and included the work of Mòhists in his treatment of this topic. His interpretation of Mòhist work was, however, partly hindered by the changes and incorrect interpretations made by the Qīng 清 scholars. Consider, for example, the passage on dynamics discussed in the last section. Needham accepted the suggestion of Sūn Yí-Ràng 孫詒讓 made in 1894 and replaced the original character *yǔ* 與 (with or and) with the character *jǔ* 舉 (to raise) and translated the character *fèn* 奮 as 'motion'.[23] Thus, the passage becomes:

> 力, 形之所以奮也.
> 力, 重之謂, 下舉重奮也.
> Force is that which causes shaped things (i.e. solid objects) to move.
> Weight is a force.
> The fall of a thing, or the lifting of something else,
> is motion due to heaviness.

which has a very different meaning. Take the last sentence for example. Instead of stating that the phenomenon of *fèn* during a fall is due to the downward force of weight, it takes on the meaning that the falling and lifting of things are motions due to heaviness.

In a footnote of this passage, Needham did express his reservation in translating *fèn* as motion. He stated that 'if the Mòhist writer had not had a vague idea of acceleration at the back of his mind, he would have used obvious words such as *hsing* [*xíng* 行], *i* [*yí* 移] and *tung* [*dòng* 動].'[24] He also pointed out that 'the word *fèn* is of particular interest here, since it connotes rushing or accelerated movement, and originally meant the taking-off of a bird from the field in flight.' Despite his reservations on the interpretation of the character *fèn* 奮, Needham nevertheless accepted Sun's suggestion and misinterpreted the Mòhist analysis of the role of force in motion and their interpretation of falling motions.

Needham thus concluded that 'the study of motion (kinetics and cinematics) seems to have been, on the whole, conspicuously absent

23. Joseph Needham (1962), vol. 4, sec. 26(c), p. 19.
24. Ibid., footnote a.

from Chinese physical thinking'.[25] Although he pointed out that this absence of Chinese discussions on dynamics 'seems to have had no inhibitory effect at all upon practical technology in the eotechic phase' and acknowledged that 'so far as vehicles, projectiles, and engines of all kinds were concerned, Chinese mechanized practice was ahead of European, not retarded, down to the very time when the scholastics of the fourteenth century were preparing the way for Galileo, and even later.'[26] Needham's view of Chinese work on motion is essentially the same as those of earlier scholars, namely, that there was hardly any theoretical interest in motion.

But the conceptual framework formulated by early Chinese scholars for the interpretation and analyses of motion is highly theoretical. It provides a sound interpretation of space-time continuum, as well as points in space and time; it emphasizes the importance and the relative nature of reference in observing motion; it realizes that in the absence of a blocking force, an object in motion will not stop; it interprets the phenomenon of *fèn* (i.e. the hastened motion) of an object in motion as caused by force; and it correctly explains that the increase in velocity of an object in free fall is the result of the downward force of weight.

The early Chinese conceptualization of motion was free from the fallacious Aristotelian concept of 'natural place' according to which an object can exhibit either 'natural' motion in seeking its 'natural place' or 'violent' motion compelled by some external force. Nor did the early Chinese analysis of motion encounter the complication of the Aristotelian theory of 'antiperstasis' in which the motion of an object was visualized to be propelled by the air rushing into the 'horror vacui' created by the moving object.[27] The distinguishing feature of the Mòhists' work on motion lies in their ability to strip away the peripheral and secondary phenomena and to concentrate on the essential physical features of the motion.

This was probably related to the Mòhist methodology known as the *xiào* 效 (model-thinking):

> 效者, 為之法也.
> 所效者, 所以為之法也,
> 故中效則是也, 不中效則非也.
> 此效也
> That being modelled is considered to be the principles.
> A model so constructed should contain these principles.
> If the model succeeds in manifesting [these principles],
> then [the reasoning] is correct.

25. Ibid., p. 55.
26. Ibid., p. 59.
27. See for example, R. Dugas (1950); C.B. Boyer (1950).

But, if the model fails in manifesting [these principles],
then [the reasoning] is wrong.
Such is [the method of] *xiào*.[28]

Indeed, the method of model-thinking discussed above is very advanced for its time and the logic in its arguments bears a strong resemblance to that of our contemporary scientific model. Needham has suggested that 'the general attitude of Chinese thinkers towards conceptual model-making might have induced in them by the structure of their language and this perhaps enabled them to attain a sophistication in differentiating those intellectual operations which can be carried on with models from those which cannot, only now being rediscovered and developed by modern philosophers of science.'[29]

Following the discussions of the method of *model-thinking*, we find, in the *Minor Illustration* section of the *Mò-Zǐ* 《墨子》 (*The Book of Master Mò*), discussions on reasoning by comparison (*pì* 辟 [譬]), paralleling (*móu* 侔), analogy (*yuán* 援) and extension (*tuī* 推). The passage for the reasoning by extension runs as follows:

推也者,以其所不取之同於其所取者,予之也.
[Reasoning by] extension consists of affirming the similarities
of those not yet considered with those already considered.

These methodologies had undoubtedly helped the Mòhists in their analysis of the physics of motion.

The conceptual framework developed by the early Chinese scholars for the analysis of motion is entirely compatible with our current conceptualizations. What was absent in the early Chinese work on motion was the means to express their physical concepts in modern mathematical terms. But such mathematization of physical concepts of motion did not begin until the time of Galileo and Newton in the seventeenth century.

28. An excellent discussion on Hu Shi's interpretation versus Maspero's interpretation on *xiào* 效 and *tuī* 推 is given by Needham (1956) on pp. 182 to 184, vol. 2 of *Science and Civilization in China*. I agree with the interpretations of Needham in translating *xiào* as 'model-thinking' and in accepting Hu Shi's interpretation of *tuī* as 'induction'.
29. Joseph Needham (1956), vol. 2, p. 184.

Epilogue

The re-examination of early Chinese works in natural science presented here, though limited only to three specific topics (the physics of motion, acoustics and astronomy) and a brief account of early scientific ideas and thoughts of nature, serves to illustrate that the traditional characterization of early Chinese work in natural science requires substantial modification. The common claim that the physics of motion as being 'totally absent from Chinese physical thinking' is in direct conflict with the extant Chinese records. Not only the physics of motion was not absent in Chinese physical thinking but the Chinese approach to motion was highly theoretical and, in many ways, is compatible with the 'modern' approach. The common view that the Chinese work on acoustic as being 'highly empirical and non-analytic' is not supported either by the extant Chinese records or by recent archaeological discoveries. In fact, the ancient Chinese not only had a highly developed physical acoustics but also provided, in musical acoustics, the only known analytic method from antiquity which is capable of generating musical scales in the pentatonic, heptatonic and chromatic intonations. And in addition, it is highly probable that Chinese acousticians had already developed, in the −5th century, an analytic method of generating chromatic scales in the natural (just) intonation. The study of early Chinese works on astronomy also reveals that the common characterization of Chinese works on astronomy as 'lacking theory' is not valid (see p.159 to p.165). In many ways, the physical theories in the Chinese cosmological views are quite compatible with the 'modern' views.

Thus, the re-examination of the early Chinese works in natural science presented here serves to illustrate that the problem with the lack of early Chinese participation in the development of modern science and technology is not a consequence of the lack of early scientific traditions in ancient China as commonly assumed. The ancient Chinese had remarkable early achievements not only in mathematics but also in science. The early scientific ideas and thoughts of nature shared by the Chinese philosophical schools were also conducive rather than inhibitive to the development of science. The decline in science and technology in China is not due to the failure of their culture but due to the failure of the post-Sòng 宋 Chinese to overcome setbacks caused by social, political and world events and to build upon the sound foundation laid down by their ancestors.

It is certainly true that science and technology in China were on the decline soon after the death of the early Yuán scholars such as Wáng Xún 王恂 (1235–81), Guō Shǒu-Jìng 郭守敬 (1231–1361), and Zhū Shì-Jié 朱世傑 (fl. 1268–1303).[293] This was a consequence caused by the long costly war between the Mongols and the Sòng and by the gross neglect of the successors to Yuán Shì-Zǔ 元世祖. Following this decline, science and technology in the Ming dynasty entered a long period of stagnation and it was at this juncture in the late sixteenth century that cross-currents between the East and West were brought on by the appearance of the Jesuits in China. At that time, even with the decline and stagnation in China, the difference between the East and West in the level of science and technological achievements was not significant. When Matteo Ricci first entered Běijīng in 1601, for example, Galileo's revolutionary work *Sidereus Nuncius* (*Starry Messenger*), which brought Europe to a new level of intellectual awareness, was not yet in existence. A pertinent question that one needs to investigate is what had happened in China during the crucial century that followed this initial encounter with the West? One needs to know what had prevented China from responding to the rapid changes in science and technology that took place in Europe in this crucial century? It is beyond the scope here to address these questions in depth, but a brief review of the subsequent events that occurred in the cross-currents in astronomy during this crucial century is instructive since astronomy was one of the major early fields that sparked the 'scientific revolution' and was also one of the major fields involved in the exchanges between the East and West.

When historians talk about cross-currents in astronomy between the East and West in the period that began in the late sixteenth century, the main topics are usually the heliocentricity of our world system and the Galileo telescope. Both these topics are from the West and their introduction in China was of great importance. Besides these two topics, there are two additional topics of equal significance, namely the empty infinite space-time world-view and the equatorial coordinate and

293. It has often been said that early science in China reached its heights in the Sòng Yuán 宋元 periods, but the Yuán dynasty produced no outstanding scholars in science based on its own tradition. The early Yuán scholars were essentially products of the late Song, based on the Sòng tradition.

mounting system. Both these two topics were well developed in ancient China long before the sixteenth century and their history and relationship with cross-currents have not been well studied. However, the adoption of the equatorial system and the abandonment of the solid-sphere world-view in favour of the empty infinite space-time world-view were of fundamental and crucial importance to the development of 'modern' astronomy in Europe. A significant question here is why, with the introduction of these new concepts and innovations, astronomy progress rapidly in Europe but not in China?

Much has been written about the manner in which the concept of heliocentricity was introduced in China by the Jesuits. There are even historians who consider that the deliberate hiding of this new concept from the Chinese by the missionaries was responsible for the setback in astronomical reform in China. I do not share such a view since the delay in the concept of heliocentricity was not as crucial as a number of other factors that affected the astronomical reform during this period.[294] Unlike in Europe, where the heliocentricity view was one of the major driving forces for astronomical reform, the situation in China was basically different since the Chinese view of geocentricity of the world system was not as interwoven with religious implications as in the West. There was much less pressure to reject concepts other than geocentricity in China than in the West. In practice, the heliocentric view of taking the sun to be at rest, despite its conceptual importance, is in fact mathematically equivalent to the geocentric view of taking the earth to be at rest, since it is a matter of coordinate transformation. In fact, once the full concept of heliocentricity appeared in China in the early nineteenth century, its acceptance was rather swift.[295]

The introduction of the Galileo telescope in China marked the beginning of the European influence on observational astronomy in China. The first reference to the telescope in Chinese literature is in the *Tiān Wèn Lüè* 《天問略》 (*Explicatio Sphaerae Coelestis*) of 1615 by Emanuel Diaz (Yáng Mǎ-Nuò 陽瑪諾).[296] In this reference, a mention was made of a *qiǎo qì* 巧器 (clever instrument) recently constructed by a famous Western scholar in astronomical science who was unsatisfied with the capability of one's eyes. With this instrument, a one-foot object at a

294. It is obvious that China could have been spared the Tychonic theory of the world view if the heliocentric theory of Copernicus was not held back by the missionaries during the early periods of contact with the West. But the delay in the concept of heliocentricity was not a major cause for the setback of astronomical reform in China.

295. One can, of course, cite some scholars in China, just as in the West, who oppose the heliocentric view of the world system.

296. See the appendix of *Tiān Wèn Lüè*.

distance of 60 mile can be seen as clear as if it were in front of one's eyes. The reference goes on describing a number of the observational discoveries made with the aid of this instrument, but the optical design of the instrument was not mentioned. It is in the *Yuǎn-Jìng Shuō* 《遠鏡說》 (*An Exposition of Telescope*) of 1626 by J. Adam Schall von Bell (Tāng Ruò-Wàng 湯若望, 1591–1666) that one finds descriptions of a telescope and its optical design.[297]

The response to the telescope and the acceptance of the discoveries of Galileo by the Míng 明 astronomical communities were very decisive and swift as evidenced by the speed and depth of the astronomical reform carried out under the leaderships of Xú Guāng-Qǐ 徐光啟 (1562–1633) and later Lǐ Tiān-Jìng 李天經 between 1629 and 1635.[298] The construction of such a telescope was included in their astronomical reform. A formal proposal for the construction of three such telescopes was submitted to the Emperor Yì Zōng 毅宗, and support was granted in 1632. Despite Xú's untimely death in the following year (1633), a telescope was constructed in 1634 under Lǐ. Hence, within seven years after the first appearance of a description on the optical design of a Galileo telescope in China, the Míng astronomers were able to construct their own telescopes for astronomical observations. In view of the long observational tradition in astronomy maintained throughout the centuries in Chinese civilization, such an enthusiastic response to a new astronomical instrument was not unexpected.

From the *Chóng-Zhēn Lì-Shū* 《崇禎曆書》 (*Chóng-Zhēn Treatise on Astronomical Science*) (137 volumes) compiled by the Míng reformers between 1629 and 1634, it is evident that the Míng reform, to a certain extent, was a one-sided adoption of the views of the West without an appropriate evaluation of their merit and relationship to the astronomical views and methods in China.[299] The reform was nevertheless timely and important. Ever since the death of Guō Shǒu-Jìng 郭守敬 (1231–1316) in the Yuán dynasty, astronomy in China had entered into a long period of stagnation. Thus, the new methods brought to China by the missionaries were important stimuli for astronomical reform.

297. This book completed in 1626 with the assistance of his Chinese colleague Lǐ Zǔ-Bái 李祖白 was published in 1630 and later incorporated (under a changed title) in the *Xī-Yáng Xīn-Fǎ Lì-Shū* 《西洋新法曆書》 (*Treatise on Calendrical Science according to the New Methods from the West*) of 1645. There are claims that this work of J. Adam Shall von Bell was based probably on the book *Telescopium* (Francoforte, 1618) by Girolamo Sirturi.

298. For a recent account of this astronomical reform, see Hashimoto Keizo 橋本敬造 (1988).

299. For oppositions to the one-sided adoption, see for example, the criticism of the solidsphere world-view by Kē Zhòng-Jiǒng 柯仲炯 in his *Xuān-Yè Jīng* 《宣夜經》 of 1628.

In retrospect, the adoption of the telescope by the Míng astronomers was indeed remarkably fast. This expeditious adoption placed China in a position capable of competing favourably with the West. This situation could be meaningful, since after the Chinese acquired the knowledge to construct their own telescope in 1633, no significant progress on telescopes was made in Europe for more than a quarter of a century. Other than Kepler's suggestion of using a convex lens for the eye-piece to broaden the range, the refracting telescope remained unchanged from the original Galileo form. Not until after the appearance of Huygens' design of a micrometer in 1659, did a potentially viable improvement of the telescope as a measuring instrument became feasible. The invention of a reflecting telescope by Newton was not made until 1668.

However, the reform initiated by Xú Guāng-Qǐ was abruptly interrupted by the destruction and turmoil resulting from the change of rulers. As the disruption caused by the overthrow of the Míng 明 dynasty by the Manchus gradually subsided, astronomy emerged in the Qīng 清 dynasty under the direct control of missionaries. Soon after the Manchus entered Běijīng in 1644, Schall submitted to the newly established Qīng government a shortened version of the *Chóng-Zhēn Lì-Shū* 《崇禎曆書》 under the new title *Xī-Yáng Xīn-Fǎ Lì-Shū* 《西洋新法曆書》 (*Treatise on Astronomical Science According to the New Western Methods*) (103 volumes) and stated:

> 臣創立新法, 規制儀象, 以測諸曜視行,...
> 臣閱曆寒暑, 晝夜審視, 著為新曆百余卷.
> Your servant established new methods and constructed accordingly instruments for the observation of the motions of planets and stars.... Your servant examined and observed, day and night, the calendrical changes of seasons and authored more than one hundred volumes on new calendrical science.

The work was approved by the Qing government and the Shí Xiàn 時憲 Calendar was then officially adopted. Within six months after the Manchus entered Běijīng, Schall was appointed to the position of director of the new Qīng Imperial Bureau of astronomy.

Schall's control of the bureau not only created strong conflicts with the bureaucratic intellectuals in the Qīng government but also was a setback to the revival of astronomical reform. For the next 20 years, Schall made no effort to upgrade astronomy in China beyond the level of the *Xī-Yáng Xīn-Fǎ Lì-Shū*. Instead, he promoted the outdated Tychonic method as the *xī-fǎ* 西法 (Western method), a science which he supposed could only be produced in a Christendom.[300] In his effort to promote the

300. Needham (1959) has commented (vol. 3, p. 449): 'The implicit logic was that only Christendom could have produced (the new science). Every correct eclipse prediction was thus an indirect demonstration of the truth of Christian theology'.

xī-fǎ, he would not create, in the Imperial Bureau of Astronomy, a division with title *Xī Kē* 西科 (Western Division) since it would place, in his view, the *xī-fǎ* on the same level as the Muslim Division (*Huí-Huí Kē* 回回科) already existing in the bureau.

Not until 1664, was the bureaucratic intellectuals led by Yáng Guāng-Xiān 楊光先 finally successful in bringing charges against Schall. Among the various charges were using the church for political purposes and plagiarism. To submit a shortened version of the *Chóng-Zhēn Lì-Shū* as his own was indeed an act of plagiarism, since the bulk of the work and measurements was done by the Míng astronomical reformers even though portions of the book, based on methods from the West, was translated and carried out with Schall's assistance. Schall was found guilty and removed from the directorship. By this time, Emperor Kāng Xī 康熙 (who succeeded the throne in 1662) was only ten years old and was not in charge of the affairs himself. In 1665, the following year, the directorship of the Bureau of Astronomy was given to Yáng Guāng-Xiān, who had little knowledge about astronomy and relied on Wú Míng-Xuǎn 吳明烜 of the Muslim Division of the Imperial Bureau of Astronomy for information on calendrical science.

Astronomical reform was not revived until 1669, one year after Kāng Xī assumed the emperor's duty himself in 1668 at the age of 15. The Yáng – Schall conflict brought to focus the ulterior motive of the missionaries for bringing Western methods to China. Kāng Xī certainly learned of this disclosure and decided to participate in the decision making. Soon after Kāng Xī assumed the emperor's duty, Schall's assistant, Ferdinand Verbiest (Nán Huái-Rén 南懷仁, 1623–88) who taught the teenage Emperor Kāng Xī mathematics and astronomy of the West, again brought the charge that the calendar issued by Yáng Guāng-Xiān was inaccurate. Kāng Xī decided to end the long standing rivalry by calling Yáng and Verbiest together to test the accuracy of their respective calendars. Little did the young Emperor know how meaningless the test was in relation to astronomy. As a result of the test, which showed that the Huí Huí 回回 calendar was less accurate than the Shí Xiàn calendar, Kāng Xī removed Yáng from the directorship and placed Verbiest in charge of calendrical reform. In retrospect, it was indeed very unfortunate that the able astronomers such as Wáng Xī-Chǎn 王錫闡 (1628–82) were not consulted.[301]

The Qīng astronomical reform, ordered by the young Emperor Kāng Xī, was basically different from that originally envisioned by the Míng

301. Wáng Xī-Chǎn 王錫闡 was critical of Schall's incorrect interpretations of Chinese work and also the inconsistencies in the methods and views of the West.

reformers. Much of the new characteristics reflected the policies and the direct involvement of the emperor himself. The most elaborate attempt in reforming observational astronomy in the Qīng dynasty was the refitting of the Imperial (Běijīng) Observatory. This important project was carried out under the directorship of Verbiest, commissioned by Emperor Kāng Xī in 1669. After six years of construction and a large budget, the observatory was finally re-equipped in 1674 with the following six astronomical instruments:[302]

1. Ecliptic armillary sphere, *huáng-dào jīng-wěi-yí* 黃道經緯儀.
2. Equatorial armillary sphere, *chì-dào jīng-wěi-yí* 赤道經緯儀.
3. Celestial globe, *tiān-tí-yí* 天體儀.
4. Horizon circle, *dì-píng jīng-yí* 地平經儀.
5. Quadrant, *dì-píng wěi-yí* 地平緯儀 (or *xiàng-xiàn-yí* 象限儀).
6. Sextant, *jì-xiàn-yí* 紀限儀.

To the six instruments, two additional instruments were later added.[303]

7. Quadrant altazimuth, *dì-píng jīng-wěi-yí* 地平經緯儀.
8. Elaborate equatorial armillary sphere, *jī-héng fǔ-chén-yí* 璣衡撫辰儀.

The quadrant altazimuth (7) was constructed by Bernard Kilian Stumpf (Jì Lǐ-Ān 紀理安) between 1713 and 1715 and the elaborate equatorial armillary sphere (8) was constructed in 1744 under the directorship of Ignatius Kögler (Dài Jìn-Xián 戴進賢) assisted by Augustin von Hallerstein (Liú Sōng-Líng 劉松齡) and Anton Gogeisl (Bào Yǒu-Guān 鮑友管), perhaps also by Antoine Gaubil (Sòng Jūn-Róng 宋君榮 and de la Charme (Sūn Zhāng 孫璋).

In retrospect, one cannot but be puzzled by the questionable selections and designs of the instruments used in equipping the Imperial Observatory. All the instruments were essentially traditional instruments relying on naked-eye observations. Except for the sextant, all the instruments were previously known in China and the constructional improvements found in these instruments were all of minor nature. It is also curious why the quadrant was not constructed in combination with the horizon circle. An obvious deficiency of the newly constructed instruments was the absence of optical aids, since none was equipped with an optical device and the telescope was totally absent. In view of

302. See for example, Joseph Needham (1959), vol.3, pp. 451–2.
303. According to a photograph of the observatory, there was a smaller celestial globe, *hún xiàng* 渾象, which later disappeared after 1920. This smaller celestial globe has not been positively identified. It could be the globe of Guō Shǒu-Jìng.

the early interest in the telescope and the achievement made by the Míng scholars in the construction of a telescope soon after its introduction in China, this was indeed unexpected. In comparison with the astronomical instruments developed in Europe during this period (from the seventeenth to eigteenth centuries), the instruments at the Imperial Observatory constructed under the direction of Verbiest and his subsequent successors were already substandard.

After completing his instruments in 1673, Verbiest also wrote the *Líng-Tái Yí-Xiàng Zhì* 《靈臺儀象志》 (*Records of the Observatory Instruments*) to describe the principle and use of these instruments.[304] The book also includes, at the end, a table of star measurements supposedly obtained by the newly constructed instruments. However, in comparison with the measurements listed in the *Xī-Yáng Xīn-Fǎ Lì-Shū*, one finds that the new values for the star latitudes are identical with those listed in the latter book and the values for the star longitudes are all different from those listed by the same value 37'.[305] Since the measurements listed in the *Xī-Yáng Xīn-Fǎ Lì-Shū* were actually made by the Míng astronomers in 1629, the value 37' in longitudes, no doubt, was introduced by Verbiest to account for the precession of the equinoxes. This implies that the measurements listed in the Verbiest's book were not new measurements, but based on those of the Míng astronomers first published in 1634 in the *Chóng-Zhēn Lì-Shū*. This is indeed incomprehensible! One of the primary purposes for the refitting of the Imperial Observatory was in fact to determine more accurately the positions of the stars.

In explaining the absence of the telescope, it has recently been pointed out that 'at that time the telescope was not yet suited to determine precisely the positions of the stars, which was the need of the Qīng government for improving a calendar.'[306] The assertion that telescopes at the time were not yet suited for precisely determining the positions of the stars was probably correct based on the telescopes known to Verbiest. However, the situation with telescopes in Europe was rather different from the time when Verbiest left Europe in 1658. By the time the Imperial Observatory was commissioned for refitting in 1669, improvements in telescopes were already made in Europe for large-angle measurements by the use of cross-threads (*miáo-zhǔn chā-sī* 瞄準叉絲) and

304. This work was later incorporated into the *Yù-Dìng Yí-Xiàng Kǎo-Chéng* 《御定儀象考成》 (*Complete Studies of Astronomical Instruments*) edited by Ignatius Kögler and Augustin von Hallerstein in 1744.

305. See Research Group of Chinese History of Astronomy (1981), p. 231 and footnote 1. The number of stars listed in Verbiest's *Líng-Tái Yí-Xiàng Zhì* is 1366, 14 more than that listed in the *Xī-Yáng Xīn-Fǎ Lì-Shū*, but this was due to misprint.

306. See Xí Zé-Zōng 席澤宗 (in press) 'Why F. Verbiest Did Not Make a Telescope'.

for small-angle measurements by the invention of the screw micrometer (*xuán cè-wēi-qì* 旋測微器). Through the use of the cross-threads, one can accurately measure the direction one sees the star by bringing the focal image of the star to the exact intersection of the cross-threads. With the direction correctly determined, the positions of the stars can then be better measured from its projection on the celestial sphere. By the use of a screw to control two parallel threads in a Huygens' micrometer, higher accuracy can also be achieved for short angular-distance measurements, such as angular diameters of planets. In addition, improvement in mounting telescopes was also being pursued.[307]

With the telescope totally absent from the instruments at the Imperial Observatory, the Qīng astronomers were not in a position to compete favourably with their counterparts in Europe in observational astronomy. In fact, three years before Emperor Kāng Xī even commissioned Verbiest to re-equip the astronomical instruments at the Imperial Observatory, European astronomers, such as Pichard (1620–89) and Flamstead (1646–1719), had already independently carried out systematic measurements of the angle diameter of planets with telescopes equipped with a screw micrometer. There were certainly many debates in Europe on the accuracy of measurements obtained using telescopes with respect to other devices relying on the naked eye. But it was through such telescopic measurements and debates that eventually led to a better understanding in Europe of the effects of atmospheric refraction and aberration of light in astronomical measurements. The failure to keep up with the progress in observational astronomy, in my opinion, was one of the crucial factors that affected the progress of astronomical reform in China.

It should be noted that the significance of a telescope lies not just as a measuring instrument. In fact, telescopes made most of its early contributions to astronomy as an observational instrument rather than a measuring instrument. This is best appreciated by examining the discoveries made by Galileo through the use of his improved telescope. Given below is Galileo's summary of his observations:[308]

1. The moon's surface is not smooth and has, just as the earth's surface, mountains, rivers, lakes and oceans.[309]

---

307. The equatorial telescope mounting in Europe reached its final stage in the work of James Short (1732 to 1768). The invention of the equatorial mounting can be traced to Guō Shǒu-Jìng of the thirteenth century in China as evidenced by his *jiǎn-yí* 簡儀 (simplified instrument). In Europe, equatorial mounting first appeared in the instruments of Tycho Brahe (see the greater equatorial armillary of 1585).
308. See Galilei Galileo, *Sidereus Nuncius* (1610).
309. The interpretation that there are rivers, lakes and oceans on the surface of the moon based on his telescope observations was, of course, not substantiated.

2. The surface of the sun has black spots.
3. Planet Jupiter has four moons.
4. Planet Venus has phase variations.
5. The Milky Way is composed of many fixed stars.
6. The number of fixed stars observable increases with the magnifying power of the telescope, and the rate of size increase for stars is much smaller than for the sun and moon.

Obviously, none of these observations provided by the telescope was based on precision measurements, nevertheless they were of great importance. The impact of these observations was particularly significant in the West due to the contrary nature of the observations, not only with respect to the traditional view of the world system but also with respect to certain philosophical and religious beliefs. These added dimensions in philosophy and religion greatly enhanced the impact of Galileo's observations.

It is worth noting that with the observations that the number of fixed stars observable increase with the telescope's power, and the rate of size increase for stars is much smaller than for the sun and moon, Galileo had also observed contradictions to the solid-sphere world-view. However, he failed to recognize the observation as an indication that stars are not attached on a crystalline sphere with a fixed ratio. Consequently, he did not initiate the process to abandon the solid-sphere world-view. Even with this failed interpretation, it illustrated the potential power of a telescope as an observational instrument.

It is evident that the telescope had been crucial to the development of the new astronomy. After a great effort to acquire the knowledge to construct their own telescope in 1633 from the missionaries by the Míng astronomers, it is ironic only to find, in the Qīng dynasty, a total absence of telescopes among the astronomical instruments in the most important and influential observatory in China. This absence of telescopes at the Imperial Observatory was detrimental to the Chinese astronomers. It not only handicapped them from competing with their counterparts in Europe, but also denied them the opportunities to develop experience and intuition by working directly with telescopes. In retrospect, it is evident that one of the driving forces in 'modern' observational astronomy has been the intuitive notion that optical devices can be further refined to provide better resolution and higher accuracy for celestial observations and measurements.

An obvious question to ask is why the Chinese did not benefit from the knowledge of telescope that they acquired from the missionaries so early in their astronomical reform? One may argue that should the astronomical reform, as envisioned by the Míng astronomers, be allowed to continue in the Qīng dynasty, astronomy in China would probably have kept better pace with the new progresses made in Europe. Such a hypothetical argument does not, however, provide any insights to the question of what caused the reform to change from that envisioned by the Míng astronomers. Aside from the disruptions caused by the Lǐ Zì-Chéng 李自成 revolt and by the Manchu conquest which evidently were beyond the control of the astronomical community, one needs to investigate the reasons why after these disruptions subsided, astronomical reform did not revive with the same vigour as exhibited by the Míng astronomical reform?

Obviously, the problem was not due to the delay in the appearance of the concept of heliocentricity in China. In fact, the disruption in the Imperial Bureau of Astronomy and the selection of astronomical instruments for refitting the Imperial Observatory had more of a negative impact than the delay in the concept of heliocentricity. From the perspective of vision and innovation, Verbiest's re-equipment (1669–74) of the Qīng Imperial Observatory commissioned by Emperor Kāng Xī 康熙 was indeed inferior to Guō Shǒu-Jìng's 郭守敬 re-equipment (1276–79) of the Yuán Imperial Observatory commissioned by Yuán Shì-Zǔ 元世祖. In the work of Guō Shǒu-Jìng, the observatory instruments were not only state of the art at that time, but were further enhanced with the addition of a new instrument, *jiǎn-yí* 簡儀 (simplified instrument, see Fig. 60), that he invented. In the work of Verbiest, on the other hand, not only were the observatory instruments not upgraded to the level of the contemporary European instruments, they were deprived of a telescope, one of the most important new instruments.

Though Verbiest had undoubtedly been exposed to certain education in science while studying at the Leuven University, and probably was also instructed in astronomy by the church in preparation for his visit to China, he was not, after all, an astronomer nor an instrumentation specialist. After arriving in Běijīng, he served as an assistant to Schall until Schall's death in 1666, three years before he was commissioned to refit the imperial observatory. Apparently he was not in close contact with new European developments in astronomical instruments. The work of Verbiest reflected well his ability as an instrumental astronomer. The two additional instruments added by later missionaries did not improve the situation. In fact, no telescope was later added to the observatory. This prolonged absence of telescopes at the observatory was detrimental to the progress of observational astronomy.

In addition to the instruments constructed by the missionaries, the relationships between the missionaries and the Qīng astronomical community were also not conducive for rapid development of astronomy. It should be noted that the missionaries gained the official position of the Director of the Imperial Bureau of Astronomy, based not on their own

Figure 60. A 1437 replica of the original *jiǎn-yí* 簡儀 devised by Guō Shǒu-Jīng 郭守敬 in 1276, the earliest known astronomical instrument with an equatorial mounting. The original *jiǎn-jí* was melted down in 1715 by Jesuit Bernard Kilian Stumpf (Jì Lǐ-Ān 紀理安) for the purpose of making a quadrant. The replicate is now preserved in the Zǐjīnshān 紫金山 Observatory, Nánjīng.

achievements in astronomy nor on their experience in the field of astronomy, but on the general impression that they were informed with the new methods of science from Europe. Their blind assurance of Western superiority was constantly a source of difficulty. Consider, for example, Bernard Stumpf who in 1715 contributed the quadrant altazimuth to the Imperial Observatory. Even though he attained the position of director of the Imperial Bureau of Astronomy, he was at best a mediocre astronomer. In the *Cāo-Màn Zhī-Yán* 《操縵卮言》, Méi-Gǔ-Chéng 梅穀成 (1681–1763) stated:

> 康熙五十四年,西洋人紀理安欲炫其能而滅棄古法.
> 復奏制象限儀,遂將台下所遺元明舊器作廢銅充用.
> 僅存明仿元制渾儀簡儀天體二儀而已.
> In the fifty-fourth year of Kāng Xī's reign (1715), Westerner Stumpf, intending to show off his ability and to eliminate ancient methods, proposed to construct a bronze quadrant. He destroyed the Yuán and Míng instruments stored below the observatory by melting them down as used bronze (to make a quadrant). Now only Míng copies of a simplified armillary-sphere (jiǎn-yí 簡儀) and a celestial globe (tiān-tí 天體) are left.

Ironically, the new instrument (a quadrant altazimuth) constructed by Stumpf was actually an attempt to correct a mistake in design made by Verbiest. It is an instrument obtained by simply combining a quadrant with a horizon circle. The quadrant altazimuth constructed by Stumpf was not only clumsy in design, but was also less valuable than some of the instruments that he had destroyed, in particular, the original *jiǎn-yí* (see Fig. 60), designed and constructed in the thirteenth century by Guō Shǒu-Jīng in his re-equipment of the Yuán 元 Imperial Observatory. The superiority attitude of the missionaries was not just a source of friction but was also responsible for the misrepresentation of the status of astronomy in China at the time.

Due to the fact that when astronomy reemerged in 1644 in the Qīng dynasty, Schall was the director of the Imperial Bureal of Astronomy and when the astronomical reform reemerged in 1669, Verbiest was in charge of refitting the Imperial Observatory, it is therefore natural to question whether the missionaries were responsible for the setback of the Qīng astronomical reform. As missionaries, they were of course under no obligation to bring the methods of the West to China. However, once they manipulated themselves into the Imperial Bureau of Astronomy and accepted positions in the bureau, they were responsible for their performance in the bureau. Thus, despite the goodwill in bringing the optical design of a telescope to China in his early days, Schall should be held responsible for the setback in the astronomical bureau in the twenty years when he was the director. For the same reason, Verbiest should also be held responsible for the inferior instruments constructed under his direction and for his decision to not include a telescope in refitting the observatory. On the other hand, one must also realize though the success of the bureau and of refitting project depended critically on the vision and ability of the individual in charge, the selection of the individual in charge is also of crucial importance. Thus, in my opinion, the important question to ask is not just whether Schall and Verbiest were responsible but also why they were selected for the task in the first place.[310] Why was the directorship of the Imperial Bureau of Astronomy placed in the hands of indivuduals such as Schall, Verbiest and Stumpf, as well as Yáng Guāng-Xiān, who were not competent in astronomy?

One may argue that events in China were such that the missionaries were able to connive their way into the directorship of the Bureau of Astronomy. This was perhaps the case with Schall,[311] but after the

310. See Chén Chēng-Yīh 程貞一 (1990) in Chinese.
311. It should be noted that the ability of translating European astronomical materials into Chinese language with Chinese assistants can hardly qualify one as an astronomer.

ulterior motive of the missionaries had been brought into focus in 1664 by the Yáng – Schall conflict, why was the practice of using missionaries continued until 1826 in the Dào-Guāng 道光 reign? Why then was Yáng appointed to the directorship? The answer had obviously to do with the Qīng authorities. Among the Qīng authorities, the person who should bear a substantial portion of the responsibility for the failure in selecting competent leaders in astronomical reform and the Imperial Bureau of Astronomy was Emperor Kāng Xī himself. In retrospect, this may appear ironical since Emperor Kāng Xī was not only a major driving force for the Qīng astronomical reform but he was also a capable ruler with a strong intellectual curiosity. In comparison with his contemporary rulers, for example, King Louis XIV (1641–1715) of France, Kāng Xī certainly showed a more personal interest in science and technology. Then, why should Kāng Xī be responsible? After all the selection of Verbiest for refitting the observatory was made when he was only sixteen years old.

One must realize, however, that the Kāng Xī reign (1662–1722) lasted more than half of a century and it was during this half of century that the gap in astronomy as well as in science between China and Europe was greatly widened. It was during his reign that one witnessed the development of calculus[312] and the Newtonian mechanics in Europe.[313] In addition, Kāng Xī was also known as a ruler who demanded to make major decisions himself. After the early mistakes, Kāng Xī certainly had adequate time and opportunities to reverse the situation but he did not. Not until near the end of his reign in 1714 did Kāng Xī order an upgrade of the *Xī-Yáng Xīn-Fǎ Lì-Shū* which after all was compiled by the Míng astronomical reformers between 1629 and 1634, almost a century earlier. The result was the book *Lì-Xiàng Kǎo-Chéng* 《曆象考成》 (*Compendium of Astronomical Science*) completed in 1722. Though this work was an improvement over the *Xī-Yáng Xīn-Fǎ Lì-Shū*, in comparison with the level of the European treatise on astronomy, it was rather substandard. In this attempt, astronomers outside the bureau were also invited to participate but the effort was rather late and limited.

The fallacy of Kāng Xī was not in the appreciation of science and technology, but in relating this appreciation at a national level. He, after all, was the ruler of a nation facing rapid changes around the world. He should have had the vision and moral duty to keep the nation contemporary with the emerging European nations. With his interest in science and technology, Kāng Xī was in a favourable position to

312. For a recent discussion on the development of the concept of limit see Chén Chēng-Yīh 程貞一 (1987), pp. 3–52.
313. See the *Philosophiae Naturalis Principia Mathematica* (1687) by Issac Newton.

accomplish at a national level, since in the second half of the seventeenth century, not only China had wealth and strength but also the gap in science and technology between China and Europe was still not yet very significant. Instead, Kāng Xī kept his interest and activity in science and technology within a small, controlled inner circle. He seems to have derived personal satisfaction in learning of new advances in science. But at a national level, in fact, he implemented no consequential policies and allocated no significant budget for the promotion and support of science and technology. No topics in science and technology were, for example, incorporated in the imperial examination. He employed missionaries frequently as a quick source of new scientific and technological knowledge from Europe but made no effort to acquire the knowledge directly. With all his interest in the new methods from the West, Kāng Xī had never sent off any team of Chinese scholars to Europe for facts finding and keeping up with European development in science and technology. In view of his interest in science and technology, and his intellectual capacity to appreciate their importance to the nation, it makes his lack of a concrete policy to promote science and technology at a national level even more inexcusable as a ruler of this critical period in the history of science.

From this brief examination of the events in the field of astronomy during this early period of crosscurrents with the West, it is apparent that the absence of the early Chinese participation in the development of 'modern' science is a very complex issue. One cannot exclude the dynamics of the socio-economical and political influence and seek answers simply in terms of the dubious concept of 'inhibitive factors' in the Chinese culture.

Index