THE
SCIENTIFIC METHOD
OF
IBN AL-HAYTHAM

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ISLAMIC RESEARCH INSTITUTE
International Islamic University
slamabad (Pakistan)

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Kitab

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FOREWORD

Islam's greatest contribution to human history is its sound and healthy concept of God, and a sound and healthy vision of life and society. Thanks to these, the followers of Islam displayed an amazing outburst of creative cultural energy during the first several centuries of their existence. The greatness of Islam in history lay in "the type of manhood" and "the cultural world", to borrow Muhammad Iqbal's expression, that sprung out of the spirit of the message of Islam. One, though not the most significant manifestation of this creative cultural energy was the impressive performance of the Muslims in the field of exact and natural sciences and technology.

Muslims appeared on the intellectual scene of the world as a people keen to learn everything useful that was available. Even as early as the last decades of the first century of the Islamic calendar, they had begun to acquire the learning of others by vigorously translating whatever seemed worthwhile from outside. In course of time a vast literature in the field of science and philosophy was translated into Arabic and proved effective in preserving the intellectual heritage of mankind. It did not take long, however, for these "translators" to launch upon innovative scientific activity as a result of which frontiers of human knowledge were vastly expanded and the realm of intellect greatly enriched. However, the greatness of the Islamic contribution to science does not consist, in the words of Robert Briffault, "in startling discoveries or revolutionary theories". That contribution is even greater. For it seems that the Muslims contributed decisively to the development of the present scientific method which has been the key to further scientific achievements. It is because of this crucial contribution that, in the words of Robert Briffault: "science owes a great deal more to Arab culture; it owes its existence."

Ibn al-Haytham (d. 430 A.H./1039 A.D.), the subject of the present work, was one of the greatest scientists produced by the Islamic civilization. His contributions cover a number of fields, but most important of these are the fields of mathematics and physics.

The late Dr. Muhammad Saud, a research scholar of this Institute, whose scholastic career came to a sudden end in 1987 by his death at a relatively young age, virtually devoted his life to highlighting the scientific achievements of the Muslims. His earlier work, *Islam and Evolution of Science*, which was published in 1986 was well received and soon its second edition had to be brought out. The present book is a work of more careful and painstaking scholarship. The subject that Dr. Saud has taken up is also more rewarding and seminal--the scientific method of Ibn al-Haytham. It is only when the method of major Muslim scientists have been carefully studied that it will be possible to come forth with some generalisation about the scientific method of the Muslims and the contribution that the Muslims were able to make to the development of the scientific method.

Dr. Saud's work is both interesting and valuable. It is particularly significant since it blazes the trail in a scholarly field which remains to be ploughed by an increasing number of researchers.

Islamabad
February 17, 1990.

Zafar Ishaq Ansari
Director General
Islamic Research Institute

PREFACE

The scientific method of enquiry is universally recognized as being essential for scientific achievements and is in common use today. However, its origin is somewhat foggy and controversial as different authorities attribute it to different scholars. According to an old English tradition, Francis Bacon was the originator of this method and the history of science was only a history of the adoption and application of his method by all subsequent scientists. Rupert Hall finds this claim plainly exaggerated. Bertrand Russell[1] remarks that the scientific method was fully developed by Galileo, who was thus the source of sound knowledge. Robert Briffault gives this credit to Muslim scientists of mediaeval times and describes Bacon as a mere preacher of this method in Europe.

One is, therefore, curious to know the truth and it was with this curiosity that I read the original works of some Muslim scientists like Ibn al-Haytham, al-Bīrūnī, Ibn Sīnā and Jābir Ibn Ḥayyān. In the works of Ibn al-Haytham, I came across a large number of remarks concerning scientific methodology, which interested me considerably. I, therefore, decided to select his method as the subject of my doctoral thesis. By using the words "his method", I only mean the method practised by him and do not by any means imply that he was the discoverer of every detail of that method.

This dissertation is a historical and philosophical investigation of Ibn al-Haytham's theory of scientific method. The study primarily concerns the philosophy of science, but it also briefly traces the history of science (with a view to provide the necessary background).

Our study begins with a brief account of the life and works of Ibn al-Haytham in Chapter I. This is followed in Chapter II by a detailed presentation of his scientific approach and some of his revolutionary ideas. Chapter III discusses his scientific method, which is naturally an outcome of his scientific approach. An example of his inductive method is presented in Chapter IV, while some examples of his physico-mathematical synthesis have been discussed in Chapter V. The influence that the works of his predecessors had exerted on him and the impact that his works, in turn, had on later scientific methodologists have also been evaluated. Our major findings and conclusions are presented in Chapter VI, which concludes this study.

I am indebted to the late Dr. Afzal Husain Qadri and to Dr. M.M. Qurashi for their valuable guidance, to Dr. I.H. Quraishi and Dr. Fazlur Rahman (former Directors of the Islamic Research Institute), Mr. A.A. Zubairi and Prof. M. Hajan (former Secretaries of the Institute) and Mr. Abdul Hakim Khan (former Joint Secretary, Federal Ministry of Law & Parliamentary Affairs) for their encouragement; to Maulana ʿAbdul Quddus Hashimi (former Librarian of the Institute), Hakim Muhammad Said (Chairman, Hamdard National Foundation) and the staff of the Karachi University Library for their help in various ways; and to Mr. Asif Imam and Mr. Muhammad Akram Ghumman for typing this manuscript. To Dr. Saghir Hasan Masumi, Dr. A.J. Halepota, Dr. S.M. Zaman the former and the present* Directors of the Institute respectively, I am deeply indebted for their all-out help at every stage of the preparation of this dissertation.

Muhammad Saud

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* This Preface was written by Dr. Muhammad Saud before his death on May 20, 1987.

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The present work is being published posthumously and hence might lack the last minute refinements from its author's pen. However, the Islamic Research Institute wishes to place on record its debt of gratitude to Mr. Syed Hamid Husain Naqvi for his competent editing of the work. Thanks are also due to Dr. Muhammad Tufail, a research scholar of the Institute and a close friend of the author, who kindly prepared the index.

CONTENTS

TRANSLITERATION TABLE

ء medial	’
ء final	’
ء initial	not expressed
ا	a
ب	b
پ	p
ت	t
ٹ	t̲
ث	th
ج	j
چ	ch
ح	ḥ
خ	kh
د	d
ڈ	d̲
ذ	dh
ر	r
ڑ	ṛ
ز	z
ژ	z̲
س	s
ش	sh
ص	ṣ
ض	ḍ
ط	ṭ
ظ	ẓ
ع	‘
غ	gh

ف	f
ق	q
ک	k
گ	g
ل	l
م	m
ن	n
ں	ṇ
و	w
ہ	h
ۃ	ah (e.g. sunnah)
ـۃ	at (in construct form e.g. sunnat al-Rasūl)
ی	y
ال	al- (’l in construct form e.g. Abū’l)

بھ	bh
پھ	ph
تھ	t̲h
ٹھ	t̲h̲
جھ	jh
چھ	c̲h̲
دھ	d̲h̲
ڈھ	d̲h
کھ	k̲h̲
گھ	g̲h̲

VOWELS

Short	ـَ	a
	ـِ	i
	ـُ	u
Long	ـَا	ā
	ـِی	ī
	ـُو	ū
	او	ō
	اے	ē
	عطف	-o- (اردو / فارسی)
	اضافت	-i- (اردو / فارسی)

DIPTHONGS

ـَو	aw
ـَی	ay
ـَے	ae

Double

ـُوّ	uwwa
ـِیّ	iyya
ـَنّ	anna

CHAPTER I

IBN AL-HAYTHAM: HIS LIFE AND WORKS

The full name of Ibn al-Haytham, who is known in the West as Alhazen, was Abū ʻAlī Ibn al-Ḥasan Ibn al-Ḥusayn Ibn al-Haytham. He was born at Basra in Iraq in c. 365 A.H./ c. 965 A.D. and is, therefore, also known as al-Baṣrī. He settled in Egypt, where he died in 430 A.H./1039 A.D.[1] and is, therefore, sometimes mentioned as al-Miṣrī as well. He was a physicist, an astronomer, a mathematician, a philosopher, an engineer and a theologian. He had a good knowledge of medicine but did not practise it. According to Ibn Abī Uṣaybiʻah, none of Ibn al-Haytham's contemporaries was equal to him (al-Haytham) in the field of mathematics.[2]

Ibn al-Haytham was educated at Basra. He was the product of an age which, in many ways, was characterized by intense intellectual activity. According to George Sarton, his age marked the climax of mediaeval thought.[3] By his time a number of Greek works on philosophy, medicine, astronomy, mathematics and physics had been rendered into Arabic and some Syriac and Sanskrit works on different sciences had also been translated into that language. A large number of scientists and scholars had also shown their creative abilities in several fields of knowledge. In philosophy al-Kindī and al-Fārābī, in medicine Abū Bakr al-Rāzī, in chemistry Jābir Ibn Ḥayyān, in mathematics al-Khawārizmī, Thābit Ibn Qurrah and Banū Shākir, and in astronomy and cosmology Abū Maʻshar al-Balkhī, Ḥunayn Ibn Isḥāq, ʻAbd al-Raḥmān al-Ṣūfī, and many others had already made their mark and their works had acquired considerable significance and had won general admiration. Some of the great intellectual leaders in Ibn al-Haytham's own time were al-Bīrūnī, Ibn Yūnūs, Ibn Sīnā, 'Ali Ibn Īsā and al-Karkhī. In short, the atmosphere within which Ibn al-Haytham worked was quite congenial and conducive to attainment of knowledge and scientific investigations.

The fame of Ibn al-Haytham in scholarship transcended the walls of Basra. The Fatimid Caliph of Egypt, al-Ḥākim bi Amr Allāh, became eager to meet him, especially on hearing that Ibn al-Haytham had told someone that he (al-Haytham) could construct a dam near Aswan for conservation of the Nile waters. Al-Ḥākim, therefore, invited Ibn al-Haytham to visit Egypt, and, on the latter's arrival, the Caliph personally received him at Khandaq, the gateway to Cairo. Ibn al-Haytham was honoured as the Caliph's guest and was provided with all amentities.

Upon receiving al-Ḥākim's signal for going ahead with the implementation of the dam-construction plan, Ibn al-Haytham visited the site with a team of engineers, but when he pondered over the problems he was bound to face—paucity of funds, shortage of labour and lack of the necessary earth-excavating and earth-moving equipment—he abandoned the idea of implementing his plan. It was only a wise decision, for had the work been started recklessly and later abandoned half-accomplished because of unforeseen difficulties, it would have resulted in huge losses to the treasury and colossal waste of time, energy and resources.

After his return from Aswan, Ibn al-Haytham explained the situation to the Caliph and apprised him of the difficulties. Although the Caliph expressed his appreciation of those difficulties and even put Ibn al-Haytham in charge of some Government office,* the latter felt insecure and feared that he might have to face the capricious Caliph's wrath sooner or later. To avoid such eventuality, he feigned madness and continued to do so until the death of the dreaded Caliph.

Ibn al-Haytham possessed a noble disposition, a keen intellect and a high spirit of enquiry. He used to devote most of his time to studying, writing and conducting experimental research, and he tried to avoid all such activities that were likely to hinder the pursuit of those intellectual activities. Ibn al-Haytham was appointed to important posts many a time, first in Basra and later in Egypt, but he always gave up his high office for the sake of study and research. He showed great patience and persistence in his intellectual pursuits.

Ibn al-Haytham made an extraordinary contribution to knowledge. He made valuable discoveries in the fields of optics, mathematics, philosophy, astronomy and other subjects. He used his optical knowledge for constructing burning mirrors, and developed techniques concerning their preparation. He also described the principles, construction and working of a number of scientific instruments.

He gave three reasons for his great enthusiasm for scientific studies. Firstly, he wanted to let those, who seek the truth and prefer it to other things, benefit from his knowledge and achievements during his life as well as after his death. Secondly, on the basis of his studies, he wanted to verify and prove the views which he had arrived at as a result of his search and due deliberation. Thirdly, he wished his investigations and writings to be preserved as his wealth and treasure for his old age and period of decay.[5]

To Ibn al-Haytham, the fruit of the proposed study of science was acquisition of knowledge of facts and handling of all worldly affairs in a balanced manner.[6]

Ibn al-Haytham held the view that only very intelligent people could discover a fact and, therefore, according to him, in his book he addressed not the common people but only those whose wisdom was equal to the combined wisdom of hundreds of thousands of people. He hoped that such people would recognise his position in those sciences and would know how he preferred to seek the truth.[7]

One great incentive for Ibn-Haytham's scientific pursuit came from his observation of people's conflicting views on most issues. He knew that there was only a single truth and that the difference of opinions was the result of the different ways adopted to seek it. Thus the conflict of opinions made him curious about the truth and impelled him to seek the sources of truth.[8]

Ibn al-Haytham led a simple life. To earn his living, he made copies, in his fine handwriting, of such standard works as Euclid's *Elements of Geometry*, *Almajest* and *al-Mutawassiṭāt* and sold them to those who valued such books. His worldly needs were few, and the sale of his hand-written books brought him enough money to satisfy them.[9]

Al-Bayhaqī has narrated an incident from Ibn al-Haytham's life to show his self-contentment. Surkhāb, a noble of Simnān in Syria, came to Ibn al-Haytham to study under him. Ibn al-Haytham demanded 100 *dīnārs* a month, to which the noble agreed and stayed with him for three years. When Surkhāb completed his education and was about to leave, Ibn al-Haytham asked him to take back the amount he had paid saying, ''You deserve this money all the more, since I wished just to test your sincerity, and when I saw that for the cause of learning you cared little for money, I devoted full attention to your education. Do remember that, for any righteous cause, it is not proper to accept a return, a bribe, or a gift''.[10]

The same biographer mentions that the Amīr-al-Umarā' of Syria offered Ibn al-Haytham a munificent sum and fixed an honorarium as well. At this, Ibn al-Haytham is reported to have said: ''All that I need is my daily food, a servant, and a maid to look after me. If I amass more than the barest minimum that I need, I shall turn into your slave; if I spend what I save, I shall be held liable for wasting your wealth.''[11]

Ibn al-Haytham recorded in his writings the knowledge he gained through books and direct studies of Nature. He was a prolific writer. Ismā'īl Bāshā has listed as many as 127 books and treatises against his name, whereas Ibn Abī Uṣaybi'ah has mentioned 200 works of his, including commentaries on some Greek works. He prepared summaries of and commentaries on many works of Aristotle and also summarized a number of Galen's works on medicine.[12] He wrote on physics, optics, mathematics, engineering, astronomy, medicine, botany, philosophy, metaphysics, logic, optics and religious creeds. His main work is his book on optics, *Kitāb al-Manāẓir*, which is a systematic and critical study based on observations and experiments. The book deals with the nature of light and colour, the anatomy and physiology of the eye, the mechanism of sight, the phenomena of reflection and refraction, the factors on which the process of sighting depends, and so on. It also provides mathematical interpretation of many optical phynomena as well as his conclusions regarding the position and number of images formed in different types of mirrors, based on mathematical reasoning. He composed treatises of highly mathematical character on rainbows and halos, spherical and parabolic mirrors, shadows, eclipses, and twilight. Most of his works were produced in the last decade of his life.

A large commentary on the *Kitāb al-Manāẓir* was written under the title of *Tanqiḥ al-Manāẓir* by Kamal al-Dīn al-Fārisī in the first half of the fourteenth century. The original work was translated by Gerard of Cremona into Latin.[13]

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2. *Ibid.*
3. George Sarton, *Introduction to the History of Science.* Vol. I (Baltimore: The Williams & Wilkins Company, 1962), p. 693, 721.
4. Abu'l Ḥassan 'Alī bin Yūsuf al-Qifṭī, *Tārīkh Al-Ḥukamā* (Leipzig: Dieterich'sche Verlagsbuchhandlung, 1903), P. 166.
5. Ibn Abī Usaybi'ah, *Op. cit.* P. 153-154.
6. *Ibid.* p. 154.
7. *Ibid.* p. 154.
8. *Ibid.* p. 154.
9. Al-Qifṭī, *Op. cit.* P. 167.
10. Abu'l Ḥassan 'Alī bin Abi'l Qāsim Zayd al-Bayhaqī, *Tatimmah Ṣawān Al-Ḥikmah* (Lahore: 1351 H), pp. 78-79.
11. *Ibid.* p. 78.
12. Ibn Abi Usaybī'ah, *Op. cit.* p. 149.
13. Sarton, *Op. cit.* p. 721.
14. *Ibid.*

CHAPTER II

SCIENTIFIC APPROACH OF IBN AL-HAYTHAM

1. Restriction of Science to Physical Phenomena

In the works of Greek scholars, excepting few like Archimedes, physical knowledge is found to be mixed up with metaphysical speculations. Much has already been written on this subject and we need not repeat it here.

The scientific records of Ibn al-Haytham reveal that his scientific studies were restricted to the sphere of physical phenomena. The ultimate questions of metaphysics, the scholastic concern with essences and final causes, and the experience of mysticism are not the subject-matter of science. Ibn al-Haytham experienced physical effects or physical phenomena with the help of senses, which he reckoned as means of knowledge,[1] and tried to find out their physical causes,[2] as we shall discuss later on. He occasionally expressed his views on restricting the studies of scientific problems to "the physical and mathematical aspects".[3] The fact that he recognized and emphasized the mathematical and quantitative aspects of science confirms his views on the matter under discussion.

The above concept of science was not clear to European scholars even a few centuries after Ibn al-Haytham. At first the mediaeval Christians of Europe cared little for secular knowledge. There prevailed the tradition of St. Augustine and St. Ambrose who maintained that the entire truth was to be found in the Bible and "for the rest the whole aim of philosophy consists in this, that through the knowledge of his creatures, the creator be known".[4] According to Werkmeister, by the middle of the twelfth century this patristic tradition, fused as it was with some aspects of Neo-Platonic mysticism and embody as it did the cosmology of the Timaeus, had been absorbed by the Western mind. Anselm of Canterbury and Abelard had supplemented it with their rationalistic systems. The climax of this mediaeval synthesis of science and philosophy was the all-inclusive system of Thomas Aquinas in which scholastic rationalism was fused with Christianized mysticism and the knowledge of the Greeks and Muslims was blended with the teachings of the Church. In this system, dogmatic theology and Greek knowledge of Nature were welded in such a way that every attempt to modify or reject the wrong views of an old science was considered to be an attack on some Christian belief, and it was this fusion of theology and science which, centuries later, resulted in the conflict of the new knowledge of Nature with the traditional theology,[5] and caused a severe hindrance in the development of physical Sciences in Christian Europe for many centuries.

In the twelfth century, the people of the West began to be acquainted with the scientific works of Muslim scientists. In the same century the *Book of Optics* of Ibn al-Haytham was translated into Latin, which influenced Roger Bacon, Vitello, Kepler and other Western scientists.[6] These works dealt a blow to the Mediaeval synthesis of knowledge, and helped the Western scholars to get a true conception of the physical science. Draper, Sarton and other historians of science have thrown sufficient light on this subject.[7]

2. Rejection of Authoritarianism

Before proceeding with the subject of scientific methodology it would be advisable to make a survey of Ibn al-Haytham's views on authoritarianism in science. As some statements in his scientific works show, he did not rely upon authority in scientific conclusions but believed in direct study of Nature. The book that was always open to him was the universe. He regarded personal investigation, based on experience, as the only reliable source of scientific knowledge. He obtained much of his knowledge of optical and other scientific and mathematical problems from his personal observations and reasoning. He accepted the scientific conclusions of others subject to their experimental verification, which, according to him, was the real test of scientific truth.

Ibn al-Haytham felt no hesitation in pointing out faults, if any, in the scientific conclusions of others, no matter how great authorities they were, and in making efforts to correct them on the basis of his own experience. In this connection, we quote below a passage from his *Risālah fi'l-Aẓlāl* (Discourse on Shadows).

> We found that all those who discussed this (the shadow) adopted the same method for all types of it. And when we considered the matter, we found their method unreliable. And because of their negligence, every problem discussed by them on the basis of shadow is beset with some shortcomings. Therefore, we thought that we should fully explain the problem of the shadow so that all that was argued on the basis of it be ascertained and whatever confusion occurred therein is comprehended.[8]

When the opinions of authorities on any problem were contradictory and confused, Ibn al-Haytham felt the necessity of rejecting them all and of making a personal study of the problems, as, for instance, indicated by the following passage:

> Observers and research workers differ in their views about the nature of space and allied phenomena. Certain philosophers have expressed the idea that by the space occupied by a certain body we mean the surface which covers it, while others are of the view that the space of a body is an imaginary vacuum which is filled by that particular body. In spite of our best efforts, we have not succeeded in finding any theory of these old thinkers which deals with the proposition *in toto;* nor do they point out any particular way which may disclose the nature of space and auxiliary facts. So, it seems to be necessary to investigate this problem in detail, so that the reality about space and its allied details comes out in such a way that the differences of opinions are resolved.[9]

Ibn al-Haytham advanced the science of optics, mathematics and some other sciences far beyond the established views of his time. The following passages reveal some of his contributions to the advancement of scientific knowledge.

(a) Later they devoted themselves to investigating into the special figures showing how the ray (of light) is reflected. They also examined the properties of conic sections and found that the rays reflected from the various sides of the concave of a hollow body converge at one single point (focus). Thus it was known to them that the ability to burn with this type of mirror is larger than with any other type of it, but unfortunately they could not prove it (mathematically), nor could they explain the method of their discovery. In view of the great benefits and general usefulness that this proposition possesses, we feel it necessary to explain it to a student who has love for learning the truth and is possessed of strong determination to utilise (this knowledge). We shall, therefore, explain it in this treatise and briefly describe the proofs of this truth. We shall also describe the method of preparing these (burning glasses). As an introduction to all this, we shall enumerate the principle which the geometricians employ in the various types of these glasses. This will be a source of guidance to the student.[10]

(b) Former geometricians deliberated upon the properties of equilateral triangles and came to learn that if from any point on any side of an equilateral triangle perpendiculars are drawn on the other two sides then these two perpendiculars would be together equal to the perpendicular of the triangle. They accordingly recorded this piece of deduction in their books. They also studied the perpendiculars in other kinds of triangles but, not finding any coherence or system in their properties, they wrote nothing on this subject. We shall first mention what our predecessors have said about the properties of perpendiculars in equilateral triangles and then we shall state those properties of perpendiculars (in other traingles) which we have ourselves inferred, so that the properties of perpendiculars in all kinds of triangles get collected in this treatise.[11]

His distrust of authority and the realization of the need of independent enquiry into scientific matters were probably caused by the observation that scientists of different ranks and periods possessed diverse opinions on even some basic scientific problems.

Ibn al-Haytham traced the causes which led scientific enquiry to yield wrong and contradictory conclusions. Among the causes enumerated by him, the prominent ones are obscurity of the relevant facts, fallability of the senses, which are instruments of perception, and the composition of a syllogism with false premises.[12]

The above treatment clearly shows that Ibn al-Haytham substituted free investigation for authoritarianism and, instead of being contented with the knowledge of his predecessors, he tried to advance knowledge still further. In the Christian Europe of those days, the test of truth for the scholars lay not in experimental confirmation but in conformity with the opinion of some authority. Their greatest authority in scientific matters was the Holy Bible. Next to it came the authority of the Holy Church; for, in their view, the Church was the keeper and dispenser of gospal truth and the living embodiment of divine revelation. Next to the Church was the authority of Aristotle whom they believed to be the master of those who possessed knowledge.[13]

Effective denial of authoritarianism appeared in Europe much later with Galileo and Kepler who "shocked their contemporaries profoundly, partly because their conclusions were inherently shocking to the beliefs of that age, but partly also because the belief in authority had enabled the learned men to confine their researches to libraries, and the professors were pained at the suggestion that it might be necessary to look at the world in order to know what it is like".[14]

When, against a law mentioned in Aristotles's *Physics*—that the rate of fall of bodies to the ground is proportional to their weights — Galileo demonstrated before the professors that the time taken by a ten pound shot and a one-pound shot for reaching the ground from a similar distance was the same, they said that their eyes must have deceived them, for Aristotle could not have committed a mistake.[15]

The same Galileo made a telescope and asked scholars to look through it at Jupiter's moons. They refused to do so on the ground that had these satellites existed, Aristotle would have mentioned them.[16]

The European scholars who advocated free investigation and made some discoveries were neglected, mocked at, and even persecuted. When Copernicus revived the idea of Aristarchus regarding the motion of the Earth, Luther remarked : "The fool wants to overturn the whole science of astronomy. But, as Holy Writ informs us, Joshua bade the Earth to stand at rest and not the Sun". Galileo challenged the authority of the Scripture and Aristotle, the two basic sources of mediaeval knowledge, by maintaining that the Earth moved round the sun. He, therefore, came in conflict with the Inquisition which disgraced him in his old age.[17]

As for the authority of the Muslim Sacred Book, the Qur'ān, it is important to note that Muslims derive from it all their decisions concerning their religious and worldly conduct. The Qur'ān and the *Sunnah,* although they both encourage and even urge scientific pursuits, are never regarded as the source book of scientific studies of natural phenomena.

3. Observations and Experiments

Although the Greeks were not usually inclined to make observations and conduct experiments for studying Nature, certain Greek scientists like Archimedes had made some observations and had performed a few experiments as well. The work of Archimedes, *On Floating Bodies,* was the outcome of his experiments with such bodies.[18] The Greeks, who borrowed their scientific knowledge from the Babylonians, were usually contented with their borrowed experimental knowledge. They displayed ability mainly in the field of Geometry, which is based on pure reasoning, and dealt with scientific problems with the help of reflection aided by a minimum of observations.

Aristotle believed that one could solve all the problems of the universe by thinking about them. There were two groups which entirely relied on the force of their understanding. One group had confidence in the spontaneous act of the mind while the other employed various forms of logic to understand things.

The Greeks had no observatories or laboratories adequately equipped for scientific observation and experiments. According to Bertrand Russell, the Greeks avoided experimentation, perhaps because they disliked manual work, which, in their society, was meant for the people of lower ranks. They, of course, made observations in the field of astronomy in which no manual work was involved.[19]

The Muslims, on the other hand, in compliance with the Qur'ānic injunctions to keenly observe the natural phenomena like the flight of birds and the falling of rain, (67:19, 27:35) were fond of observing Nature. They not only made observations of natural facts in their original conditions but also observed them under artificially controlled conditions. In other words, they performed experiments as well.

Ibn al-Haytham's scientific works are full of accounts of observations and experiments. His *Book of Optics* is a monument of observational optics, which gives details of obvious and keen observations and experiments, both of which were, in some cases, made with the help of scientific instruments. He used the word *I'tibār* for the experiment and the word *Mu'tabir* for the experimenter.[20] He performed both qualitative and quantitative experiments. Some instances of the latter are his experiments for the measurement of the angles of incidence as well as the angles of reflection leading to the establishment of the laws of reflection and refraction.[21]

His *Book of Optics* reveals a series of discriminative and planned experiments which are occasionally aimed at discovering the causes of physical phenomena. Such expressions as the following abound: "Let us enquire into its causes by reasoning and experiments".[22] His experiments were also meant for confirming hypotheses as is evident from such frequent expressions as "this problem is confirmed by observation and experiment".[23] We shall discuss this point further in our chapter on Hypothesis.

Besides this, the role of experiments in his works was to settle whether or not anything can be known. This is the import of the following passage:

> And when the matter was such and we did not find any satisfactory discussion on the nature of the light of this body (the moon) and the men are curious to know the nature of the existing things and do not feel contented unless they are so much assured that the doubts are eliminated, the situation invited us to make an enquiry into the nature of this body, to deepen the study of it and to reveal what is ambiguous in the matter. So we initiated our study by searching out the characteristics of all the luminous bodies and experiencing their conditions.[24]

In order to illustrate what has been said so far, some observations and experiments recorded by Ibn al-Haytham are cited below:

1. If a spinning-top, having lines of different colours extending from the middle of its outer surface to its last circumference, is made to rotate vigorously, then an observer would observe only a single colour as if that colour was composed of all the colours of those lines. He would not be able to perceive its lines or colours. Besides this, it would seem to him as if it was stationary.

When it is in motion, no point remains stationary for a perceptible time. It traverses, in very short time, the whole circle in which it moves. So the point is seen for a very brief moment on a circumference of the circle out of its whole circumference perceived by the vision, with the result that the colour of that point appears to be moving in the circle. Similar is the case with all the points on the surface of the disc of the spinning-top. And all the points at equal distance from the centre move now on the circumference of the circle. Due to this the colour of all the points at equal distance from the centre appears on the circumference of the circle. So the colours of all the points in the whole circumference of the circle would appear to be mixed together, without being distinguished separately by the vision. For this reason, the colour of the surface of the spinning-top seems to be a single colour composed of all the colours on its surface. So, if it were possible for the vision to perceive a single colour at one moment, all the colours in the spinning-top in motion would be perceived distinctly because every individual colour, whether at rest or in motion, remains the same.

So, if the vision does not perceive individual colours while the spinning-top is rotating very fast but perceives them only when it is moving slowly or is at rest, it is inferred that the vision perceives a colour only when it remains at rest for a perceptible time or moves with a speed that does not affect the position of the colours. It is also inferred that when the time factor is involved in the perception of the colours, it would be rather more involved in the perception of the features of all the visible objects perceivable by distinction and analogy, because they need keen observation.[25]

It would be noted with interest that the above experiment is wrongly ascribed to Newton under the name of Newton's Disc. The inference which Newton derived from this experiment was that 'white light is composed of seven colours', which can be seen by dispersing light through a prism. Since motion in this experiment is a basic factor for reasoning and no motion is involved in white light, the reasoning of Newton seems to be quite illogical.

2. Put some lamps at various places in a room facing a narrow hole leading to a wall in a dark room. The lights of these lamps would appear separately on the wall, equal in number to that of the lamps. When a lamp is covered, its light alone would disappear, and when it is uncovered, again, it would reappear.

It is obvious that the lights of the lamps, which gathered in the atmosphere of the hole, would remain separate after passing through it. Had they got mixed they would remain so in the atmosphere of the hole as well as in the atmosphere in front of it, and would not be distinct. And since colours accompany light, they too would not be fused together.

With the help of this experiment Ibn al-Haytham explained a physiological fact. He remarked that, in the same way, in the transparent regions of the eye the appearance and colours of all the objects facing them are simultaneously transferred and are neither mixed together nor coloured with them, with the result that all the objects are distinctly perceived by the vision.[26]

It is to be noted that Ibn al-Haytham proved this physiological fact by way of analogy with other natural phenomenon which, according to him, was not a sure proof, as would be discussed later. But since any direct experiment on this phenomenon could not be devised by him, this experiment may be considered valid until some direct experiment is performed, which either establishes or falsifies this proof.

3. Sometimes, for some reason, heavenly bodies on the horizon temporarily appear to be larger than their normal size. This is because dense vapours often accumulate on the horizon and intervene between the eye and the heavenly bodies on the horizon. But when the vapours are on the horizon and do not cover the middle of the sky, they become like the part of a sphere whose centre is the centre of the Earth because it surrounds it. And when these vapours form a part of the sphere and do not cover the middle of the sky, their surface as perceived by the eye would be a plane. In such cases, the shape of the body would be perceived through the vapours which are denser than the air in between the vapours and the eye. So it would appear larger in size in the same way in which all objects appear larger in water (by refraction).[27]

Here Ibn al-Haytham obviously interprets an observation in the way in which another observation of the same nature was previously interpreted. This seems to be reasoning by analogy with other natural phenomenon, as in the previous experiment. But in fact it is a case of application of an argument to a set of things of similar nature, while in the previous experiment the two phenomena were of entirely different nature.

The facts of observations as well as of experiments selected for study by Ibn al-Haytham, as in the above cases, are such as to lead to the discovery of causes. The prime purpose of their selection is not to study them for their immediate practical application.

Ibn al-Haytham recognised the value of repeating an experiment under varied conditions.

> When this experiment is completed, the piece of glass near the second hole be removed and the light observed, and the experiment repeated. The experimenter would find the matter as in the previous case. Then the other pieces of the glass be detached one by one, and the experiment repeated. This would show that the light of both the holes has travelled in a straight line through the centres of the surfaces of all the pieces, and would prove that the light travels in a straight line in glass as well, and when it (the ray of light) is perpendicular to the plane surface, it would pass through the glass along the perpendicular line.[28]

Ibn al-Haytham also realized the value of performing more than one experiment for studying a scientific fact. We occasionally come across such expressions as "Let us prove it by two experiments",[29] and "We perform two experiments to study it".[30]

Cases of repeating an experiment under same circumstances, to verify the results, are also found in his scientific records.[31]

Since unaided senses are capable of only a limited experience, to increase the scope and nature of scientific observations the need of instruments was realized and some instruments were used by Ibn al-Haytham in his scientific practice.

The need of using instruments arose particularly in quantitative experiments, which are scientifically more significant than the qualitative ones.

Like other Muslim scientists, Ibn al-Haytham gave much importance to accuracy in quantitative experiments, realizing the fact that even the slightest fault in measurement may lead to such a wrong conclusion that even the best of hypotheses may be ruined. Such expressions as "of utmost accuracy"[32] are often found in his works. The passage quoted below would provide an instance of his use of precise instruments in his scientific enquiry.

> The experimenter should take a scale of utmost accuracy and straightness, and draw in the middle of it a straight line parallel to the marginal lines of it. He should also take a cylindrical pipe which should be quite straight and whose roundness should be of utmost accuracy.....[33]

Since accuracy cannot be attained without instruments, he attached much importance to such things as the levelling of the horizontal surfaces of the instruments and the accuracy of their divisions. His description of the instruments used for the measurement of angles of reflection and refraction and of other instruments employed by him in his scientific investigation prove his keen realization of the need for precise instruments.

Under the influence of Ibn al-Haytham and other Muslim scientists, some later Western scientists like Bacon and Leonardo da Vinci also advocated experimentation. Roger Bacon held that "without experience nothing can be known sufficiently" and that "he who wishes to enjoy, without doubt, the truth of things should know how to devote his time to experiment".[34]

Nearly six centuries after Ibn al-Haytham, the early seventeenth century was a phase of transition in the history of scientific experimentation in Europe. The experimental method was now applied by medical chemists, by Gilbert and his predecessors in the study of magnetism, and by others like Cornelius Drebble (1572-1634), who hovered rather dubiously on the frontiers between science, technology and natural magic.[35] But in all the experiments of the seventeenth century the element of precision was lacking.

> Harvey's experiments were little more than demonstrations of, for example, the action of the valves in the veins of the arms of a living subject, and his famous quantitative argument on the flow of blood through the heart rests on an approximation, not a measurement. Many of Galileo's experiments (or rather, appeals to experience) were rhetorical; they were not reports of events made to occur in a precise fashion. This is not to deny that Galileo made experiments on floating bodies, thermoscopes,

pendulums and many other things: nevertheless, the most famous and decisive experiment in all his writing — that of rolling a ball down a variously inclined plane—is described in terms that could not possibly be exact. Only in the second half of the century, mainly in the work of men born when Galileo was already aged, did experiment become a meticulous tool of science.[36]

Combination of Experience and Reason

Ibn al-Haytham, in his scientific practice, combined experience and reason. Such expressions as "Let us make it clear by reasoning and experience",[37] frequently occurring in his works, show that he believed in combining rational and empirical elements for studying Nature. Kamāl al-Dīn al-Fārisī, a commentator of Ibn al-Haytham, commenting on his *Book of Optics*, says: "I found in this book innumerable useful and novel points arrived at by correct observations and experiments performed with the help of mathematical and astronomical instruments, and of syllogisms composed of true premises"[38]. The premises of a syllogism used by him for reasoning to reach a conclusion are the rules based on reliable observations and experiments and, sometimes along with them, the mathematical propositions as well. The observations and experiments quoted in the previous section illustrate the combination of experience and reason. One more instance is quoted here.

Discussing the phenomena of the morning light and the evening light, Ibn al-Haytham remarks that the difference between the day and the night was due to the light of the Sun; and although in the morning before the sunrise and in the evening after the sunset there is no sun, some light is still there. He makes enquiry into the phenomena of the morning light and the evening light by combining experience and reasoning in the following way.

(1) By common observation, the morning light begins to appear when it is still night. The light appears first in the east and then extends to the middle of the sky with the result that the intensity of the light increases; in the evening the case observed is just the reverse.

(2) As would be discussed in Chapter V, he experimentally proved that light travelled in a straight line.

(3) He also observed that when sunlight fell on a wall facing which there was another surface, then that surface was also lighted up. And if there was a hole in that surface, leading to a wall of a room, the part of the wall just opposite to the illuminated wall became brighter than the rest of it. And when the sunlight disappeared from the wall, the room became dark. The same phenomenon was also observed with the light of the Moon and the light of fire.

Experiments: The experimenter should select a closed room with a vast hole in the wall opening towards a high wall which should be near it and which should stand between the hole and the sky. The experimenter would find that the greater the intensity of the morning light on the wall, the more lighted up the room would be , and the place opposite to the hole would be brighter than the rest of the room. This process goes on till the sun rises and the light of the sun continues to fall on the wall. When the light ceases to fall on it, the light in the room becomes dim.

If in this room there is another dark room with hole whose position in relation to the bright part of the room is the same as the position of the first room in relation to the wall, then the second room would be brightened by the light coming from the wall of the first room in the same way in which the first room received the light.

This experiment shows that light is also emitted by a body receiving light from another body just as it is emitted by a luminous source possessing its own light.

Reasoning: The atmosphere receives light from the Sun while the Sun is still below the horizon. The atmosphere in turn emits secondary light with which the Earth is brightened. The primary light from the Sun to the atmosphere, and the secondary light from the atmosphere to the Earth travel in straight lines. When the light of the atmosphere is very weak, its effect is not felt on the

Earth. But when it grows strong, it appears on the Earth, and the stronger the light is in the atmosphere, the stronger it is on the Earth till it reaches its climax. In the evening, the intensity of the sunlight in the atmosphere gradually decreases and ultimately it totally disappears, and darkness prevails.[39]

At times Ibn al-Haytham experimentally studied a physical phenomenon and interpreted it with mathematical reasoning. Discussing the positions of the images formed in various types of mirrors, he said: "Now we intend to describe the positions of the images formed on the bright surface and the methods of experiencing them and proving them by reasoning."[40]

In the light of the above discussion, the claim of the contemporaries and disciples of Newton[41] that Newton alone was in possession of the true rules of experimentalism and that he alone had known how to draw from them irrefragable conclusions is not valid.

Derivation of Inferences from Experience

Ibn al-Haytham studied physical phenomena not merely to collect facts but also to derive inferences, generally in the form of general principles. In other words, he formulated scientific laws. The procedure that he adopted for this purpose was to perform an experiment and then to reason from the material thus obtained. The statements such as the following throw light on his procedure: "So it has been evident from this experiment that...."[42]; "So these circumstances (revealed by the experiment) show that...."[43] and "Let us enquire into the characteristics of light, the way at its radiation and the media between the eye and the light. Then by these means we shall reach some conclusion".[44]

A number of scientific generalizations or laws occasionally occur in his writings. Some of them are as under:

1. The light, whatever its type may be, travels in a straight line.[45]

2. The appearance of an object perceived by vision depends on the light on the object, the light that

falls on the eye while seeing it, and the air in between the eye and the object.[46]

3. The incident ray and the reflected ray make equal angles with the normal at the surface of reflection.[47]

4. The incident ray, the reflected ray and the normal at the surface of reflection lie in the same plane.[48]

5. The ratio between the angle of incidence and the angle of refraction remains constant (in the case of small angles).[49]

Whenever Ibn al-Haytham derived an inference by mathematical reasoning, he verified it with experience. At a place in his *Treatise on the Light of the Moon* he says: "These propositions are well known to the mathematicians connected with the mathematical science, arrived at by reasoning and verified by induction (based on experience)".[50]

To quote an instance, he derived an inference regarding the number of images formed by a concave mirror under certain conditions, and then verified it with experiment. The inference is as follows.

If a point lies outside the diameter of a concave mirror, which passes through the centre of the vision, and its distance from the centre of the mirror is different from that of the eye from it, then sometimes it is reflected either from one point or from more than one but not from more than four points.

Experiment: If an experimenter intends to experience all the images formed by a concave mirror, he should prepare the mirror out of a great sphere. He should cut the sphere from the opposite sides so that there remains a piece like a ring. Then he should bring his eye near the surface of the mirror in such a way that he may see the whole surface of it. He should place an object of bright colour at the other side of it and see in the whole mirror. He would find the images of the object formed at various places. If he notices only one image, he should change the position of the mirror or the eye. In this way several images, not exceeding four in number, can be perceived by him.[51]

Some more general inferences arrived at through mathematical reasoning can be seen in Chapter IV of this book dealing with Physical-Mathematical Synthesis.

The above discussion and the scientific records of other Mediaeval Muslim scientists, like al-Birūnī, refute the remark of Bertrand Russell that "they (the Muslim scientists) sought detached facts rather than general principles, and had not the power of inferring the general laws from the facts which they discovered".[52]

Application of Mathematics to Science

From the very beginning, a metrical element of varying importance has always been involved in science. The ancient scientific records, e.g. the charts of the positions of the stars and the timings of the revolutions of the planets, provide an evidence of the application, though in rudimentary forms, of mathematics to science. Complicated mathematical methods were employed in astronomy earlier than in other branches of science. The two ancient astronomical works, Almagest and Sịḏhḏhāntā reveal the mathematical aspect of astronomical science.

Ibn al-Haytham fully recognized the link between science and mathematics. He remarked that "the problems of the science of optics have both the physical and the mathematical aspects".[53] In his *Treatise on Light* he remarks:

> The discussion of the nature of light belongs to the physical sciences, and the discussion of the way of propagation of light concerns mathematical sciences because the light travels in lines. Similarly the discussion of the nature of the ray belongs to the physical sciences, and the discussion about its form and structure concerns the mathematical sciences. Similar is the case with the transparent bodies through which light passes. The treatment of the nature of their transparency concerns the physical sciences, and the treatment of the way of

> propagation of light through them belongs to the mathematical sciences. Thus the discussion of the light, the ray and the transparency requires both physical and mathematical sciences.[54]

Ibn al-Haytham made use of the mathematical logic of Archimedes, according to which the effects of a cause of a physical phenomenon should be mathematically deduced. The detection of such effects in Nature provides a proof of the correctness of the cause. Thus the physico-mathematical deductions explain the experimental evidence and sometimes they even lead to the discovery of physical facts even before our instruments and senses detect them. This point is evident from the numerous examples of such deductions found in that part of his *Kitāb al-Manāẓir* which deals with the geometrical optics.

This method of mathematical reasoning employed by Ibn al-Haytham in optics was later used by Galileo in his study of the science of motion. Other latter physicists, too, followed this example.

Ibn al-Haytham applied mathematics to physical questions where directly measurable quantities alone were used, as in the study of the angles of reflection and refraction. He also used mathematics to derive a conclusion in the form of a number or a magnitude or a position, as he did in his study of images reflected or refracted by various types of mirrors.

He did not regard as valid that use of mathematics which offered a proof to the effect that a certain idea was or was not plausible; for a device like mathematics could only show that if a thing was of a particular type in one respect, it must be like that in another, too. Thus, while, it showed consistency; it did not show that the thing was actually so in Nature. In such cases, an experimental verification was required as is evident from the following passage in his treatise on *The Halo and the Rainbow.*

> These two (halo and rainbow) are always found in dense air and have the shapes which are the characteristics of a single system. The halo is

> always circular as long as there is no other factor tending to change its shape. The rainbow always acquires the form of an arc of a circle. Since they appear in air, therefore we have to look into it from the physical or qualitative point of view; and since they are found in a circular shape, so we have to look into it from the mathematical or quantitative point of view. Therefore while discussing the nature of these two phenomena we have to consider both physical and mathematical aspects of the problem.
>
> Let us say something about them after making investigations in accordance with the demands of the physical phenomena and the mathematical principles, and in conformity with the existing facts relating to them.[55]

Ibn al-Haytham also took interest in the problems that arose in the theory of physics. An instance of this is the mathematical problem, known as Alhazen's problem: To draw lines from two points in the plane of a circle in such a way that they meet at a point on the circumference and make equal angles with the normal at that point.[56]

It is the mathematical form of the following problem of catoptrics: "In a spherical (concave or convex), cylindrical or conical mirror, to find the point from which an object of given position will be reflected to an eye of given position". It leads to an equation of the fourth degree. Alhazen solved it with the help of an hyperbola intersecting a circle.

Kepler too employed a curve (parabola) to satisfy such a physical requirement, and remarked that a burning mirror should be a paraboloid.[57]

The same argument is applicable in connection with the reception of radio waves of very high frequency.

Boyle also proceeded in Ibn al-Haytham's fashion by collecting empirical data to reach a conclusion, and thus laid down Boyle's law in the form of a table of the compression of air, which shows inverse proportionality between the volume and pressure of a gas at constant temperature.[58]

Ibn al-Haytham made some other original contributions to mathematics, which have been described by him in his mathematical works.[59] Since mathematical study is an essential aspect of science, the greater the resourcefulness of mathematics, the richer the physical potentialities. Thus, by contributing to mathematics, Ibn al-Haytham also played his indirect role in the progress of science.

Inductive Attitude

In order to derive inferences, the Greeks used deductive reasoning rather than the inductive one based on experience. They, of course, were quite at home with mathematics, particularly geometry, which, in their belief, was an *a priori* study proceeding from self-evident premises and not requiring experimental verification.[60] The Greek science was corrupted in Aristotle's school by logic and in Plato's by natural theology.[61] They recognized induction, but in their inductive procedure they proceeded from superficial observations. Speculation and syllogistic reasoning played the main role in it.

As we have already seen, experimentation was not a characteristic of the Greek temperament. The Greeks, therefore, did very little for the evolution and development of sciences.

Archimedes, however, made some important contribution to science. But in his famous book on statics he proceeded from what he believed to be self-evident axioms, which were not arrived at experimentally. In his book On *Floating Bodies*, too, he displayed the deductive attitude of the Greeks. He proceeded from postulates by a method of deduction. But it can be supposed that he arrived at the postulates through the experimental method.[62]

Ibn al-Haytham, in his scientific investigations, displayed an inductive attitude. As we have seen in the section on **'Observations and Experiments'**, he proceeded with the experimental study of the particulars and then made generalizations by assuming that what was experienced as occurring in a particular case or cases of a certain class would, under the same circumstances, occur in all the particulars of that class. In other words, he made generalizations from experience. An example of his inductive procedure will be given, in detail, in Chapter IV.

Ibn al-Haytham advocated gradual induction, which means a gradual passage from particular facts to broader and broader generalizations. It will be discussed in its proper place in the next chapter.

As we have already seen, Ibn al-Haytham, in his scientific enquiry, conducted deduction as well with simple or mathematical reasoning. But deduction was conducted from the laws formulated by inductive method. He did not proceed deductively even from the self-evident physical principles —a method of reasoning ascribed to Descates.[63] Ibn al-Haytham, however, emphasized the need for experimental verification of the conclusions reached through the deductive method.

In Europe, for centuries after Ibn al-Haytham, Western scholars continued to use the deductive method. Werkmeister threw light on their deductive attitude in the following words:

> Upon the foundation of Scripture passages and quotations from "authorities" the scholastics erected their towering systems of "philosophy" and "Science". Dialectical speculation led from deduction to deductions until the whole of knowledge was enmeshed in a closely knit web of arguments. The test of truth was not experimental verification but conformity with the opinion of accredited authority and inclusion in the approved scheme of deduction.[64]

According to an old English tradition, Bacon is regarded as the originator of the method of induction from experience.[65] In the light of the above discussion, it is quite clear that this method was practised by Ibn al-Haytham centuries before Bacon. At best, Bacon can be regarded as the first scholar to convey this method of Muslim scientists to the West. It is interesting to note that Bacon's best known exemplification of an inductive investigation— into the nature of heat— is nothing more than an instance of how one might compile justification of a preliminary hypothesis. As an inductive proof, it is worthless.[66]

The Uniformity of Natural Laws

The definition of induction obviously implies an assumption of uniformity of nature. In other words, anything that happens once under certain circumstances is bound to happen as often as the same circumstances recur.

This assumption of the scientists is a conviction of Muslim scientists; for the Holy Qur'ān declares that there is no altering (the laws of) Allah's creation and says that "thou wilt not find for Allah's way of treatment any substitute, nor wilt thou find for Allah's way of treatment aught of power to change" (35:43).

The Object of Scientific Enquiry

To Ibn al-Haytham, the object of a scientific enquiry is the discovery of facts relating to natural phenomena. Once it has been established that in science only those inferences are considered trustworthy which are made from sense experience, the investigator must clear his mind of all prejudices as to what might or what ought to be the order of nature in the case under investigation. The opinions which an investigator comes to receive without any adequate experiential evidence have no place in science. This point is quite evident from Ibn al-Haytham's remark that "by all this (investigation) our object would be to search after truth and not the wish-fulfilment, the application of justice and not the imposition of opinions".[67] If an investigator is not free of prejudices or preconceptions, he may deviate from the right path and thus may not be able to discover facts.

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67. Ibn al-Haytham, The preface to his *Kitāb al-Manāẓir.*

CHAPTER III

THE SCIENTIFIC METHOD OF IBN AL-HAYTHAM

Survey of Contradictory Optical Conclusions

In the preface to his *Book of Optics*, Ibn al-Haytham discussed various, even contradictory, views regarding the nature of vision and the way of perceiving with it.

Physicists were of the view that perception with vision was caused by the image coming from a visible object to the eye. On the contrary, mathematicians held that the eye perceived an object with the help of the rays emanating from the eye to the visible object in the form of a cone whose apex was at the centre of the eye and the base at the surface of the object. They further differed about the form of the ray and the mode of its origin.[1]

Ibn al-Haytham expressed his dissatisfaction with these contradictory views. He remarked that confusion was prevalent, certainty was lacking, and it could not be said that the goal could be reached in this way.[2] He pointed out various factors which could be responsible for such confusion. One among them was the weakness of the senses. When the senses make erroneous observations, the premises of a syllogism, which in science are formed on the basis of observational data, become false and the syllogism may lead to wrong conclusions.[3]

The Greeks, too, usually distrusted the senses because of their apparently contradictory nature and the lack of immunity from error. They, therefore, did not attach much importance to sense experience.

Another factor was the presence of prejudice or preconception of any kind which tended to turn the mind away from the right path and caused the reasoning to proceed in the wrong direction.

Yet another factor was weakness of mind which rendered the mind unable to infer rightly from the sense data presented to it.

The Greeks admired and extolled the powers of mind and, therefore, employed it for acquiring knowledge by reasoning with the help of the forms of logic. On account of their distrust of senses, the incipient and valuable connections between theory and practice were divorced in favour of general theories based upon superficial observations. Thus the Greek thought tended to become more exclusively philosophical.[4]

Ibn al-Haytham was not of the view that the mind or the senses, on account of their inherent weaknesses, should not be employed for the study of Nature. Nor did he hold the view that they should be left to their own spontaneous mode of activity. On the one hand he recognized the faculties of the senses and the mind and, on the other, in view of their weaknesses, realized the need for helping them with a right method.

Emphasis on Fresh Study of Nature

Ibn al-Haytham remarked that contradictions in optical conclusions might have been due to the particular methods employed by his prodecessors to reach them. He, therefore, emphasized the need for a fresh study of Nature (in this case, the optical problems) with the help of his own method, which he thought to be the right one.

> And when the matter is such, and despite the prevalence of difference of opinion among investigators on this (problem) for a long time its nature remained ambiguous and the mechanism of sight uncertain, we thought that we should attach maximum possible importance to it, pay consideration to it, exert serious efforts for the study of its nature, and initiate the study afresh on the primary and basic characteristics of it[5]

This refutes the claim of Bacon that "no one has yet been found so firm of mind and purpose as resolutely to compel himself to sweep away all theories and common notions, and to apply the understanding, thus made fair and even, to a fresh examination of particulars",[6] and that "there is no hope except in a new birth of science, that is, in raising it regularly up from experience and building it afresh, which no one (I think) will say has yet been done or thought of".[7]

These quotations from Bacon's *Novum Organum* also reveal his dissatisfaction with the then existing knowledge.

Descartes also felt discontentment with the state of contemporary knowledge as is evident from the following passage.

> I found myself involved in so many doubts and errors, that I was convinced I had advanced no farther in all my attempts at learning, than the discovery at every turn of my own ignorance. And yet... not contented with the sciences actually taught us I had in addition read all the books that had fallen into my hands, treating of such branches as are esteemed the most curious and rare.... I was thus led to the liberty of judging all other men by myself, and of concluding that there was no science in existence that was of such a nature as I had previously been given to believe.[8]

Following Ibn al-Haytham, Descartes, like Bacon, also stressed the need of original inquiry into natural phenomena after provisionally rejecting the scientific opinions of his predecessors.[9]

OUTLINE OF IBN AL-HAYTHAM'S SCIENTIFIC METHOD

Ibn al-Haytham advocated a scientific method for the study of Nature which was an outcome of his scientific approach. His *Book on the method*[10] was not available to us, but the statements scattered throughout his writings on optics, astronomy and other branches of science, and the records of his scientific practice reveal the doctrine of his method.

In the preface to his *Book on Optics*, he gave an outline of the method advocated by him for proving or disproving any of the above-mentioned two rival hypotheses on the nature of vision, or for helping to formulate some other theory. He remarks:

> One of these two contradictory views may be right and the other wrong or both of them may be wrong and the right may be something else. Or both of them may be leading to the same thing which is the reality but each of these two groups holding these views has failed in investigation, and so they could not reach the destinction and stopped before it. Or one of them reached the destination but the other could not, with the result that the contradiction has only apparently occurred and on deep study their objective would be found to be the same. And sometimes the contradiction in the matter under investigation is caused by the difference in the method of enquiry but when the enquiry is thoroughly undertaken and a keen study is made, agreement would be revealed and the contradiction would be removed.[11]

Ibn al-Haytham gave the outline of his scientific method in the following passage:

> We shall commence our investigations of the existing objects through induction and by searching for the conditions of the visible objects and by distinguishing between the characteristics of individual objects. And out of the characteristics associated with sight we shall inductively select those which are permanent and immutable and those which are quite clear and not ambiguous during the process of seeing. Then we shall advance in investigation and syllogism gradually and in order, criticise the premises and secure conclusions against errors.[12]

The method formulated by Ibn al-Haytham has been discussed in the above passages in a connected and systematic form. The other numerous remarks found in his works throw light on the nature of different constituents of the method and on the various rules concerning them. His method is based on the following four steps:

1. Formulation of a Hypothesis and its Verification;
2. Observation of Particulars;
3. (a) Classification;
   (b) Selection of the Relevant Data; and
4. Gradual Induction.

These steps are discussed below.

Formulation of a Hypothesis

In every scientific enquiry, some general but well-reasoned idea or hypothesis is involved without which experimentation itself becomes meaningless. The method of hypothesis had been employed by the ancients in their astronomical investigations.

An important aspect of Ibn al-Haytham's doctrine was his use of the method of hypothesis-formulation for the investigation of Nature. The way in which he formulated the hypotheses and used them in connection with his optical and astronomical researches reveals his views on the basis, nature, functions and other points relating to the hypothesis.

The Basis of a Hypothesis

Ibn al-Haytham recognized two bases for the formulation of a hypothesis: (i) Observations of the natural phenomena and (ii) analogy with those phenomena. Thus, in his view, a hypothesis was meant to explain observed facts. In the course of his discussions on the mechanism of radiation of light from the Moon to the Earth, he says:

> We started our study on this problem on the basis of our observations of other luminous bodies. From these observations we have come to the conclusion that there are three possibilities (hypotheses) about the light of a luminous body reaching some other body:-
>
> I. Every point of the luminous body which is opposite to the other body appears to be luminous. This is the condition in the case of those bodies which are self-illuminated.

II. The light that falls on any portion of a body from some other source is reflected. This phenomenon occurs in the case of all lustrous bodies and mirrors which appear to be bright.

III. Refracted light is visible on the surface of the body. It happens in the case of all transparent bodies.[13]

Verification of A Hypothesis

In the opinion of Ibn al-Haytham, a hypothesis is valid only if it is conformed to the observed facts. This is the import of the following passage.

> When the eye comes across a visible object, the form of its light and colour comes from every point of the object to the whole surface of the eye. Now, if the eye receives this form from the whole surface of it, no distinction of various parts would be possible. But if the eye perceives a particular point on its surface and not all the points, the various parts of it would be in order and the distinction of colours and features would occur. This is because when the form of a point is perceived from a definite point on its surface the form of the other point from the other point and so on till the forms of all the points of the object facing it are received by all the points on its surface, no confusion would occur. Let us consider the possibility of this view and verify its conformity with the facts.[14]

In case a hypothesis based on certain observations was unable to account for some other observations, Ibn al-Haytham tried to assign various possible reasons for this unaccountability. If the reasons were not found to be valid, the hypothesis was rejected. An instance of this is found in his study of the light of the Moon. Having observed the Moon to be illuminated, the hypothesis that the Moon had its own light was provisionally formulated. But this hypothesis could not explain why this light vanished partially or fully in the case of lunar eclipse and why the Moon changed its shapes on different days of the month, in which case the light appeared on only some particular portion of the Moon. The following passage relates to this point.

> So if we admit that the Moon has its own light, the occurrence of the Moon eclipse and the changing of its shapes can be due to the following four possible causes:
>
> 1. Change in the volume of the Moon;
> 2. Change in the distance between this object and the eye;
> 3. Defects in observation; and
> 4. The intrusion of some foreign body between eye and that object.

All those four possible causes proved to be incorrect on the basis of his observations and thus the hypothesis of self-illumination of the Moon was abandoned by Ibn al-Haytham.[15]

In the opinion of Ibn al-Haytham, a hypothesis framed by way of analogy with other natural phenomena also needed verification by direct and positive observations. In other words, analogy only suggests a hypothesis; it does not constitute a proof. The passage in the beginning of his treatise entitled *Ḍaw' al-Kawākib* (The Light of the Stars) reveals his ideas on the subject.

> Thus they (scientists) have concluded that the Moon derives its light from the Sun, and in itself it is a dark body. They have same ideas about stars, and have begun to think that the stars, too, derive their light from the Sun, like the Moon. But they could not present a convincing proof in support of their conclusion; nor could they point out any reason on the basis of which this idea could be proved. It is, therefore, obvious that it is only a hypothesis. When some of the followers of these scientists talked to me about it and pressed me to accept their ideas, I thought it opportune to make investigation into the light of the stars and the related characteristics. During these investigations I came to the conclusion that the stars themselves emit light, and their light is due to certain properties which they possess themselves; with the exception of the Moon, none among the stars derives its light from the Sun.[16]

This statement refutes the claim of Charles Singer and Agnes Arber that, in the Middle Ages, analogy provided the recognized clue for the interpretation of the Universe, and the conclusions reached in this way were not deemed to be in need of any further proof and that it is the modern researcher who is willing to accept only the guidance of analogy in tackling his problem but has recourse to some other procedure for proving his contention.[17]

Verification of Consequences of A Hypothesis

In the view of Ibn al-Haytham, the truth of a hypothesis is tested by deducing consequences from it and then testing those consequences with further observations. If the consequences are found in agreement with the observed facts, the hypothesis is accepted; otherwise it is rejected and some other hypothesis is formulated. This is evident from his discussion of the nature of the light of the stars. He rejects the hypothesis that the stars borrowed their light from the Sun on the ground that in that case the appearance of the stars would be different in their different positions relative to the Sun. According to him, they should appear crescent-shaped when they are near the sun, as is the case with the Moon. But since they do not acquire such shape (in other words, the consequence of the hypothesis is not confirmed), the hypothesis that stars shine with borrowed light was rejected by Ibn al-Haytham.[18] Ibn al-Haytham further argues on the same basis, as follows.

> And also sometimes the distance between the Sun and the stars which are in the vicinity of the poles and are not on the route of the Sun become equal to one-fourth of a circle or less than this. The stars which appear more than one hour after the sunset lie at such distances. If they borrowed the light from the Sun, then those among them which are near the West would appear every night in the form of half a circle as it happens in the case of the Moon when it is at the same distance from the Sun.
>
> And since the stars are spherical, the part of them facing the Sun should be illuminated and the rest should remain dark. When the distance between the

> Sun and the stars is not more than one-fourth of a circle, the eye would perceive some portion of their bright surfaces and the dark part of them. In such a case, they would be seen as parts of circles as in the case of the Moon.
>
> Besides, this, when the distance between the Sun and the stars is more than one-fourth of a circle and less than half a circle, the stars which are in the northern and southern west are seen in the form of a section of a circle or rectangular in the first parts of the night. In short, if the stars borrow the light from the Sun, some of them should appear circular while the others should appear rectangular or like parts of circles. But since no star is seen at any time in the night in any form except the circular one it follows that no star derives its light from the Sun.[19]

Here again the hypothesis has been rejected because the conclusions derived from it were not proved.

One more example is quoted from Ibn al-Haytham's *Book of Optics*. He presents two hypotheses regarding the rectilinear propagation of light in transparent media. One of them is that such propagation is the property of light while the other is that it is the characteristic of transparent media. Then he refutes the latter hypothesis on the ground that if such were the case, light would travel in such media only in a particular direction. But since it travels in them in all directions, therefore, the rectilinear propagation is not a characteristic of them. Here also Ibn al-Haytham rejects the hypothesis because the inferences drawn from it were not confirmed by observation.[20]

Discrimination between Alternative Hypotheses

If more than one hypothesis explained the observed facts, Ibn al-Haytham accepted them all provisionally and then subjected them to experimental tests. He then proceeded on the basis of the results established by the experiment to a criticism of those hypotheses and a rejection of all those whose results were not in conformity with facts. In his discussion on the nature of the light of the Moon, he says that the scientists concluded from their observations that the light of the Moon was borrowed from the Sun but they did not deal with the problem in a way which could show that this was the only valid hypothesis and that the alternative hypotheses, showing that the light of the Moon was its own, were not valid. Thus, to Ibn al-Haytham, the truth of a hypothesis in such cases depended on two types of proof: the direct one (which proved it on the basis of the evidence of experience), and the indirect one (which disproved all the conceived alternative hypotheses on the same basis).[21]

A Hypothesis should not Repudiate a Law

According to Ibn al-Haytham, a hypothesis should not be in contradiction of an established law. This view is fully evident from his discussion of the heat of the solar rays falling on plains and on the tops of mountains. According to the law, places near the source of heat are hotter than those away from it. The tops of mountains, therefore, should be hotter than plains. But the case observed is the reverse of it. On the basis of this observation, some physicists formulated the hypothesis that the rays of the sun were an exception to this law. But, in the opinion of Ibn al-Haytham, the law held good in the case of solar rays as well, and the deviation was caused by the presence of some other causes such as the nearness of the mountain tops to the colder region of the Atmosphere and the small number of the reflected rays of the sun on the tops.[22] It means that whenever an instance of deviation from the law is witnessed one should not rush to declare that law to be inapplicable to that instance. Instead, the cause(s) of the deviation should be traced.

The Functions of A Hypothesis

From what has been said so far it is obvious that hypotheses are essential to experimental research. They enable the researcher to start an experiment, determine the nature of an experiment, and distinguish between the relevant and the irrelevant data. Initially they are just suggestions, which if found to be compatible with facts, lead to the formulation of scientific laws.

Sometimes a hypothesis serves to explain a wide range of diverse phenomena besides the particular phenomenon that is under investigation. To Ibn al-Haytham, if the truth of such a hypothesis is established, it becomes a law. As will he discussed in Chapter IV, an instance of this is the hypothesis of rectilinear propagation of light based on the observation of straight beam of light entering into a dusty or smoky room through a slit. This hypothesis not only explains this observed phenomenon but also some other ones like the formation of shadows, the lunar and solar eclipses and some other ones observed when light passes through narrow holes and so on.

Observation of Particulars

Ibn al-Haytham recommended that all the particulars concerning the phenomena under investigation should be observed. As will be seen later, in his study of the path of light he studied the light of different types—primary, secondary, and tertiary lights; reflected and refracted lights; the lights emanating from different sources (namely the Sun, the Moon, the stars and the fire); and the lights travelling in different media such as air, water and glass.

Since the variety of objects and the relations that observations reveal to the investigator is so great as to confuse the investigator he emphasized that observations should be limited at any one time to one fact, or a number of facts so closely resembling together as to seem to constitute one fact. Ibn al-Haytham, therefore, advocated that one should begin with an enumeration of the varieties of the existing objects. But since in discussing light he was concerned with the process of perception by vision, he restricted his observation to the conditions of visible objects only.

3. Classification and Selection of the Relevant Data

The third step in Ibn al-Haytham's procedure included the distinction or classification of the characteristics of the particulars, the separation (by the process of exclusion and rejection) of those instances which were either ambiguous or liable to change during the process of seeing, and the selection (by simple enumeration) of all those which are clear and remain constant during this process.

The same idea of classification was later presented by Francis Bacon in the passage given below, without making any reference to Ibn al-Haytham.

> ...... must analyse nature by proper rejections and exclusions and then, after a sufficient number of negatives, come to a conclusion on the affirmative instances; which has not yet been done or even attempted, save only by Plato, who does indeed employ this form of induction to a certain extent for the purpose of discussing definitions and ideas.[23]

Gardual Induction

The inductive attitude of Ibn al-Haytham has already been discussed in the previous chapter. At this step of his method he proposed that, armed with relevant facts, the investigator should proceed in research and reasoning gradually and systematically, which means that from particulars some general inferences would be derived in the form of a law, and then by the general law some more general law would be formulated till the most general law is reached at the end.

Approximation of Scientific Truth

In view of the weaknesses of the human mind and senses, Ibn al-Haytham held that the general scientific conclusions arrived at by this method of induction were open to doubt and not capable of ensuring certainty. Since such conclusions were liable to errors, they could only be regarded as approximately, but not exactly, true. Thus they needed correction with the advances of scientific knowledge. This point is evident from his remark that "despite this we are not free from the weaknesses of our human nature. But we shall strive with whatever human power we have, and from Allah we seek help in all matters."[24]

Ibn al-Haytham, however, hoped that "through this method we may reach the truth with which the heart gets contented, and arrive gradually and steadily at the goal where certitude is achieved, and succeed with this criticism and scrutiny in finding the fact with which the difference is removed and the material of doubt is eliminated."[25]

The same view of the lack of absolute certitude and finality in natural science was also held by Newton and his contemporary Christian Huygens. The latter expressed his view on the matter in the Preface to his *Treatise on Light,* published in 1690.[26]

Theories identical to those of Ibn al-Haytham as delineated above are traceable in the works of later Western methodologists of science. By way of illustration, a few passages from Bacon's *Novum Organum* and Descartes' *Discourse On Method* are quoted below, the first three being from Bacon and the last three from Descartes.

(i) Meanwhile, I give constant and distinct warning that by the methods now in use neither can any great progress be made in the doctrines and contemplative part of sciences, nor can they be carried out to any magnitude of works.[27]

(ii) Now I certainly mean what I have said to be understood of them all; and as the common logic, which governs by the syllogism, extends not only to natural but to all sciences, so does mine also, which proceeds by induction, embraces everything.[28]

(iii) For I am of opinion that if men had ready at hand a just history of nature and experience, and laboured diligently thereon; and if they could bind themselves to two rules, the first to lay aside received opinions and notions; and the second, to refrain the mind for a time from the highest generalization, and those next to them, they would be able by the native genuine force of the mind, without any other art, to fall into my form of interpretation.[29]

(iv) ... but as for the opinions which up to that time I had embraced, I thought that I could not do better than resolve at once to sweep them wholly away, that I might afterwards be in a position to admit either others more correct, or even perhaps the same when they had undergone the scrutiny of reason.[30]

(v) When I considered the number of conflicting opinions touching a single matter that may be upheld by learned men, while there can be but one true, I reckoned as well-nigh false all that was only probable.[31]

(vi) ... the diversity of our opinions, consequently, does not arise from some being endowed with a larger share of reason than others, but solely from this, that we conduct our thoughts along different ways, and do not fix our attention on the same objects. For to be possessed of a vigorous mind is not enough; the prime requisite is rightly to apply it.[32]

It has already been stated that Ibn al-Haytham's *Kitāb al-Manāẓir* greatly influenced the Western thought. For more than five centuries it served as a reference book in the West. Its last Latin translation was published at the end of the sixteenth century.[33] It is, therefore, obvious that these ideas of the Western scientists concerning the method of science were borrowed from Ibn al-Haytham.

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2. *Ibid.*
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4. W. Fowler, *The Development of Scientific Method*, (Pergamon Press, 1962), p. 6.
5. Kamāl al-Dīn Al-Fārisī, *Tanqīḥ al-Manāẓir*, Vol. 1 (Hyderabad, [Deccan]: Dā'irat al-Ma'ārif al-'Uthmānīyah, 1347 H.), p. 14
6. Francis Bacon, *Novum Organum* (Edited by Saxe Commins and Robert N. Linscott in their work entitled *The World's Great Thinkers* (New York: Random House). p. 180.
7. *Ibid.* p. 130.
8. A. Rupert Hall, *The Rise of Modern Science* Vol. III (London: Collins, 1965), p. 100.

9. J.P. Scott, *The Scientific Work of René Descartes* (London: Taylor and Francis Ltd.), p. 10.

10 The names of the books as mentioned by Ibn Abī Uṣaybī'ah in his *'Uyūn al-Anbā fī Ṭabaqāt al-Aṭibbā,* Vol. 3 (Beirut: Dar al-Fikr), p. 157, are as follows:
(i) *Maqālah fī anna Jihatah Idrāk al Ḥaqā'iq Jihatun Wāḥidah*
(ii) *Maqālah fī anna al-Burhāna Ma'nan Wāḥid.*

11. Ibn al-Haytham, *Op. cit.,* The preface.

12. *Ibid.*

13. Ibn al-Haytham, *Ḍaw' al-Qamar* (Hyderabad [Deccan]: Dā'irat al-Ma'ārif al-'Uthmānīyah, 1357 H.), p. 4

14. Al-Fārisī, *Op. Cit.,* Vol. I, P. 113.

15. *Ibid.* pp. 6-11.

16. Ibn al-Haytham. *Aḍwā al-Kawākib* (Hyderabad [Deccan]: Dā'irat al-Ma'ārif al-'Uthmānīyah, 1357 H.), p. 2.

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CHAPTER IV

AN EXAMPLE OF INDUCTIVE PROCEDURE

In Chapter II we discussed in detail the concept of induction and inductive procedure revealed by the writings of Ibn al-Haytham. Here we quote, from his practical records, an example of his inductive procedure.

Example

The observation of the fact that light entering through a slit or a hole into a room whose atmosphere is contaminated with dust or smoke appears as a line extending from the hole or slit to the place where it falls was responsible for the formulation of the hypothesis that light travels in a straight line.[1]

This hypothesis was verified with experiments on the light emanating from various sources and traversing various media. The experimental study was made not only of direct primary light, but also of secondary, tertiary, reflected and refracted lights.

In case the atmosphere of the room is quite clean (i.e. it is free of dust, smoke, etc.) the experiment, according to Ibn al-Haytham, should be performed in the following way.

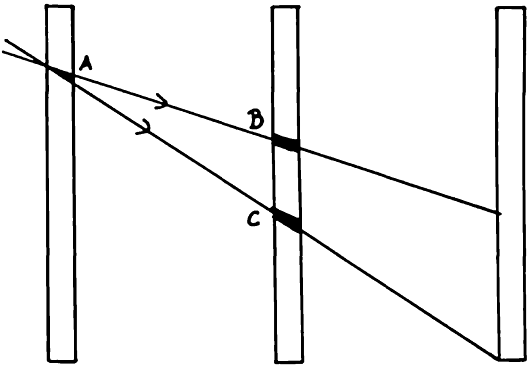
The experimenter should interrupt with an opaque body the straight path between the hole and the spot of light at any point. He would find that the light would now fall on the intervening body instead of falling on the original position. The straight line can be determined with the help of a straight rod, one end of which is kept on the spot of light and the other on the hole or passing through it. If the body is placed at any point other than the straight line, the light would not stop. If the hole is narrow, the experiment would be clearer.[2]

The same phenomenon is observed if the experiment is performed with the light of the Moon or other heavenly bodies, like Mars, on a dark night. If the hole is narrow and a particular star is observed through it for a definite time till it traverses a certain distance, its light in the room would be found to have shifted from its original position and fallen along the line joining the hole and the star. The same is observed in the case of light from fire.[3]

To prove that the reflected light also travels in a straight line Ibn al-Haytham described the following experiment.

If an opaque body is placed across the straight line joining the reflecting surface and the place where the light reflecting from it falls, the reflected light would be seen on the opaque body instead of falling on the original position. If the body is moved in this straight line, the light will always be observed on the body. If the body is moved away from the line, the light would appear in its original position. If the place where the reflected light falls is near the reflecting line the shadow of it will appear in the reflected light and the reflected light on the rod. If the rod is moved in the straight line between it and its shadow, the shadow will always be found on the same spot and the reflected light on the rod.[4]

To show that refracted light also travels in a straight line, Ibn al-Haytham stated that if a clean and transparent glass with plane surface was held in the sun, the light would pass through it and appear as a secondary light on the earth or the wall. If the straight line between the transparent body and the spot of the light passing through it was blocked by an opaque body, the light, instead of falling on the original place, would fall on the opaque body. The same phenomenon would be observed if the experiment was repeated several times.[5]



(Fig. 1)

It is possible to make reliable experiments on rectilinear propagation of secondary lights. In the case of morning light, select two adjacent rooms along an east-west line. There should be no passage for the light to enter. The eastern wall of the eastern room should be open to the sky. In the upper part of this wall a round hole, Hole A (Fig. 1), whose diameter is not less than a step, should be made. The hole should be conical in shape, its inner part being broader than the outer one facing east. In the common wall of the two rooms, two conical holes, Holes B and C, facing (and equal in size to) Hole A should be so made that when the straight line joining the point at the external end of Hole A to the nearest point on the surface of the conical hole in the common wall is extended, it reaches the western room. It would be proper to make the two holes nearer the floor than Hole A in such a way that an observer watching through either of them, should be able to see the sky through Hole A. Particular care should be taken to see that the wall should be thick so that it may be possible for the holes to be conical. Then, a piece of thread should be stretched from Hole A to Hole B so that the thread passes through the external extremity of Hole A and the corresponding extremity of Hole B. The end of the thread should be tied outside Hole A.

The experimenter should enter the western room and stretch the thread in the above-mentioned manner till its end reaches some spot in the room. The thread should be tightly stretched till its straightness and form are ascertained. Then a mark should be made at the point in the western room which will fall on the straight line joining the point at the external end of Hole A with the point at the extreme external end of Hole B. Now the thread should be taken out of Hole B and passed through Hole C and the same operation should be repeated so that the spot of the westward room on the line of the holes is fixed. The experimenter should enter the room on dark night, close the door and leave no place for the light to enter it with the result that the room should become extremely dark. Then he should enter the western room, look through one of the holes B and C till he can see the sky through Hole A and notice that no star from among the big ones is facing him. Then he should take notice of the spot marked. He would find that spot to be dark. He should perform the same operation through the other hole. He would find the associated spot equally dark. Likewise, the whole room would be dark.

The experimenter then should wait for the morning. When it dawns, he should see through the two holes B and A (or C and A) till the space becomes bright. Then he should move from there and look at the marked spot. He would find a weak light there. The light would grow brighter with the light of the space till it becomes quite bright. The spot of light on both the places would be round and bigger than the size of the hole because of the tendency of light to diverge.

Then, if one of the holes is covered, its light on the place facing it would be cut off. If the straight path between the hole and its light is cut off by an opaque body, the light would appear on the body and vanish from the original place. The same phenomenon would be observed if this operation is performed on the path between Hole A on the one hand and Hole B or C, on the other.

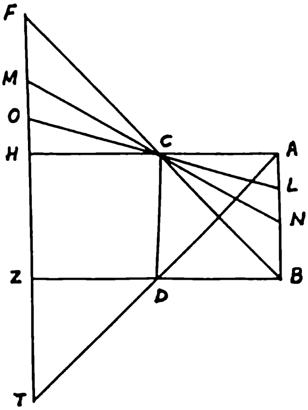
If a number of holes are made in the western room, an equal number of light spots would be observed on the above-mentioned pattern. It is possible to ascertain this path with a straight rod. If curved paths are interrupted by an opaque body, the light would not disappear from the original place and would fall on the opaque body.[6]

These experiments prove that light, whatever its type, travels in a straight line.

INTERPRETATION OF SOME PHYSICAL PHENOMENA ON THE BASIS OF THE ABOVE HYPOTHESIS

(a) Formation of Shadows

When light falls on an object, shadows of different intensities are formed behind it. They are continuous and conical and lie on the straight line in which the light travels.



(Fig. 2)

Let us suppose a luminous body and, in front of it, an opaque one. Let A and B be the points at the ends of the luminous body, and C and D those on the opaque one (Fig. 2). Let us join A to C and B to D and produce the lines further. They will either go parallel or meet in the direction of AB or in the opposite direction. Let them be parallel in this case. We produce A to H and draw through H a line FT parallel to CD, which would meet an extension of BD at Z. We join B to C and produce the joining line further till it meets FT at F. We join A to D and produce the line till it meets FT at T.

Let AL be a small part of the luminous body. We join L to C and produce the line LC further till it meets FH at O. Now, lines from all points on AL, when drawn through C, would meet FH between O and H. So the light coming from all the points of AL through C would fall on OH. The line OH is thus illuminated with the light coming from the portion AL, and all the lines coming from all the points of LB to OH would be blocked by CD, and OH would be the shadow of LB. So OH would be both shadowed and illuminated. Since AL is very small compared with LB the shadow would be more intense than the illumination.

In the same way we treat the portion LN. We join N to C and produce the line NC till it meets FH at M. Now the light coming from the portion LN through C would fall on OM. The light from AL would also fall on it. No light from NB would reach it. So the portion OM is illuminated with the light coming from the portions AL and LN and the shadow of NB falls on it. The portion OM would be both shadow and illumination. Since the portion AL and LN are smaller than NB, the shadow in OM would be more intense than the illumination in it, and its illumination would be more than that of HM. The same is the case in all the portions of FH. It is obvious that in FH there is a continuous shadow of varying intensities: most intense near H and the weakest near F. And there is also light in it; most intense at F and least intense at H.

Similar is the case of ZT. So far as HZ is concerned, it is a complete shadow because all the lines coming from all the points on AB to HZ are stopped by CD.[7] Similar considerations can be seen to apply, with some modification, if the sides of the luminous and opaque bodies are such that either AC meets BD in the direction of AB or they meet in the direction of CD.[8]

(b) Solar and Lunar Eclipses

Ibn al-Haytham explained the phenomena of solar and lunar eclipses on the basis of rectilinear propagation of light. He observed that in case of partial solar eclipse, the image of the sun on the screen behind a narrow round hole was crescent-shaped. He explained this observation by tracing the straight lines representing the rays of the light emanating from the Sun.[9]

(c) Pin-Hole Camera

Ibn al-Haytham interpreted on the basis of the above theory a number of phenomena relating to the light passing through narrow holes. For instance, he remarked that if a luminous object was placed in front of a narrow hole made in a box, the image of the object formed on the screen inside the box would be an inverted one. And if a number of luminous objects were placed in front of the hole, then, besides the formation of inverted images, the images of the objects on the right would appear on the left, and vice versa.[10]

(d) Reflection and Refraction of Light

Other phenomena explained by Ibn al-Haytham on the above basis are the phenomena of reflection[11] and refraction[12] in which the incident, reflected and refracted lights are believed to travel in straight lines, making angles with the surfaces which they strike or through which they pass.

NOTES AND REFERENCES

1. Ibn al-Haytham. *Kitāb al-Manāẓir* (Photocopy of Ms. No. 3215, Fatih, Istanbul, made available to the author by the Hamdard National Foundation, Karachi). Discourse I, Chapter 3, Section B.
2. *Ibid.*
3. *Ibid.*
4. *Ibid.* Sec. H.
5. *Ibid.* Sec. T.
6. Kamāl al-Dīn al-Fārisī, *Tanqīḥ al-Manāẓir*, Vol. I (Hyderabad [Deccan]: Dā'irat al-Ma'ārif al-ʿUthmānīyah, 1347 H.), pp. 23-30.
7. *Ibid.* vol. II, pp. 359-361.
8. *Ibid.* vol. II, pp. 361-362.
9. Ibn al-Haytham. *Maqālah Ṣūrat al-Kusūf*. Given in Vol. II of *Tanqīḥ al-Manāẓir*, mentioned above. p. 381.
10. Al-Fārisī, *op. cit.*, vol. II, p. 397.
11. Ibn al-Haytham. *Kitāb al-Manāẓir*. Disc. IV.
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11. Ibn al-Haytham. *Kitāb al-Manāẓir*. Disc. IV.
12. *Ibid.* Disc. VII.

CHAPTER V

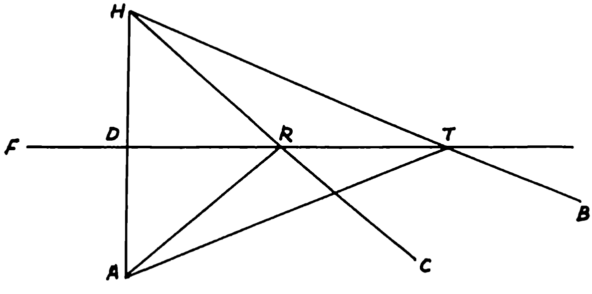
PHYSICO — MATHEMATICAL SYNTHESIS

As mentioned in Chapter II, Ibn al-Haytham recognized the mathematical aspect of science and employed mathematics in his scientific investigations. By combining physical laws and geometrical propositions, he interpreted certain physical phenomena and derived conclusions for their own sake as well as for their immediate practical application. To illustrate this point, we quote some examples of each category from his works.

Examples of Mathematical Interpretation

1. *The image of an object with reference to both the eyes is one.*

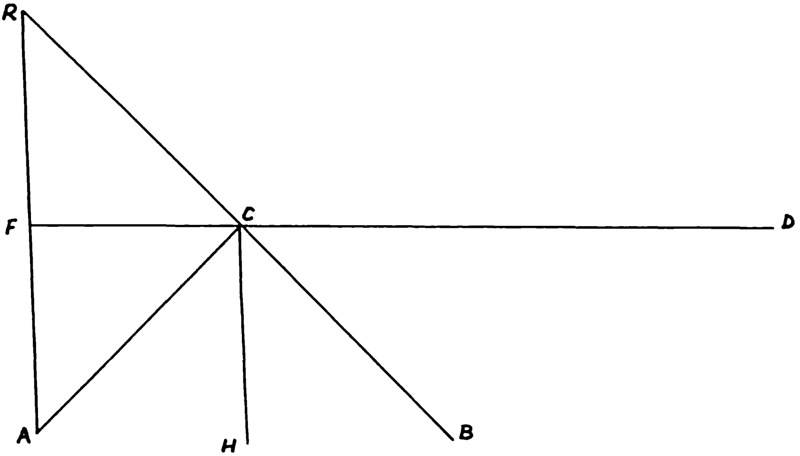
Let A be a point on the object, and B and C be the centres of both the eyes (Fig. 3). Let the image of A be reflected to B from T and to C from R. From the point A a perpendicular AD is drawn on the surface of the mirror and produced to H. Join the points B and A to T, and C and A to R. The line BT on producing further would meet AD produced at H behind the mirror. AD is equal to DH. The same is the case with CR. The point H is the image of A with reference to both the eyes.



(Fig. 3)

This shows that since the point lies on the perpendicular, the image of a point on the surface of the object is one. Similar is the case with the images of other points surrounding it, with the result that the image formed is only one, and the pyramids issuing from the centres of both the eyes to the image are those in which the images of this object are reflected to the eyes. Therefore the image of the object with references to both the eyes is also one.[1]

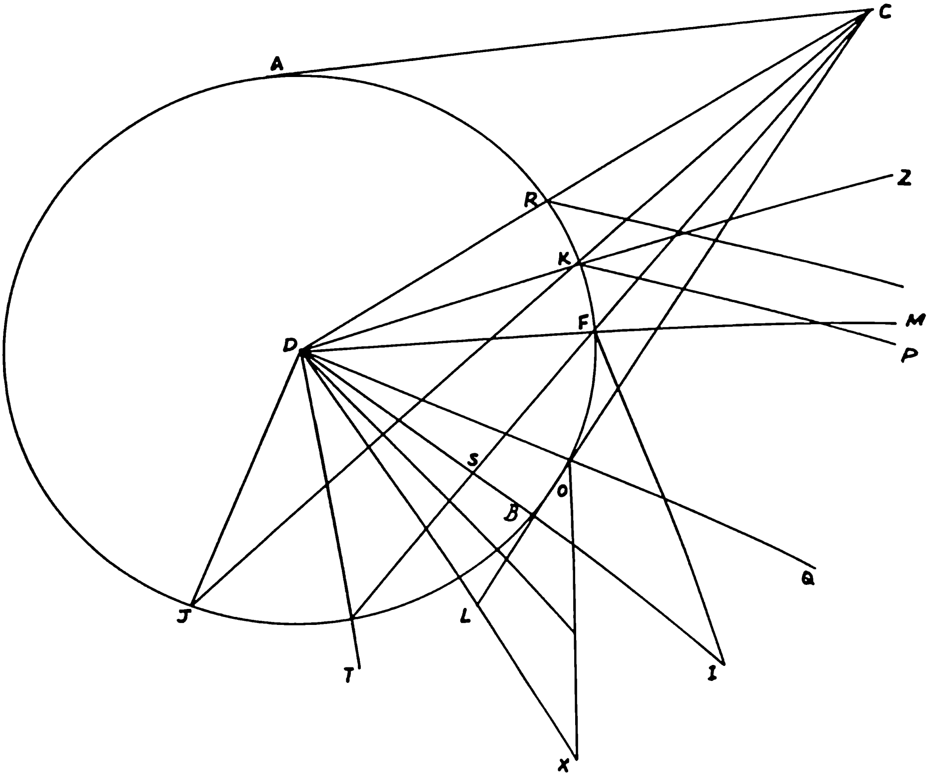
2. *The image of an object formed in the plane mirror appears behind the surface of the mirror at a distance equal to that between the object and the mirror, and that there is only one image for one point:*



(Fig. 4)

Let A be a point on the object, and B the centre of the vision and C a point on the surface of the mirror (Fig. 4). Suppose A reflects to B from C. Join AC and BC. They would be in the plane of reflection. Let FCD be the surface of reflection. Let a perpendicular CH in the plane of reflection be drawn from C. From A draw a perpendicular AF at FCD. It would also be a perpendicular on the surface of the mirror and therefore parallel to HC, and BC produced would meet AF at R behind the mirror. R is the image of A. The < BCH=opposite < R = < ACH = the alternate < A. Therefore < DCB = < FCA. < RFC and < AFC are right angles. ∴ RF = FA.[2]

3. *In a convex mirror, the image is formed on its surface behind it (and sometimes in front of it.)*



(Fig. 5)

Let A and B be two points on the spherical mirror where centre is D and let the centre of vision be C (Fig. 5). The line CD would cut the circumference at R. At this a surface cutting the spherical mirror is supposed, and thus a circle ATB is formed. From C two lines CA and CB touching the circle at the sides of CD are drawn, which would be in the conical surface touching the surface of the mirror which separate the point opposite to I. The arc ADB is all that is facing I from the circle ATB. Then from the point C a line cutting the circle (at point F) is drawn. The part of it which is inside the circle is equal to the radius of the circle. Join D to F and T and produce DF to M. Make the < MFI = < MFC = < DFT. The angle DFT is equilateral. < MFI = < FDT. So FI is parallel to DT. Therefore any line produced to D from any point on the line FI, though extended to infinity in the direction of I, would cut FT at point I between F and T.

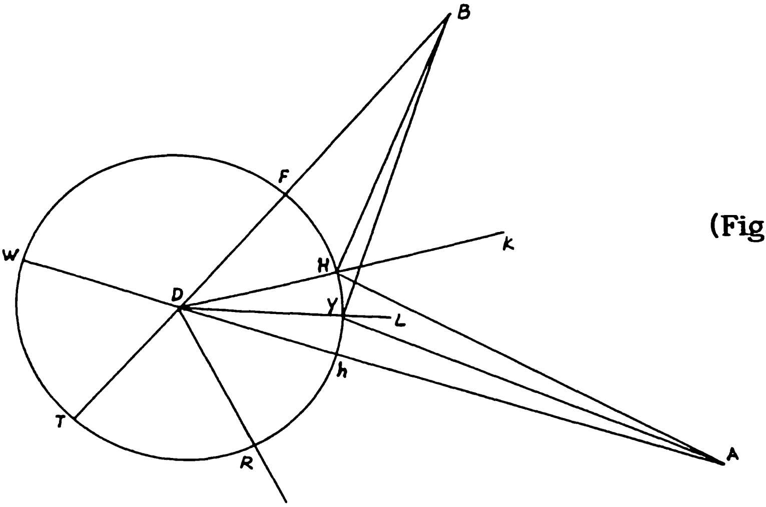
The joining line ID would cut FT at S and the circumference of the circle at B. It is evident from the previous figure that the image of I extending along IF would reflect from F to C, and its image S would be inside the circle. Similar is the case with every point on FI extending to infinity in the direction of I.

And also draw from C a line CKS which cuts the circle from behind FT. So KS would be greater than the radius. Join D to S and K and produce DK to Z. Make < ZKP = < ZKC. Thus < SKD, i.e. < PKZ, would be smaller than < SDK. Therefore, the line PK would meet SD in the direction of KD.

So when a line is drawn to D from point K, it, though extending to infinity in the direction of P, would cut KS at a point inside the circle. And it is evident from the above that the image of all the points on the line KP would be formed behind the mirror as well. Similarly it has been made clear that the image of every point reflecting from a point between F and R would be formed behind the mirror.[3]

Examples of Derivation of Scientific Conclusions

1. *A point does not reflect to another point from a spherical convex surface but from only one point on it.*



(Fig. 6)

Let A be the point from which the light comes to the mirror, B the point to which this light reflects, and D the centre of the mirror (Fig. 6). Let the plane ADB cut the surfaces of the mirror at the great circle as shown in Fig. 6.

It is clear that the plane of reflection of A to B is the plane of this circle. So the reflection of one of the two points to another in the plane other than the plane of the figure is impossible. We join these two points to the centre of the circle. Let one of the straight lines be AhD, which meets the circumference of the circle at h and W. Let the other line be BFT which meets the circumference at two points F and T.

Each of these two points does not reflect to the other from the convex half circumference of the circle in the direction opposite to the direction in which the other point lies. The point A, for instance, does not reflect to B from the circumference of the arc HTW. Ibn al-Haytham's argument on this is that when a point, like R, is supposed on this arc, the extension of radius DR does not divide the angle formed between the straight lines AR and BR. So it is impossible that the angle be formed between one of these two lines and the radius be equal to the angle formed between other line and the radius. In this case, one of the two laws of reflection does not apply. So it is necessary that if the reflection of A to B occurs, the point of reflection must be on the arc hH. In other words, it is necessary that the point of reflection should lie on the arc bounded by the two straight lines extending from the two points to the centre.

Let h be the point of reflection. To prove that reflection from other point is not possible, we should suppose that the two points also reflect from another point Y on the mirror. It will necessarily fall on the arc hF and it should lie between h and H as is evident from Fig. 6. We join D to H and Y and extend DH and Dy to K and L respectively. We join the points A and B to the points H and Y.

$$\angle BHK = \angle KHA$$

$$\therefore \angle BHD = \angle AHD$$

Similarly, < ByD = < AyD

And < Byd is smaller than < BHD

∴ < ByD is smaller than < AHD

∴ < AyD is smaller than < AHD

And this is impossible because

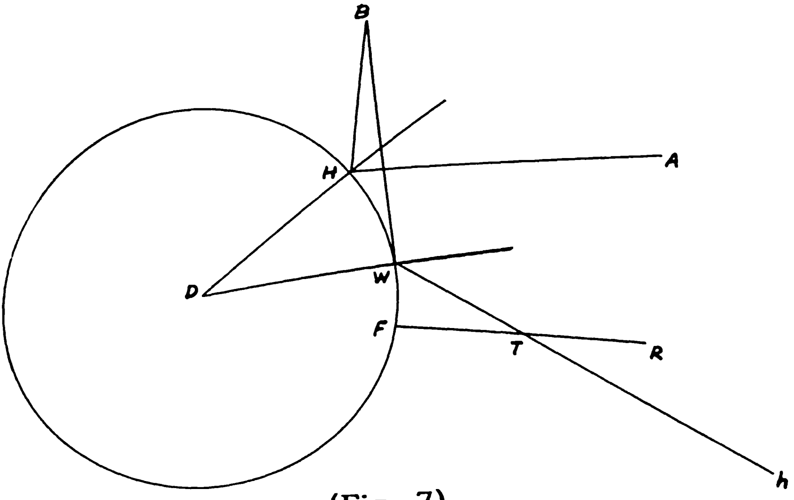
< AyD is greater than < AHD

Similarly it is impossible when the point lies between H and F. So one of the two points A and B does not reflect to another but from one point.

On the above proposition, Ibn al-Haytham based a number of problems. One of them, in his own words, is as follows.

> Every point which is perceived by the eye in the spherical convex mirror and is outside the diameter of the mirror passing through the centre of the eye, there would be only one image of it.

Another problem is that when two straight lines reflect to one point from a convex circumference of the circle, then no point between these two lines would reflect to this point from any point which lies on the arc other than the one which is bounded by the two points of reflection of these two straight lines on the part of the circumference facing them.



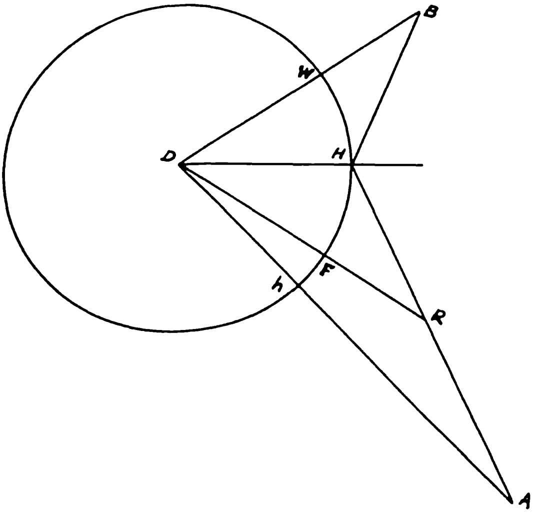
(Fig. 7)

Let there be two lines AH and hW (Fig. 7) reflecting from H and W respectively to a point B. We should suppose any point like R between them. Our claim is that the point H would not reflect to B from a point which does not lie on the arc HW facing the points.

In this case as well, the argument of Ibn al-Haytham is the argument of contradiction. Let us suppose that the point R reflects from a point which does not lie on this arc. Let it be F lying nearer to W than to H. The line joining R and F cuts the line hW at T. The point T then would reflect from W to B and also from F to B, and it is impossible.

Similarly it would also be found impossible if the point F lies nearer to H than to W.*

2. *When a line is reflected between two points from a convex circumference of the circle and the parts of the line are of different lengths, the point of reflection divides the arc, which is separated by the two straight lines extending from the two points to the centre, into two parts, of which the greater is the one which lies closer to the greater part of the reflected line.*



(Fig. 8)

Let the two points be A and B and let the point of reflection be H (Fig. 8). The reflected line between A and B is AHB, and let AH be greater than BH. Let the centre of the circle be D. Let AD meet the circumference at h and BD at W. From HA we separate HR equal to HB, and join RD which meets the circumferences at F. It is easy to prove that

$$\angle HDW = \angle HDF$$

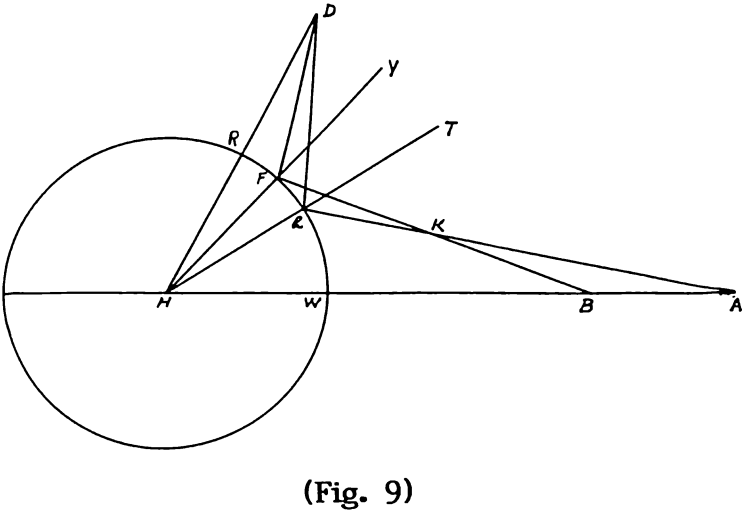
And since HA is greater than HR,

∴ $\angle HDF$ is smaller than $\angle HDh$

∴ $\angle HDh$ is greater than $\angle HDW$

∴ Arc Hh is greater than HW.[5]

3. *If there are two points lying on the same diameter in the same direction in relation to the centre of the mirror and the rays issuing from them reflect to a third point, then the point of reflection of the point which is nearer the centre of the mirror would be farther from the third point.*



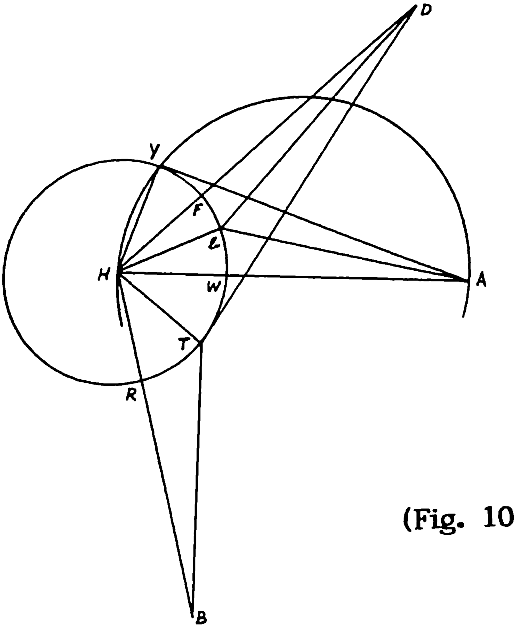
(Fig. 9)

Let A and B be two points and H the centre of the mirror. Let point A be more distant from the centre than point B (Fig. 9). Let the third point be D. Let the plane AHD cut the surface of the mirror at the greatest circle as shown in Fig. 9. Let the meeting point of AH with the circumference of the circle be W, and the meeting point of DH with it be R.

Now, as it was proved in the first case, the point of reflection of both A and B to D would necessarily be on the arc RW. Let the point of reflection of A to D be h. The point B does not reflect to D from R, W or h. Otherwise there would be one value for the angle of incidence and another for the angle of reflection. Let us suppose that the point of reflection of B to D is F on the arc Rh. We join H to h and produce Hh to T and join H to F and produce HF to Y. We join F to D and B. BF cuts Ah at K. In this way the point K would reflect to D from two points h and F, which is impossible. So the point B does not reflect to D from a point on the arc Rh. And in this case B would not reflect to D from a point lying on an arc other than arc hW.

So the point of reflection of B to D would be farther away from D than the point of reflection of A to it. And also it would be more distant from R than the point of reflection A.[6]

4. *If two points lying in the plane of a circle at equal distances from its centre reflect to a third point, the arc formed between the lines joining the points to the centre of the circle would be greater than the one formed between the two points of reflection.*



(Fig. 10)

Let the two points be A and B. And let the centre of the circle be H and the third point be D (Fig. 10). According to the second law of reflection, point D would necessarily lie in the plane ABH. Let < AHD be smaller than < BHD. Let A reflect from h to D.

Let AH, BH and DH meet the circumference of the circle at W, R and F respectively.

Then, as it was made clear in the first case, the point of reflection of B to D would necessarily lie on the arc FWR.

And, as it was made clear in the third case, the point of reflection of B to D is not the point F, R or h, nor any point between F and h. So it is a point T on the arc hR, and the distance of T from F would be greater than the distance of h from it. So join T and H.

It is quite clear that < DhH and < DTH are obtuse. It is easy to prove that < DhH is greater than < DTH.

And < DhH = < AhH

And < DTH = < BTH

∴ < AhH is greater than < BTH.

When on the chord AH and an arc of the circle which faces BTH, an angle equal to < BTH is made, it would cut the circumference of the first circle at point Y whose distance from W would be greater than that of h from it. The point Y would be nearer to h than to w. And when AY and YH are joined, < AYH = < BTH.

And in the triangles BTH and AYH the obtuse angles T and Y are equal.

And TH = YH, and BH = AH

Therefore, the two triangles are congruent.

So < BHT = < AHY

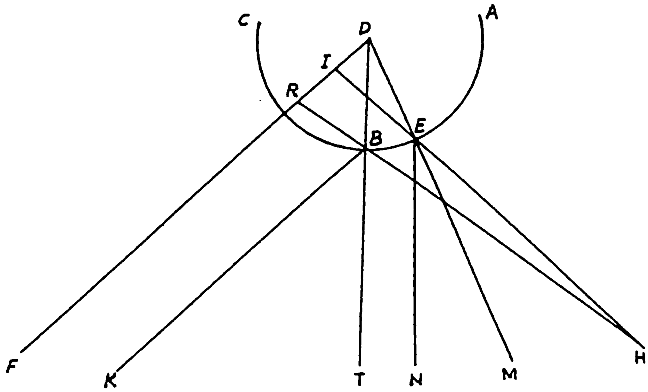
And < AHY is greater than < AHh

So < BHT is greater than < AHh.

When an angle equal to < THA is added to or subtracted from any one of the two, it is proved that < BHA is greater than < THh.

And, therefore, arc RW is greater than arc Th.[7]

5. *If a point on any diameter holds such a position that, when it is joined to the centre of vision, the part of the joining line inside the circle is equal to the line extending from the point to the centre of the circle, then this point determines the position of the images in the vicinity of the circle. No image would be formed of any point on the visible object which could be seen by reflection.*



(Fig. 11)

In Fig. 11, ABC is the surface of reflection whose centre is D, and H is the centre of the vision. Diameter DF is among those diameters whose points are seen by reflection. Let HBR come out from the vision H to the diameter DF. Let the line BR be equal to the line RD.

It is claimed that no image of a point lying on DH, even though it extends to infinity, can be formed on RD.

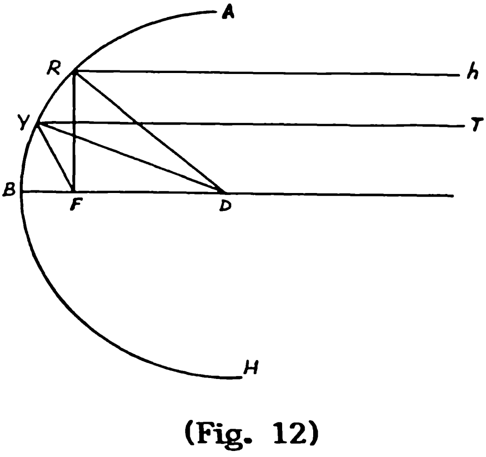
Join B and D and produce DB to T. Make
< TBK = < DBR. It would thus be equal to < TBH.
And since BR = RD, < RDB = < RBD = < KBT.

Thus, BK is parallel to DF and therefore would not meet it. So R would be the image neither of any point lying on DF, even though it extends to infinity, nor of a point lying outside the diameter DF.

No point on DH can be the image of a point lying on the object seen in the mirror. Otherwise, let I be the image of a point reflected from R. Join H, E and I and join D and E and produce DE to M. Make < MEN = < HEM. < HID is greater than < HRD, and < KDI is greater than < BDR. There remains < DBR. But < BDR is greater than < DEI. Therefore, < EDI would be much greater than < DEI. And < MEN, (i.e. < HEM) = DEI. Therefore < FDE is much greater than < NEM. So NE would meet FD in the direction of D, and so I would not be the image of a point on the diameter DF.•

Examples of Derivation of Scientific Conclusions By Mathematical Argumentation For Immediate Practical Application

1. *If a concave mirror, which is less than half the sphere, is made to face the sun in such a way that when its principal axis is extended it reaches the Sun, then the rays of light emanating from the body of the Sun parallel to the principal axis will reflect from the surface of the mirror to the principal axis.*



(Fig. 12)

Let hR be one of the rays, D the centre of the mirror, and the extension of BD its principal axis (Fig. 12). Let the planes of hR and DB, which are parallel, meet the surface of the mirror at arc ABH, which is the arc of the circumference of the greatest circle in the sphere. Let us draw RF in such a way that < DRF = < hRD.

Now since the surface of the mirror is less than half the sphere, arc AB is less than one-fourth of the circumference of the greatest circle and < RDB is less than a right angle.

And since < RDB = < hRD = < DRF, so < DRF is less than a right angle, and RF and DB would necessarily meet.

In the same way every ray which is parallel to the principal axis would reflect in such a way that it would meet it.

If we denote the meeting point of RF and DB by F, and suppose the principal axis BD as fixed, and rotate the figure round it, then point R would form on the surface of the sphere of the mirror the circumference of a circle. The position of every point on this circle with respect to F would be like that of point R with respect to it. In this way, Ibn al-Haytham proved that all the rays which emanate from the Sun parallel to the principal axis and reach the circumference of this circle, reflect to the point F on the principal axis.[9]

2. *If a ray is reflected from the circumference of a circle, lying on the surface of a spherical concave mirror, to a point on the principal axis of the mirror, then no other ray, except the one reflecting from the circumference of this circle, would reflect to this point.*

Ibn al-Haytham proved this proposition by the argument of contradiction. If hR (Fig. 12) is reflected to F, we should suppose that the other ray TY parallel to the principal axis is reflected from Y also to F.

Then, since < RDB = < DRF, FD must be equal to FR. But this is a contradiction.

So it is impossible for any ray to be reflected to point F from a point which does not lie on the circumference of the circle formed by rotating R round the principal axis.

These two propositions indicate that only those rays are focussed on a definite point on the principal axis of a spherical concave mirror which are parallel to it and fall on the surface of the mirror at the circumference of a definite circle on it.[10]

3. *The distance of a point on the principal axis of a concave spherical mirror, to which a ray is reflected from the centre of the sphere, is greater than one-fourth of its diameter.*

To prove this, we suppose that hR (Fig. 12) is reflected from R to F. It was previously made clear that FD = FR.

And since FR is greater than FB, so FD is greater than FB. In this case, FD would be greater than half of DB. Therefore it would be greater than one fourth of the diameter of the mirror.[11]

4. *All the rays which are reflected from a circle, the distance of which from the end of the principal axis of the mirror is equal to the side of the octagon which is formed in the greatest circle in the sphere, would be reflected to the centre of the circle.*

Ibn al-Haytham meant a regular octagon here. So, obviously it would make an angle equal to half of the right angle at the centre of the circle. If the point D be the centre of the mirror, the extension of BD be its principal axis, and < DBR be made equal to half of the right angle, then DR should be like the side of a regular octagon. If a perpendicular RF is drawn from R on the principal axis and from R a straight line Rh is drawn parallel to the principal axis, it is easy to prove that hR is reflected to F, and point F is the centre of the circle formed by point R as a result of the rotation of the figure round the principal axis.[12]

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CHAPTER VI

CONCLUSION

On the basis of the extracts quoted from the writings of Ibn al-Haytham on optica, astronomy and related topics, and their critical analysis, it can be concluded that Ibn al-Haytham possessed a superior spirit of scientific enquiry. He was an alert observer and an accurate, painstaking and persistent experimental investigator. Thus he possessed all the qualities of a true scientist, and amply displayed them in his scientific practice. He improved and invented scientific instruments to provide an aid to the eye for perceiving more than it could perceive by itself. In his works the experimental procedures were properly recorded and the course of an experimental enquiry was reported step by step.

His constant search after truth led him to develop the doctrine of the Scientific Method. Although we had no access to his books on Methods, the numerous statements scattered through his scientific works (mentioned in the bibliography), and the records of his scientific practice gave us a clear conception of his scientific methodology. The rules of various constituents of the method, e.g. observation, hypothesis, experiment, classification and generalization, are fully understood from his writings. As was shown in the previous pages, some of these rules were known to the Chaldeans, the Babylonians and the Greeks, and some were formulated by Ibn al-Haytham himself. The latter gave those constituents a new arrangement and helped in formulating a novel method.

In ancient times, the Scientific Method was employed in astronomy. Ibn al-Haytham perfected it and made a successful use of it in optics and other branches of science including astronomy. In recent times, this method proved remarkably successful in the development of atomic physics.

2. *Ibid.* Disc. V, Chap. 3, Sec. A.
3. *Ibid.* Disc. V, Chap. 4, Sec. W.
4. Muṣṭafā Naẓīf Bik, *Al-Ḥasan Ibn al-Haytham,* Vol. I (Cairo: Maṭba'ah Nūrī, 1942). p. 383.
5. *Ibid.* pp. 383-386.
6. *Ibid.* pp. 386-387.
7. *Ibid.* pp. 387-388.
8. *Ibid.* pp. 389-390.
9. Ibn al-Haytham, *Risālah al-Marāyā al-Muḥriqah bil Dā'irah.* (Hyderabad [Deccan]: Dā'irat al-Ma'ārif al-'Uthmānīyah, 1357 H.), p. 2.
10. Muṣṭafā Naẓīf Bik, *Op. cit.,* p. 404.
11. *Ibid.* pp. 404-405.
12. *Ibid.* p. 405.

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In ancient times, the Scientific Method was employed in astronomy. Ibn al-Haytham perfected it and made a successful use of it in optics and other branches of science including astronomy. In recent times, this method proved remarkably successful in the development of atomic physics.

The Greek studies of Natural Science were seriously tainted —— in Aristotis's school by logic and in Plato's by natural theology. Ibn al-Haytham had a clear concept of Science, which he restricted to the phenomenal world discoverable by means of senses. Thus, unlike the Greeks, he excluded barren Scholasticism and the knowledge gained through intuition from the sphere of Science.

Like other Muslim scientists, Ibn al-Haytham rejected authoritarianism in science, and, instead, laid emphasis on fresh observations of Nature. Thus, after many centuries, he opened the way to the acquisition of new knowledge of nature which made it possible to improve upon and make additions to the scientific knowledge of his predecessors. This was certainly a remarkable and revolutionary step in the development of Science.

In Science, Ibn al-Haytham did not proceed deductively like the Greeks but used the inductive procedure effectively. His scientific practice shows that he firmly believed that all the premises of a syllogism, or in other words, the materials for reasoning, should be based on sound experience. Thus he combined experience with reason. This combination was another revolutionary step in the evolution of Science and the scientific method.

He recognised the mathematical or quantitative aspect of Science, formulated quantitative laws, derived consequences of Scientific laws through mathematical reasoning, and confirmed them with experimentation.

Yet another important step in this connection was his advocacy of gradual and systematic generalization in contrast with that of the Greeks, which passed immediately from the particular to the most general axioms.

Ibn al-Haytham's mode of Scientific approach clearly refutes the claim of some Western historians of Science, like Rupert Hall, that the revolution in ideas which made modern Scientific achievements possible occurred in Europe. In fact, the Scientific revolution in Europe was affected about seven centuries after Ibn al-Haythan, under the influence of Scientific ideas and methods of Medieval Muslim Scientists of whom the most important was Ibn al-Haytham.

Ibn al-Haytham's Scientific Method was an outcome of his Scientific approach. His method was an interplay of induction and deduction. It consisted of formulation of a hypothesis on the basis of some observations, deduction of consequences from the hypothesis, and experimental verification of the consequences. It was a means of acquiring knowledge of facts in the form of general principles, on the basis of the evidence of Science experience without prejudice or preconception of any kind. To Ibn al-Haytham, the theory formulated by this method had only a probable truth and was thus liable to be corrected on the basis of further experience.

This is the so called modern experimental method ascribed usually by some historians of Science to Francis Bacon, and by some others to Galileo. Another method advocated by Ibn al-Haytham was the mathematical method. This method, too, was later ascribed to Galileo. Bacon, though influenced by Ibn al-Haytham, could not go as far as Ibn al-Haytham. While Ibn al-Haytham was interested in causal explanation and formulation of laws, Bacon aimed at discovering the nature or essence of things. According to Werkmeister, the pioneers of modern science, therefore, did not accept Bacon's leadership, for their aim was the discovery of 'laws' rather than of 'essences'. Bacon was, of course, a vocal exponent of experimentation and thus the preacher, in Europe, of Ibn al-Haytham's experimental or inductive method. But Bacon could not give even a single complete example of the method that he mentioned in his *Novum Organum* while many such examples can be quoted from Ibn al-Haytham's works. One example has already been discussed in Chapter V.

It may even be concluded that nothing essential was added to the Scientific Method after Ibn al-Haytham. Turning to the works of Galileo, Kepler or Newton and to more recent leaders, like, Einstein, in the field of theoretical science, we find the same mode of approach which characterised the work of Ibn al-Haytham. Western scientists of the post-Ibn al-Haytham period freely adopted his mode of approach and utilized his method. They did, however, extend its use to numerous other branches of science, e.g. the extension, by Galileo, of the use of mathematical logic to the science of motion, and the extension of experimental inquiry, by Faraday, to electricity, and by, Thomson, to atomic physics. Sometimes the use of Ibn al-Haytham's method was made for further inquiry into the problems tackled by Ibn al-Haytham himself, e.g. the use of it, by Newton, for further investigation of the refrangibility of different rays of light.

Ibn al-Haytham accepted the scientific knowledge of his predecessors after its experimental verification, and with the help of his scientific method he himself made a number of remarkable discoveries in the field of optics, astronomy and other sciences. For instance, he proved that objects were seen by means of the light rays emanating from them. Before him, Euclid, Ptolemy, and most of the Greek Mathematicians believed that rays from the eye impinged on visible objects and thus caused them to be sighted. These scientists tended to regard the rays from the eye to be like tiny organs of insects through which they experience sensation. However, a matter of considerable surprise is that this idea of sight persisted even after Ibn al-Haytham's days and a scientist of Descartes's stature remained its adherent.

Ibn al-Haytham made some important original contributions to mathematics, and thus played an indirect role also in the progress of science.

It would not be out of the place to mention that Ibn al-Haytham aimed at utilizing the fruits of his Scientific method for the conquest and control of Nature. In his treatises on *Burning Mirrors*, which showed his technological achievements, the applications of many discoveries and laws of optics have been discussed. Thus, in these treatises, we find examples of application of pure science to technology, which is commonly regarded as the characteristic of modern science.

According to George Sarton, the Latin translation entitled *Optica Thesaurus Al-Hazeni*, of Ibn al-Haytham's main work on Optics (*Kitāb al-Manāẓir*) exerted a great influence on Western science (Roger Bacon, Kepler). It has already been observed that all the experimental and mathematical methods ascribed to Western Scientists do not, in fact, belong to them, We have already shown that some of the ideas on Scientific Method, contained in the works of the Western methodologists, were really borrowed from Ibn al-Haytham.

Bertrand Russel remarks that "Whatever we may like or dislike about the age in which we live, its increase of population, its improvement in health, its trains, motor cars, radio, politics, and advertisements of soap—all emanate from Galileo". In the light of what has been discussed so far, there is no justification for the claim that in the process of acquiring knowledge, at once secure and general, Galileo took the first great step, and, therefore he is the father of modern science. It has already been proved that Ibn al-Haytham employed scientific investigation which influenced later Western Scientists from Leonardo da Vinci onwards. Hence would it not be historically proper to substitute the name of Ibn al-Haytham for that of Galileo.

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