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The lodestone in the Greek, roman and Arab scientific heritage till the end of the mamluk Era (41- 923 AH/ 662-1517 AD): A cultural historical study

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Abstract

This research sheds light on the history of lodestone (magnetite) through a comprehensive historical and civilizational study of the achievements of the Greek, Romans and the Arabs in the study and utilization of lodestone till the era of the Mamluk state. It provides a brief overview of the lodestone stone in earlier civilizations, tracing the evolution of knowledge about its physical properties, philosophical significance, and diverse applications. The study chronicles the earliest instances of human observation of the magnet since antiquity, as well as the myths associated with its discovery. It then transitions to Greek civilization, where Thales of Miletus is identified as the first to explain the magnet's attraction to iron. The study then reviews the views of Plato and Aristotle, and documents the first systematic description of the magnet. Following the same sequence, the study then notes that the Roman thought, that inherited the Greek knowledge, infused it with a mythical and poetic character, as exemplified by the works of Pliny the Elder and Lucretius. Finally the study analyzes the significant role played by Arab and Muslim scholars in this field which is the central focus of the study. It elucidates the multiplicity of Arabic terms used to designate the lodestone, as well as the divergence in theories regarding its origin: ranging from those who attribute it to a predominance of dryness and heat to those who explain it through the chemical theory of sulfur and mercury as seen in the works of Dāwūd al-Antāki and al-Irāqi an approach considered more advanced.

Keywords: Abu Rayhān al-Birūni, Aristotle, Lodestone (Magnetite), Magnetic Attraction, Thales of Miletus, Theophrastus.

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1. Introduction

The phenomenon of iron attraction by the lodestone or "magnetic stone," ranks among the most ancient physical phenomena known to humanity. Throughout the ages, the lodestone has captivated the attention of scholars and researchers, not merely for its physical properties, but also for its philosophical, medical, technological, and symbolic implications.

The lodestone is, in essence, magnetic iron ore (Fe_3O_4); a mineral widely distributed in nature, known since antiquity, and a primary constituent of igneous rocks. Scientifically, it is identified as a form of magnetite that exhibits permanent magnetic properties; indeed, it was the very first material discovered by humans to possess magnetic characteristics. In ancient sources, the lodestone or natural magnet was referred to as al-magnitis.

It is said to have been named after the city of Magnesia in Asia Minor (present-day Turkey, within its Asian borders). References to it appear in numerous Arabic texts including Greek sources that noted that the finest varieties of this stone were dark blue (lapis lazuli) in color, possessed strong magnetic attraction, and were not excessively heavy.

In both folklore and philosophical traditions, the lodestone became associated with supernatural properties. Furthermore, as documented in ancient pharmacopoeias, it was utilized in early medicine to treat a variety of ailments. The lodestone played a pivotal role in both philosophical and scientific development. Within the context of the Arab-Islamic scientific heritage, the lodestone was regarded as far more than a mere physical object, rather, it served as a nexus where various disciplines converged ranging from medicine and philosophy to physics. It contributed significantly to the evolution of the scientific method, acting as a vital link between observation and experimentation, as well as between imagination and empirical science. Ultimately, the lodestone stands as a testament to the richness of the Arab-Islamic scientific heritage, specifically its rigorous and multifaceted approach to studying natural phenomena, which seamlessly integrated both empirical practice and theoretical inquiry.

1.1. Research Significance

The significance of this study emanates from the fact that it is the first scientific study – as far as the researcher knows – that discusses the knowledge of the Greek, Roman and Arab scholars about the lodestone and the mines from which they used to extract it during the period from the dawn of history until the end of the Mamlūk era.

1.2. Research Objectives

The main goal of this research is to shed light on the most important scientific achievements of the Greek, Roman and Arab scholars in terms of the manner in which they determined the properties, benefits, and applications of lodestone.

1.3. Research Questions

The research will answer a major question, which is: What are the novel scientific and practical additions that the Greek, Roman and Arab scholars have added to the science of lodestone during the period from the dawn of history until the end of the Mamlūk era? Three questions branch out from this major question, which are:

1. Have there been any previous studies about the Greeks, Romans and Arabs knowledge of lodestone, and what is particularly important about such knowledge?
2. What is the value of the lodestone and its applications compared to other stones during the eras subject matter of this study?
3. Where are the locations of lodestone mines as identified by Greek, Roman and Arab scholars?

1.4. Research Methodology

This research adopted the historical, analytical, critical and descriptive research method in which scientific material is collected from the most reliable sources and then arranged, classified and presented in the form of a descriptive, analytical and critical study, by comparing it with the scientific material contained in the contemporary sources.

2. Section One: The Lodestone in Ancient Civilizations

Throughout ancient civilizations dating back as far as the Paleolithic era, the lodestone captivated humanity with its mysterious allure and its remarkable ability to attract iron.

Bernal [1]. This fascination marked the very genesis of the science of magnetism. While some researchers date the discovery of the lodestone to over 2,000 years before the Christ Era (BC), [2] others place its origins even earlier approximately 3,000 years BC [3].

A popular legend recounts the discovery of the lodestone as follows: One day, a shepherd named Magnes encountered difficulty lifting his staff which was tipped with iron from certain spots on the ground. Upon closer investigation, he realized that this resistance occurred only when the iron tip of his staff came into contact with a specific type of dark-colored stone. These stones were, in fact, natural magnets containing a specific variety of iron ore known as magnetite [3].

There is a tale concerning a shepherd boy from the Troad who was sheltering behind a rock from the heat of the sun; it is said that his curved iron staff was pulled from his hand and became stuck to the rock above his head [4].

In fact, we find that most of these accounts later became widespread and prevalent within the Roman tradition; a foundation upon which all subsequent historians would rely.

Examining the historical records of ancient civilizations can yield a wealth of information regarding their modes of thought and how they interacted with the physical world around them. Indeed, familiarity with electrical or magnetic phenomena is often attributed to the ancient Egyptians during the Pharonic era [5].

However, the German archaeologist Karl Richard Lepsius (d. 1884) argued that iron or steel was entirely absent from the Old and Middle Egyptian Kingdoms, appearing only during the New Kingdom. He further suggests that the scarcity of such artifacts may be attributed, at least in part if not entirely, to the rapid corrosion of iron within the Egyptian soil, which is rich in nitrous oxides, or to its oxidation upon exposure to air. Indeed, as he notes, even the most astute contemporary Egyptologists believe that while the use of iron during the Pharaonic era was rare and, at best, sporadic, the metal itself was not entirely unknown; it was likely imported into the country from Phoenicia in its already manufactured form [6].

3. Section Two: The Lodestone in Greek Civilization.

The earliest mention of the lodestone in classical Greek literature appears in surviving fragments of the play Oenius by Euripides (d. c. 406 BC) specifically in the text Ion which were subsequently cited in the Suidās Lexicon [6]. These passages clearly attest to the lodestone's ability to attract iron. The Greeks were well acquainted with this mineral, referring to it as Magnēs, from which the word "magnetism" is derived; a designation subsequently applied to the entire spectrum of phenomena associated with the attractive force of this stone. They also referred to it by the name *The Stone of Heracles* [7]. Among the most prominent Greek scholars from whom we can benefit in this field are the following:

3.1. Thales of Miletus (6th Century BC)

Thales of Miletus (d. c. 548/ 545 BC) is regarded as the foremost of the Ionian philosophers The Ionians [8] and the first of the Greek philosophers; he posited that water was the fundamental element, [9] establishing it as the origin of all things [10]. According to Aristotle (d. 322 BC), Thales was the first founder of natural philosophy, which he defined as the knowledge of the principles and causes of things [11].

Thales was astonished when he first observed that a mass of black ore attracted a piece of iron from a distance, an observation that prompted him to declare: "There must be life within this ore [12]. This concept subsequently found proponents who supported it [13]. Thales likely attributed "life" to the lodestone because he perceived its influence remotely, without it physically touching the iron much in the way living organisms exert their effects upon other objects. Indeed, Thales asserted: "The soul is a motive force; the lodestone possesses life or rather, a soul because it moves iron [14]. He posited the existence of a mysterious, living force inherent in objects that instigates their motion, a force he identified as the soul [15]. This very concept would later be articulated by Aristotle in his treatise On the Soul (De Anima) [16]. Thus, Thales viewed the soul as a self-moving principle; he believed that the lodestone possessed a microcosm of the universal soul, which replete with divinities [17].

The origins of Thales's ideas regarding the lodestone may well stem from his earlier observations concerning amber. He noted that when amber was rubbed with a cloth, it would attract small strands of hair, bits of straw, or specks of dust. He attributed this phenomenon to a hidden spirit or a latent jinn dwelling within the material. He subsequently discovered that another substance possessed this same attractive power over objects: the lodestone. Consequently, he interpreted the stone's capacity for attraction as evidence that the iron ore was inhabited by a spirit whether hidden or manifest [4].

From these assertions, one may infer that Thales possessed a distinct religious or theological inclination. For the ancients, matter itself was often imbued with the quality of life; consequently, his philosophical system has been characterized as Hylozoism, a doctrine that permeated the majority of ancient philosophical schools regarding the nature of matter [16]. The historian of science George Sarton argues that, assuming this account is indeed accurate, it indicates that Thales was aware of one of the properties of the lodestone; he could, therefore, be designated the "founder of magnetism [18]. One might, however, ask: Is a person's knowledge of a single property within a scientific discipline sufficient to qualify them as the founder of that science, particularly given that he grounded such knowledge in a theological perspective?

3.2. Plato (4th Century BC)

The explanation offered by Plato completely rules out the concept of attraction. The philosopher states: "Furthermore, regarding flowing water, falling lightning bolts, and the wonders observed concerning the attraction of amber and the Stone of Heracles [the lodestone], in none of these instances is there any actual attraction. Rather, anyone who investigates truly will find that such wondrous phenomena are attributable to the absence of a void, bearing in mind the fact that these substances rotate, shift, and move each separately toward its own proper place by virtue of their composition and affinity [5].

Although Plato denies the existence of attraction in amber, he associates its effect with that of the lodestone; however, regarding precisely what amber acts upon or how its effect differs, if indeed it differs at all, from that of the Stone of Heracles, he offers little further comment [19]. Thus, the attraction of the lodestone to iron takes on a distinct form within Plato's dialogues [20].

3.3. Theophrastus (3rd Century BC)

Theophrastus discusses the lodestone in his treatise *De Lapidibus* (On Stones). While his discussion is brief, it is of immense significance, as it constitutes the earliest surviving written record within Greek philosophy regarding the properties of this stone. In this respect, Theophrastus's work differs from that of Thales, as our knowledge of Thales's views is derived solely from secondhand accounts and oral traditions, rather than from any text written by the philosopher himself. Theophrastus, conversely, was the first to document the subject of the lodestone in writing, within a systematic work that has survived to the present day. In his book, Theophrastus notes that "the stone known as the lodestone" possesses a distinctive property: the ability to attract iron. He did not explain the cause of this attraction, but rather focused

on describing the phenomenon itself. He also noted that the magnet originated in a place called Magnesia hence its name [21].

Theophrastus's book, *On Stones*, is fundamentally a systematic classification of the minerals and stones known in his time, enumerating their properties, benefits, and uses. Consequently, the mention of the magnet constituted a part of this classification rather than a detailed inquiry into the physics of the phenomenon itself. While Theophrastus discussed the magnet stone directly and concretely, Aristotle did not do so in the written works that have survived to us. The fundamental difference between the two lies in their methodology.

Figure 1.
Magnetite rock deposit, from East Inner Mongolia, China.
Note: Retrieved from mindat.org and the Hudson Institute of Mineralogy November 2018.

Nevertheless, Theophrastus's mention of the magnet stone is considered strong evidence that Aristotle was indeed aware of the phenomenon. It is implausible that Theophrastus would dedicate a section of his book to this stone without having previously discussed it with his mentor. Thus, it can be argued that Theophrastus's writings represent a practical application of Aristotle's philosophical concepts about a specific natural phenomenon, albeit one limited to description, without delving into the underlying philosophical causes that were of interest to Aristotle.

In summary, Theophrastus provided us with concrete information regarding the magnet stone, whereas Aristotle offered a philosophical framework capable of explaining that phenomenon, the matter which renders their respective works complementary in our understanding of ancient Greek philosophy concerning this subject.

3.4. Galen (3rd Century AD)

Galen of Pergamon (d. 216 AD) informs us that the magnet stone and the Heraclean stone are one and the same, bearing a resemblance to hematite or "bloodstone [5].

3.5. Dioscorides (1st Century AD)

Dioscorides of Cilicia (d. c. 90 AD) declared that the best magnet is one that attracts iron with ease, which is blue in color (lapis lazuli), dense, yet not excessively heavy. He then abruptly concluded his account with a somewhat unrelated observation, saying that three drachms of powdered magnet, if ingested with sweetened water, would prevent corpulence [20].

4. Section Three: The Lodestone in Roman Civilization

The phenomenon of magnetism garnered particular interest among the Romans, who inherited their knowledge of it from earlier civilizations most notably, the Greek. In his epic poem *De Rerum Natura* (On the Nature of Things), the Roman poet Titus Lucretius suggests that the name "magnet" is derived from the region of "Magnesia" in Asia Minor, where this wondrous stone is believed to have been first discovered. Lucretius observed the stone's ability to attract iron rings and form metallic chains, expressing his astonishment at the mysterious behavior exhibited by iron when under the influence of a magnet.

Figure 2.
Magnetite crystal rock from Bolivia.
Note: https://en.wikipedia.org/wiki/Magnetite.

Pliny the Elder, meanwhile, recounts the legend of the shepherd "Magnes," who discovered the stone when the iron nails in his sandals adhered to it on Mount Ida; a narrative that exemplifies the attempt to explain a natural phenomenon through the lens of mythology. The poet Claudian, conversely, portrays the magnet as a living entity that feeds upon iron, endowing it with emotional attributes and drawing analogies to love and passion, which is a perspective that reflects a poetic and imaginative interpretation of the phenomenon. Although the Romans lacked a precise scientific understanding of magnetism, their observations and narratives constitute a vital link in the history of magnetic science, bearing witness to the engagement of human thought with the strange and miraculous aspects of nature [5]. To avoid undue length, we shall now examine examples drawn from the scholars of Roman civilization.

4.1. Pliny the Elder (1st Century AD)

Pliny the Elder (d. 79 AD) noted that the unlearned referred to the magnet as "the swift iron." However, the full extent to which this phenomenon of magnetic attraction captured the human imagination is best illustrated by the legend of the shepherd Magnes. While on Mount Ida (on Crete island), he found himself pulled forcefully toward the ground when his iron-tipped staff and the iron nails in his sandals adhered firmly to the earth and he could barely manage to pull himself free. Magnes dug into the ground to investigate the cause and discovered a wondrous stone: the lodestone.

To quote Pliny: "What phenomenon is more astonishing? Where has Nature displayed greater audacity? For iron which conquers all other substances is itself drawn to the lodestone, following some invisible attraction; and the closer it approaches, the more it leaps forward to meet it." Pliny claims that the name "magnet" derives from a shepherd named Magnes, who discovered that his shoes and staff, both fitted with iron nails, had become stuck to the ground. It seems, however, more likely that the name originates from the region of Magnesia, one of the locations where natural magnetic ore can be found, rather than from the name of the shepherd [22].

Figure 3.
Crude magnetite rock with smooth edges.
Note: https://www.britannica.com/science/magnetite

4.2. Claudius Claudianus (5th Century AD)

The Roman poet Claudian (d. c. 404 AD), whose full name was Claudius Claudianus, believed that the lodestone attracts iron for the specific purpose of feeding upon it [23]. Naturally, Claudian was neither a scientist nor a philosopher; rather, he was a poet who wrote on a diverse range of subjects, including natural phenomena. In one of his poems, he described the lodestone as a "dull, black, and common stone" that subsists on iron, asserting that iron constitutes "its food and its strength."

His poetic expressions regarding the magnet were not grounded in scientific principles; rather, they formed part of a literary interpretation of the phenomenon, wherein he personified the lodestone, endowing it with the attributes of a living organism in need of sustenance. Claudian also drew connections between the magnet and other phenomena; most notably love likening the magnet's attraction to iron to mutual passion, and suggesting that the magnet "groans and burns" and is "emaciated by love." It is possible that he was influenced by the earlier assertions of Thales, and the vitality the latter had ascribed to the lodestone.

5. Section Four: The Lodestone in Arab-Islamic Civilization

The earliest documented Arab knowledge concerning the lodestone dates back to the 2nd Hijri century AH (8th Calendar century). Muslim scholars undertook the study and analysis of the lodestone, elucidating many of its properties most notably, its capacity to attract iron.

The lodestone is discussed in *Kitāb al-Aḥjār* (the Book of Stones), a work attributed to Aristotle [5]. In reality, however, Aristotle is not known to have authored any standalone treatise specifically dedicated to mineralogy or stones. The book attributed to him which was likely a Syriac text, was translated into Arabic during the Abbasid era. It is believed that its original author may have been Luqa Ibn Israfilun (d. 350 AH /962 AD) who claimed to have translated it, or perhaps another, unidentified individual did. The phenomenon of *naḥl al-kutub* (literary attribution forgery) was prevalent during the middle ages, leading to the circulation of numerous works falsely ascribed to ancient scholars. Indeed, some Arab scholars themselves such as Ibn Sīnā (Avicenna; d. 428 AH / 1037 AD) expressed skepticism regarding the authenticity of Aristotle's authorship of certain such books. The information regarding the lodestone as presented in the book attributed to Aristotle, which exerted significant influence upon the majority of Arab scholars is, in reality, an integral part of the heritage of Arab science that flourished during the Abbasid era.

5.1. Arabic Designations of the Magnet Stone

Wiedemann observed: "How is it that this stone was discovered in Arab lands, yet they failed to give it an Arabic name? Surely, they had no need for the foreignness of this term; they could have readily adopted the name *al-Jādhib* (The Attractor), which is a name that not only captures the stone's true intrinsic property, but also possess linguistic elegance and grace. However, their adoption of the Greek term suggests that, at the time, they were unaware of the stone's specific properties and, consequently, borrowed the designation from the Greeks [24].

Yet, Wiedemann was mistaken in this conjecture. The Arabic language is far too capable and rich to be characterized as deficient in expressing any concept regardless of its nature or complexity. Furthermore, the Arabs possessed an astonishing knowledge of the magnet stone's properties insights that had gone unnoticed by the Greeks and Romans before them, and would remain unobserved by the Europeans who followed. This fact becomes evident through the sheer multitude of names they bestowed upon the stone.

Indeed, the names for the magnet stone proliferated within Arabic culture either indigenous terms or translated from other civilizations. Among the names we have cataloged are *Armīṭīqūn* and *Abraqalīṭā*. In Syriac, it is known as *Kīfāsaf Farzalā*; in Hindi, as *Kadahak* and *Harbāj* [25]. In Persian, the magnet is termed *Āhankrubad* literally, "the Iron-Attractor [26]. It was also designated *Ḥajar Barāqablī*, [20] *Ḥajar al-Ḥadīd* (The Iron Stone), [19] *Ḥajar al-Hunūd* (The Stone of the Indians), [27] and *al-Anṭīlis* [28]. The common people, meanwhile, refer to it as *Ḥajar al-Ṭāʿah* (The Stone of Obedience) [29]. The term *al-Dawḥī* is specifically applied to black magnetic iron oxide [30].

Additionally, the term *al-Maghnāṭīs* may also be used to designate the compass itself. Ibn Hishām al-Lakhmi states: "People say *ḥajar al-maghnāṭis* [with a fatḥah on the mīm]; however, the correct form is *al-mighnāṭīs* with a kasrah on the mīm and the addition of a yā' following the ṭā'[31]. It is also said that its name is *al-maghnānīṭīs* [32]. The author of Al-Qāmūs mentions it within the entry for the root gh-ṭ-s, stating: "*Al-mighnaṭis*, *al-maghniṭīs*, and *al-maghnāṭīs*, all refer to a stone that attracts iron; the term is a naturalized loanword." He further notes: "*Al-maghnāṭīs* also referred to as *al-maghnīṇas* and *al-maghnāṭīs* is the stone that attracts iron; [33] it is not a term of pure Arabic origin, although some lexicographers have included it within this specific root structure [34].

It appears that Ibn Abī Ḥajalah al-Tilimsānī Aḥmad Ibn Yaḥyā (d. 776 AH / 1375 AD) was the sole writer in the Arabic literary tradition to employ the term *al-Maghnāṭīs* (the Magnet) in the title of a book *Al-Maghnāṭīs fī al-Durr al-Nafīs* (The Magnet for Precious Pearls), [35] doing so in a metaphorical rather than a scientific sense. For the book did not address the physical phenomenon of magnetism, rather, the author used the term symbolically to denote the inherent allure of its literary and historical content. This intent is evident from the context of the introductory epistle he penned for his work *Mujtabā al-Udabā'* (The Selection of Literati), wherein he deployed the word "magnet" as a rhetorical metaphor designed to draw the reader toward the "precious pearls" of anecdotes and poetry contained therein.

5.2. The Origin of the Magnet Stone

According to traditional Arabic literature, the origin of the magnet stone is explained as being a mineral that initially began to form as iron, but subsequently underwent exposure to factors of heat and desiccation within its mineral matrix.

Consequently, it transformed into an intensely hard, black stone due to its diminished moisture content and extreme aridity. A number of Arab scholars including Ibn Israqiyūn, [36] al-Tughrā'i (d. 515 AH / 1121 AD), [37] al-Tifāshi (d. 651 AH / 1253 AD), [38] al-Qibjāqi (d. after 660 AH / 1262 AD), [39] al-Irāqi (d. 700 AH / 1300 AD), [40] al-Ansāri al-Dimashqi (known as Sheikh al-Rabwa; d. 727 AH / 1327 AD), [41] and al-Antāki (d. 984 AH / 1576 AD) [27] have attributed this particular theory to Aristotle.

Figure 4.
Crude magnetite ore with its natural shape.
Note: https://www.istockphoto.com/photos/magnetite.

Dāwūd al-Antāki posited that its origin lies in the union of high-quality sulfur with a small amount of mercury, provided that the ambient temperature is low. Al-Irāqi, on the other hand, linked its formation to terrestrial chemical processes, asserting that its black color results from the combustion of its scant moisture.

The Sulfur-Mercury Theory as a systematic chemical framework for explaining the origin of minerals was not formulated solely by Jābir Ibn Hayyān (d. c. 200 AH/815 AD), rather, he was the first to develop it and articulate it in a systematic and scientific manner within the Arabic intellectual tradition, endowing it with profound theoretical and chemical depth.

Its intellectual roots trace back to Greek philosophy, particularly to Aristotle, who expounded upon the four elements (fire, air, water, and earth) and the fundamental qualities (hotness, coldness, wetness, and dryness). Furthermore, certain Hellenistic writers such as Zosimus (fl. 300-350 BC) discussed the existence of two fundamental principles governing the formation of minerals. Jābir Ibn Hayyān was the first to systematize this theory and formulate it with chemical precision, positing that all minerals are formed through the union of two fundamental principles: sulfur (the principle of combustibility) and mercury (the principle of volatility and luster). He subsequently added salt as a third element to complete his theoretical triad. Later scholars such as al-Antāki and al-Irāqi explicitly employed this theory to explain the origins of magnets and iron, thereby demonstrating that it constituted the dominant theoretical framework within Arabic chemistry; a framework established and firmly grounded by Jābir.

However, there were other Arab scholars who relied on the theory of "moisture and dryness" to explain the origin of the lodestone. Who, then, is more likely to have been correct? The answer requires striking a balance between historical context and scientific advancement.

First: Who adopted the theory of "moisture and dryness"?

As is evident from the Arabic texts, authors such as Lūqa Ibn Israqiyūn, al-Tifāshi, and al-Qibjāqi and indeed even al-Irāqi he employed the language of "hot and dry" (or "low moisture and intense dryness") to account for the hardness and blackness of the magnet. This terminology is derived from Aristotle's Four Natures (heat, cold, moisture, and dryness), which constituted the dominant explanatory framework in the natural sciences, medicine, and chemistry throughout antiquity and the Islamic era.

However, herein lies the distinction, for al-Antāki and al-Irāqi did not stop there; rather, they introduced the Sulfur-Mercury theory as a chemical explanation for the very formation of the mineral itself, moving beyond a mere physical description of its properties.

Secondly: Who Was Right?

From the perspective of modern science: The theory of moisture and dryness, despite its apparent accuracy in describing hardness and aridity, remains a philosophical and descriptive framework, for it fails to explain the true chemical composition of the magnet (which is, in fact, magnetic iron oxide). Conversely, the Sulfur-Mercury theory, though chemically imprecise by modern standards, stands closer to the spirit of empirical chemical inquiry. This is because it attempts to explain matter through chemical elements or principles capable of undergoing reaction and transformation,

thereby representing a step toward understanding chemical reactions and atomic structure. Moreover, al-Irāqi's description of the "union of water with earth" and the notion that "heat ignited, causing the stone to turn black" bears in terms of its underlying logic a resemblance to the concepts of oxidation and combustion, which serve to explain the black coloration of iron oxides.

Thus: Who is most likely to have been correct?

Al-Antāki and al-Irāqi come closer to the truth than their counterparts, for they adopted a chemical explanation (the Sulfur-Mercury theory), which is an approach that aligns more closely with the methodology of the empirical sciences. As for the theory of humidity and dryness, which was prevalent and accepted in its time, it was insufficient to explain "chemical origin," but only explained the "physical state."

In terms of scientific advancement, chemists such as Jābir, al-Irāqi, and al-Antāki stood closer to the essence of modern science, for they sought to interpret matter from within rather than from without. In doing so and despite the imprecision of their specific details, they were on the right path toward the development of modern mineralogy and chemistry.

A comparison between the ideas of Arab and Muslim scholars and those of Balinas the Sage reveals a point of agreement: Balinās concurs with Arab and Muslim scholars such as Dāwūd al-Antāki, al-Irāqi, and al-Tifāshi that the lodestone (magnetite) is the product of an incomplete mineral transformation. It began its formation as iron but solidified prematurely due to the predominance of dryness and heat, coupled with a scarcity of moisture. However, Balinās attributes this formation to the influence of the planet Mars through which he interprets the stone's characteristics of blackness, hardness, and magnetic attraction along an astrological-astronomical framework that links the "fiery body" of Mars (Aries) with its "watery soul" (Scorpio). By doing so he identifies the fundamental intrinsic property shared by the lodestone and its associated minerals as "extreme dryness and absolute potency."

The Arab scholars, conversely while ostensibly relying on the very same terminology of the Four Natures (heat, dryness, moisture, etc.) often transcended this descriptive philosophical framework. Many of them particularly al-Antāki and al-Irāqi advanced toward a systematic chemical explanation grounded in the Sulfur-Mercury theory pioneered by Jābir Ibn Hayyān. They posited that the formation of the lodestone resulted from an internal chemical combination rather than from an external planetary influence. Accordingly, Blinās interprets magnetism through the lens of a coherent metaphysical cosmology, whereas Arab scholars particularly the alchemists among them tend toward an internal, empirical explanation that closely approximates the methodology of modern science, even if they employ different terminology.

6. Magnetite Mines

During antiquity, iron was mined along the shores of the Aegean Sea and on the islands of the Mediterranean. It is said that magnetic iron ore was also discovered near Magnesia in Asia Minor [42]. Furthermore, magnetite, which is the name which is derived from the Magnetes, which is in turn the people who inhabited the vicinity of the city of Magnesia on the Meander River in ancient Lydia [43].

Arab sources did not agree on a specific mine for lodestone in India; some state that it is found within the Indian subcontinent itself, [27] others claim it exists in the Indian Ocean, [44] while still others assert that it is located along the coast of the Indian Ocean [45].

Furthermore, Arab sources indicate that lodestone is prevalent in the Red Sea (known as Bahr al-Qulzum). Some sources point to its presence within the coastal mountain ranges, [46] while others suggest it is situated at the very bottom of the Red Sea (specifically, on the seabed of the Gulf of Suez) [47]. However, Ibn al-Jawzi (d. 597 AH / 1201 AD) posits that the actual deposit is more likely to be found within the mountains rather than on the seabed [19].

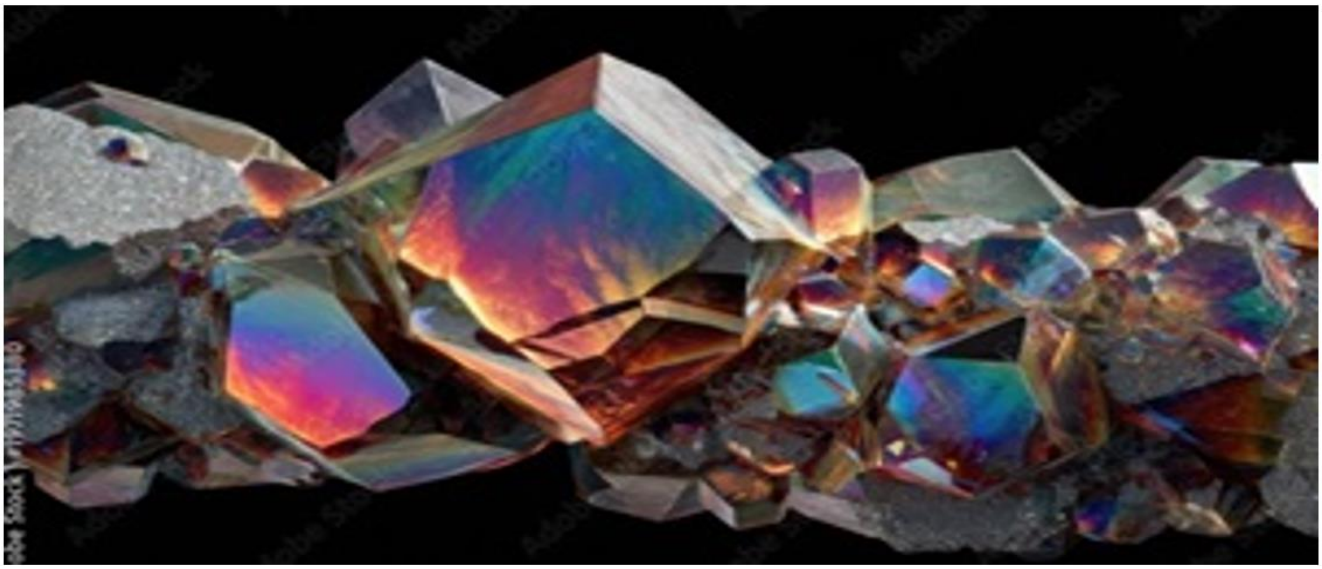

Figure 5.
Iridescent geometric crystal cluster with metallic sheen.
Note: https://stock.adobe.com/in/search?k=&token.

It is also said that a mine for this stone exists in Sana'a, Yemen spanning the full extent of that region [48]. It is likewise found in Oman [27]. Additionally, it is widely distributed throughout *Al-Andalus* (Islamic Spain) [44] in an area known as the *Regions of Tudmīr* [49] or the *Territory of the Sanhāja* [50]. It is also found in a district within the region of *Khorasān* [41].

Lodestone is present in the Arabian Gulf (referred to as the "Eastern Sea") [20] and in the Indian Ocean [6]. Its richest deposits and finest varieties may well be those found in the vicinity of *Zabtra*, located near the borders of the Byzantine Empire [51]. It is also found in the maritime sector of *Mount Malanda al-Harrāni* (a mountain or hill situated nearby most likely *Būkit Cīna*, or the Chinese Hill, a historical hill located in the center of modern-day *Malaga*, *Malaysia*) [52]. Furthermore, it is found in Morocco (North Africa), specifically in the locality of *Ghasāsa*; [47] indeed, within the waters off the Maghreb coast, there are said to be entire mountains composed of lodestone [53].

7. Types of Lodestone

According to Arab sources, there are several varieties of lodestone capable of attracting iron. The finest variety is described as being azure-colored, solid, pure, and dense, yet not excessively heavy [48]. Conversely, the black variety is considered to be of inferior quality [27]. However, some sources contend that the very best types of lodestone are those that appear black with a reddish tinge, [54] or gray with black speckles [55].

Arabic literature [53] also records the existence of other types of material-attracting substances in China distinct from the lodestone that attracts iron. Among these is the *gold magnet*, which attracts gold; if subjected to heat treatment (by fire), it acquires the properties of a standard lodestone. Other varieties include the *silver magnet*, which draws silver toward itself from a considerable distance; the *copper magnet*, which is utilized as a remedy for epilepsy; the *lead magnet*; and the *flesh magnet* a substance of ill repute and corrupt nature, which if placed upon human skin, it adheres to it so firmly that, upon being forcibly removed, it tears away fragments of the skin itself.

There is also the *hair magnet*, which attracts hair toward it such that if placed upon a person's head, it plucks out their hair, leaving them bald. There is also the *nail magnet*, which tears away fingernails if brought into close proximity. Sheikh al-Rabwa noted that gold acts as a magnet for mercury; when the two are brought near one another, in which case the gold attracts the mercury and absorbs it. Consequently, if filings of gold, iron, lead, copper, and tin are mixed together and mercury is added to the mixture, the mercury will seek out the gold and amalgamate with it, disregarding the other substances (metals); a phenomenon which is attributed to the existence of a "magnetic affinity" between gold and mercury. However, a comparative analysis of these various texts reveals that they all ultimately trace their origins back to the treatise attributed to Aristotle.

Figure 6.
Crystalline magnetite rock with sharp facets and natural sheen.
Note: https://stock.adobe.com/in/search?k=&token

Abu al-Rayhān Muhammad Ibn Ahmad al-Birūni (d. 440 AH / 1048 AD) recounted that: "Attraction and mutual attraction are found in many things other than the above-mentioned. For example, *naphtha* attracts fire to itself, and the *olive stone* attracts oil, hence its name. Likewise, the *vinegar stone* and the *dropsy stone* draw water from the bellies of those suffering from dropsy; all of which are well-known, even if we ourselves have not witnessed them. Furthermore, if a

strand of boiled silk is suspended near clothing, it is drawn toward it. Indeed, even if one runs a hand over the back of cat fur, then it is lifted up slightly toward the palm and becomes erect."

"A certain Rabbinic Jew recounted to me that he had seen, in the possession of another Jew, a stone that attracted gold. He offered to purchase it for fifty dinars, but the owner refused. If the narrator was telling the truth, such a stone would be worth a fortune and would spare moneychangers the trouble of extracting impurities from fine, earthy gold dust; a task they typically perform using an elongated, finger-shaped magnet, which they stir and agitate within the mixture in order to make the impurities adhere to it. These impurities consist of heavy black sand that naturally accompanies such gold as such impurities cannot be removed by washing. Thus, they purify the gold using such a magnet. This phenomenon suggests that the black grains remaining within gold dust belong to that very same mineral class, as the magnet distinguishes them from the rest. This separated black material is subsequently sold to goldsmiths in order to use it in their craft [51]. Some scholars observe that the magnet capable of attracting gold held particular significance; for if gold exists in the form of a fine powder mixed with sand, the gold magnet would effectively isolate every single particle of the metal. This latter observation constitutes the earliest recorded proposal for the process of magnetically separating metals from other materials with which they are intermixed.

The removal of iron specifically from mixtures containing sand and other materials using this method is a very old concept. Indeed, while this process was described in detail by the Italian Giambattista della Porta (d. 1615) and others in the sixteenth century, and the very same principle has been applied in recent years to the magnetic extraction of the metal from its crushed ores, [5]. Al-Birūni's text suggests that this technique was, in fact, already known to the Arabs.

Atārid Ibn Muhammad al-Bābili al-Baghdadi the Calculator (d. 206 AH / 821 AD) presented us with another classification of the types of magnets that may exist, based on their magnetic polarity. He noted that: "They are of three types:

- The first is attractive.
- The second is repulsive.
- The third has one side that attracts, while the other repels [41].

8. Physical Properties of the Magnet Stone

Arab and Muslim scholars explored several physical properties of the magnet stone including the magnet's capacity to lift iron weights, the variation of its magnetism under the influence of temperature, and the process of magnetization through friction.

Jābir ibn Ḥayyān [56] discussed the subject of the magnet's capacity to lift iron weights, noting that "a small piece of it can exert an effect upon a large piece of it; however, the principle regarding quantity dictates that a piece the size of a grain of the magnet will attract only a small amount of iron, whereas a piece weighing a pound will attract a proportional amount. The greater piece possesses the power to attract the smaller piece; a power it exercises due to the smaller piece's limited power and the fact that its mass falls within the sphere of influence of the larger piece. This dynamic, however, does not apply to the smaller piece; due to its limited mass, the quantity of the larger piece does not fall within its sphere of influence. Therefore, one should understand and verify this principle, and base one's judgments regarding the interactions of these substances upon it [56]. In other words, a large quantity of the magnet can attract a small quantity of iron, but the converse is not true. This phenomenon is attributed to the inherent attractive property of the magnet.

Furthermore, Jābir ibn Ḥayyān [56] discovered that the strength of a magnet stone diminishes over time. For instance, a stone capable of lifting 300 grams might, after the passage of time, be able to lift only 240 grams even though its own physical weight remains unchanged. He cited this observation as evidence that certain physical realities are at work here, driven by an influence yet to be fully understood Wiedemann [57]. Subsequently, Jābir ibn Ḥayyān [56] proceeded to measure the lifting capacity of magnets relative to their own weight, and he found that this capacity indeed decreases as time passes.

Figure 7.
A specimen of black magnetite ore with metallic luster.
Note: https://stock.adobe.com/in/search?k=&token

In *Kitāb al-Raḥma* (Book of Mercy), Jābir Ibn Ḥayyān recounted that: "We once possessed a magnet capable of lifting a weight of one hundred dirhams of iron; yet, after the passage of some time, it could no longer lift more than eighty dirhams even though its own weight remained unchanged, having diminished not in the slightest. The reduction, rather, occurred solely in its magnetic force. This observation aligns with what we have previously noted regarding the gradual erosion of the stone's exposed surfaces due to the effects of sunlight and atmospheric air."

He further recounted: "We also discovered a specimen weighing thirty astārs that was capable of attracting six hundred dirhams of iron. Since thirty astārs are equivalent to one hundred and thirty dirhams, this meant the stone attracted a weight equal to three and one-third times its own mass; a truly rare and astonishing phenomenon." He added: "My associate, al-Maḥbūsī, while supervising mining operations in the gold mines of Khashbājī, discovered a magnet unlike any other of its kind; it bore no resemblance to the typical black, dull appearance of such stones. Instead, its color and texture resembled that of a highly polished iron mirror so much so that observers were inclined to believe it was, in fact, merely a piece of iron. A fragment of this stone, weighing nine dirhams, was found to be capable of attracting an equal weight of iron [51].

However, the chemist 'Izz al-Dīn 'Alī Ibn Muḥammad Ibn Aydamur al-Jildakī (d. 743 AH / 1342 AD) offered a different interpretation of the aforementioned passage. He argued that by the term *magnet stone*, Jābir did not intend to refer to the conventional magnet as we understand it today; rather, he was alluding to the *Eternal Water* namely, mercury. This interpretation is corroborated by a passage in Jābir's *Kitāb al-Khāliṣ* (Book of Purity), wherein he states: "Know with absolute certainty that the *Eternal Water* is a reality, and it is none other than mercury. It is so named for its enduring persistence within any solid body it permeates, remaining inextricably bound to it without ever escaping Jābir ibn Ḥayyān [56].

Al-Jildakī [58] recounted that: "The mentor Abu Mūsa Jābir Ibn Hayyān al-Sūfi mentioned that this *Water* may be weakened by prolonged inactivity if left in isolation. He related that: 'We once possessed a lodestone weighing one hundred dirhams, which was capable of attracting one hundred and twenty dirhams of iron. It remained in our possession for some time; subsequently, when we tested it again, we found that it could no longer attract even eighty dirhams. We then weighed it, only to discover that its weight remained unchanged.' By the 'lodestone,' Jābir (may God have mercy on him) is referring to the *Eternal Water*, by the 'iron,' he signifies the residual matter, by the figure of 'one hundred and twenty', he denotes the potency and the power of attraction toward the celestial realm, and by the figure 'eighty,' he indicates the weakening of the *Water* and its regression toward the terrestrial center, for eighty lies lower than one hundred and twenty. Such is the instruction of our mentor. However, should the residual matter return and reunite with it, it impedes its spiritual efficacy, leaving only its material substance intact. These are matters that have been substantiated by empirical experimentation, which, indeed, may run contrary to theoretical deduction [58].

Figure 8.
Cluster of Magnetite Crystals of Iron Oxide Mineral.
Note: https://stock.adobe.com/in/search?k=&token

Al-Jildakī [59] then expounded upon the dictum of Jābir Ibn Hayyān, offering a deeply analytical and detailed explanation of the concepts of property and weight (quantity), and the mutual interactions within the context of ancient chemistry. In doing so, he synthesized precise physical observation exemplified by the force of a magnet with a philosophical-mystical methodology involving the concepts of *al-hijab* (veiling) and intellectual perception. This analysis revolves around a central idea: that a specific property is the direct result of the presence of a pure, unencumbered essence (substance), and that the presence of impurities acting as veils leads to the alteration or nullification of that property [59]. This exposition underscores two fundamental principles:

The First: The Principle of Unique Property (The Law of Incompatibility).

This principle is rooted in Jābir's dictum: "For it is impossible for two distinct essences each defined by its own unique set of parameters to share a single, identical property." In terms of modern scientific thought, this principle corresponds to the concept of identifying a substance based on its distinctive physical and chemical properties (such as density, melting point, or chemical reactivity). Every substance (essence), possessing a unique composition (defined by its individual parameters), must necessarily exhibit a unique property. Furthermore, should different substances (essences) combine or harmonize; the result is the emergence of a new substance endowed with an entirely new property.

The Second: Knowledge of the Apparent and the Hidden.

Al-Jildakī [59] observes that the force of a magnet, specifically its power of attraction, is a phenomenon evident in the apparent (the observable realm); yet, its true origin and the underlying causes for the variations in its intensity remain hidden (unknown), accessible only to those capable of perceiving them through the faculty of intellect or through Divine Revelation. This approach, characteristic of ancient methodologies, draws a distinction between the Science of Quality (Metaphysics/Hidden Nature) and the Science of Quantity (Measurable Quantity). It reflects Al-Jildaki's acknowledgment that empirical measurement (Natural Balance) is capable of apprehending quantity; however, a true understanding of the mechanism by which a specific property operates, for instance, why a magnet attracts remains a mystery of either a higher intellectual order or a Divine nature. Al-Jaldaki then offers a remarkably precise and quantitative observation regarding magnets, thereby demonstrating the acuity of his observational skills:

Measuring Attractive Force: Al-Jaldaki clearly notes that lodestones vary in strength; some attract only a needle, while others attract an amount of iron equivalent to one-tenth, one-fifth, one-quarter, or one-half of their own weight or even several times their own weight. This variation stems from subtle physical and chemical factors, including:

- The purity of the magnetic material (specifically, the proportion of magnetite Fe_3O_4 within the rock).
- The internal crystalline structure of the magnet.
- Its remanence (residual magnetism) following exposure to a strong magnetic field.

Measuring a magnet's strength relative to its own weight represents an advanced quantitative methodology. A prime example of this is the concept of the *hijab* (veil) and how it serves to nullify the magnetic property, wherein the *veil* acts as a physical or chemical barrier to the magnetic effect.

Finally, Al-Jaldaki's exposition demonstrates a profound understanding of the relationship between the intrinsic composition of matter and the manifestation of its properties. He emphasizes that a property diminishes or is even nullified in the presence of "veils" (i.e., impurities and material interferences), and that purification is the key to unlocking latent potential.

In reality, it is more likely that Abu Rayhān al-Birūni's observation namely, that the cause of the decline in magnetic attraction is the magnet's exposure to solar heat, is the correct one. We shall explore this further later, when discussing the relationship between heat and magnetism.

The Arabs observed that high-quality lodestone found in the district of *Tudmīr* (the territory of the *Sanhāja* tribe in *Al-Andalus*), specifically stones weighing one or two dirhams, possessed the capacity to lift a load of iron from the ground to a height equivalent to that of a human stature, or even higher [41]. Shihāb al-Dīn Muhammad Ibn Ahmad Ibn Mansūr al-Abshīhi (d. 852 AH / 1448 AD) noted that: "The finest variety is that which attracts half a mithqal of iron [60]. By this latter statement, he implies that the most superior type of magnet is one capable of attracting half a mithqal, a unit equivalent to 2.2 grams of iron. The historian Wiedemann points out that this datum aligns with his own observations regarding small magnetic stones [24].

It appears that the relationship between the weight of a magnet and the weight of the object it attracts was utilized by the Arabs as a method for detecting fraud in weighing. Specifically, the Arabs employed a balance scale featuring an iron tongue containing a magnetic stone [24].

Subsequently Observations regarding the relationship between a magnet's weight and its capacity to lift heavy objects first emerged in 14th century Europe with Thomas Bradwardine (d. 1349). Bradwardine believed that the combined weight of a magnet and the iron suspended from it did not exceed the weight of the magnet alone; he asserted that this conclusion was derived from empirical observation. The German scholar Heinrich von Langenstein (d. 1397) later reiterated this claim, though neither man had actually examined the matter with true scientific rigor.

Indeed, many medieval texts contained conceptual experiments that had never been subjected to practical testing [61]. With the dissemination of the work on magnetism by William Gilbert (d. 1603), Galileo Galilei (d. 1642) undertook to replicate Gilbert's experiments and ultimately surpassed him. Galileo succeeded in amplifying a magnet's attractive force to such an extent that it could lift a weight equivalent to twenty-six times its own; by contrast, Gilbert's magnets were incapable of supporting more than four times their own weight. As a tribute to his patron, the Grand Duke of Tuscany, Cosimo II de' Medici (d. 1621), Galileo presented him on the occasion of his wedding with a symbolic emblem: a magnetic sphere from which hung several pieces of iron. This imagery served to symbolize the Prince's love and benevolence toward his subjects, as well as their own deep attachment to him [62].

It is also said that the renowned English physicist Isaac Newton (d. 1727) once possessed a small fragment of lodestone; a naturally occurring magnet which he had set into a ring. Although the weight of this magnet did not exceed three grains (approximately 0.1944 grams), it was capable of lifting an iron mass weighing seven hundred grains; in other words, it could lift a load equivalent to about 333 times its own weight (approximately 45.37 grams) [63]. This demonstrates that this small magnet weighing less than one-fifth of a gram was capable of lifting a mass of about 45 grams, an astonishing feat for the power of a natural lodestone at that time.

It appears that the concept of creating a magnet by assembling a number of separate, smaller magnets aligned such that their like poles face one another, thereby causing them all to function as a single unit, first occurred to the British physicist and inventor Gowin Knight (d. 1772). Since then, numerous other scientists have significantly advanced this concept; such devices are now manufactured as compound magnets or, as they are sometimes termed, magnetic batteries and possess immense power.

As noted previously, a magnetic battery consists of a number of separate, smaller magnets assembled in such a way that they collectively function as a single magnet. The first magnetic battery devised by Knight did not possess the full potential strength it would have achieved had he not assembled the constituent magnets in direct contact with one another. The first to identify the cause of this partial inefficiency was the French physicist Charles-Augustin de Coulomb (d. 1806); his research on magnetic needles garnered such high acclaim from the French Academy that it awarded him a prize for his work. Coulomb noted that when separate magnets are placed together, they interact in a manner that diminishes their individual strength; consequently, to achieve optimal results, the magnets situated at the center of the stack should be slightly longer than those positioned on the periphery [63].

9. Conclusion

1. Arab and Muslim scholars such as Dāwūd al-Antāki and al-Irāqi moved beyond the Aristotelian philosophical framework based on the four "natures" (specifically, humidity and dryness). Instead, they relied on the Sulfur-Mercury theory (originally developed by Jābir Ibn Hayyān) to explain the formation of magnets. This shift represents a transition toward an empirical chemical methodology, moving beyond mere descriptive physical observation.
2. Scholars such as Jābir Ibn Hayyān and al-Birūni conducted quantitative measurements regarding the relationship between the weight of a lodestone (natural magnet) and the maximum weight of iron it could support. Jābir recorded that a magnet could lift up to three times its own weight, while also observing that this lifting capacity diminished over time, even if the magnet's own weight remained constant. Furthermore, al-Abshihi noted that the finest quality magnets were capable of attracting half a mithqal (approximately 2.2 grams) of iron.
3. Izz al-Dīn al-Jaldaki presented a physical analysis positing that the presence of impurities or veils in iron, such as non-magnetic substances or garlic, nullifies the magnet's attractive property. He further suggested that purification

processes (such as treatment with goat's blood) could restore this property. This concept demonstrates an early understanding of the intrinsic relationship between a substance's internal composition and the manifestation of its physical properties.

4. The research identified and cataloged more than 15 distinct Arabic names for the lodestone (including *al-Maghnatīs*, *Hajar al-Hadīd* (Iron Stone), *Hajar al-Ṭāʿah* (Stone of Obedience), *and al-Dawḥī*, among others). This extensive nomenclature refutes any notion of linguistic deficiency and serves as evidence of a diverse and sophisticated body of knowledge regarding this mineral knowledge that extended its reach to regions as far-flung as India, Persia, and the Syriac-speaking world.
5. Arabic sources mention deposits of magnetite across vast regions including India (the sea or the Indian Ocean coast), the Red Sea (a mountain or the seabed of the Gulf of Suez), Yemen (Sana'a), Oman, *Al-Andalus* (*Tudmīr*, the territory of the *Sanhāja*), *Khorasān*, the Arabian Gulf, the Indian Ocean, Morocco (*Ghasāsa*), *Zabtra* (on the Byzantine frontier), and Malaga (present-day Malaysia). This indicates a wide geographical dissemination of knowledge regarding this mineral.
6. Atārid Ibn Muhammad al-Bābli identified three types of magnetite: an attracting type, a repelling type, and a type that attracts on one side while repelling on the other. This constitutes an early indication of an understanding of magnetic polarity predating its explicit description in Europe.
7. Al-Birūni recorded that certain goldsmiths utilized a stone known as *Awrsank* (magnetite) to separate alluvial gold from black sand; this represents an early proposal for magnetic separation processes. Furthermore, Arabs employed magnets within iron-tongued balances to detect fraud in weighing.
8. Scholarly consensus holds that the Arab scientific heritage regarding the study of magnetism was not confined solely to the empirical physical realm; rather, it integrated the subject with medicine (therapeutic applications), philosophy (connections to the theory of elements), chemistry (the sulfur-mercury theory), and Sufi symbolism thereby constituting a unique model for the interdisciplinary study of natural phenomena.

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