By the Book: Alchemy and the Laboratory Manual from Al-Rāzī to Libavius, 920-1597

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Today, when alchemy evokes wizards and crystal balls, it may seem odd to refer to a book of procedures on the transmutation of ordinary metals into gold as a practical laboratory manual free of mysticism. Yet it was alchemy, the most ancient form of chemistry, which first brought the book and the laboratory together. Over a thousand years ago, the Persian physician and alchemist Abū Bakr Muhammad ibn Zakarīyā al-Rāzī (c. 865 - 923)[1] wrote the earliest laboratory manual to reach us in its entirety. He called it the *Kitāb al-Asrār* or *Book of Secrets*. The most valuable "secrets" in the *Kitāb al-Asrār* are organized procedures and written specifications for proportions, temperature, timing, and endpoints, the same strategies for achieving reproducibility that laboratories use today. This paper will demonstrate that there was a continuum of practical laboratory manuals from al-Rāzī's *Kitāb al-Asrār* in 920 C. E. to Libavius's *Alchemia* published in 1597 C.E., which some historians refer to as the first chemistry textbook.[2]

Al-Rāzī, as his name indicates, was from the city of Rayy, a thriving trade center in tenth century Persia. He wrote massive volumes on medicine, philosophy, and astronomy, and engaged in energetic defenses of the controversial practice of alchemy.[3] Observation of mixed ores in the mines supported Aristotle's theory that metals evolve to a higher state over time within the earth.[4] Even in the tenth century, a debate centered on the possibility of replicating this metamorphosis in the laboratory.[5] Alchemists knew how to use controlled heat

[1] Abū Raihān Muhammad ibn Ahmad al-Bīrūnī, "Al-Bīrūnī als Quelle für das Leben und die Schriften al-Rāzīs," trans. and ed. Julius Ruska, *Isis* 5 (1923): 32.

[2] References to *Alchemia* as the first chemistry textbook include: Bruce T. Moran, *Andreas Libavius and the Transformation of Alchemy: Separating Chemical Cultures with Polemical Fire* (Washington Publishing Company: Sagamore Beach, MA, 2007), 34. J. R. Partington, *A History of Chemistry* vol. 2 (London: MacMillan & Co., 1961), 253. Owen Hannaway, *The Chemists and the Word: The Didactic Origins of Chemistry* (Baltimore: Johns Hopkins UP, 1975), 81, 89.

[3] Abū Bakr Muhammad ibn Zakarīyā al-Rāzī, *Kitāb al-Asrār*, in *Al-Rāzī's Buch Geheimnis der Geheimnisse, Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin*, Band 6, trans. and ed. Julius Ruska (Berlin: Verlag von Julius Springer, 1937), 9, 83.

[4] Aristotle (384-322 B.C.), *Meteorology*, vol.1 of *Great Books of the Western World*, ed. Robert Maynard Hutchins (Chicago: William Benton, 1952), 445, 482 .

[5] Avicenna (980-1037 C.E.), "On the Formation of Minerals and Metals and the Impossibility of Alchemy," trans. and ed. E. J. Holmyard and D. C. Mandeville, in *A Sourcebook in Medieval Science*, ed. Edward Grant (Cambridge, MA: Harvard UP, 1974), 569-70. Earlier Islamic scholars questioned alchemy, but Avicenna's emphatic refutation of it was the basis for continuing debate in medieval Europe.

to transform matter with processes such as sublimation, the conversion of a solid to a vapor, and calcination, the conversion of a solid to a powder. The human fascination with the transformation of metals led to the first application of theoretical chemistry—the use of the workspace not to mix the ingredients for an alloy or a perfume, but to recreate natural processes in an artificial environment and transform the substance of matter itself.

The *Kitāb al-Asrār,* however, was not a defense of alchemy, but a systematic procedure manual with a modern resonance that contrasts with theoretical or allegorical medieval texts. In fact, the structure of al-Rāzī's tenth-century book closely resembles that of *Alchemia*, a chemistry text written in Germany in 1597 by Andreas Libavius. During the seven hundred years that separate these two works, other practical alchemical texts shared elements of this structure as well, including the thirteenth-century *Summa Perfectionis* of Pseudo-Geber and the fourteenth-century *New Pearl of Great Price* by Petrus Bonus.[6]

In 1937, historian and linguist Julius Ruska (1867-1949) published a German translation of the *Kitāb al-Asrār* based on three Arabic manuscripts.[7] In order to study this work, I translated Ruska's German text into English and analyzed its content based on my own laboratory experience. Mid-twentieth-century historians such as E. J. Holmyard, who wrote *Alchemy* in 1957, gave al-Rāzī credit for his systematic classification of chemicals.[8] More recently, William Newman and Lawrence Principe describe how seventeenth-century laboratory texts demonstrate the continuity of alchemy and chemistry.[9] However, the antecedents of modern laboratory manuals extend much further back. It is time to take a fresh look at the *Kitāb al-Asrār.*

What does it mean to claim that *Kitāb al-Asrār* resembles a modern laboratory manual? The laboratory today, inextricably integrated into the world's economy, is a controlled space that uses specialized equipment for repetitive testing. Whether its purpose is medical diagnosis, seismic material testing, or stem-cell research, mistakes can be costly and randomness has no place. The *Kitāb al-Asrār* is suggestive of a modern manual because it systematically addresses equipment, materials, quality, and testing processes. When al-Rāzī

[6] Petrus Bonus, *The New Pearl of Great Price: A Treatise concerning the Treasure and most Precious Stone of the Philosophers*, ed. Arthur Edward Waite (London: James Elliott & Co., 1894; reprint, London: Vincent Stuart Ltd, 1963), viii. Written in c. 1330. Geber, *The "Summa Perfectionis" of Pseudo-Geber: A Critical Edition, Translation and Study*, trans. and ed. William R. Newman (Leiden: E. J. Brill, 1991). According to Newman, the *Summa Perfectionis* was probably written in the late thirteenth century by Paul of Taranto.

[7] This translation was published in: Julius Ruska, *Al-Rāzī's Buch Geheimnis der Geheimnisse: Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin*, Band 6 (Berlin: Verlag von Julius Springer, 1937).

[8] E. John Holmyard, *Alchemy* (Middlesex, England: Penguin Books, 1957; reprint, New York: Dover Publications, 1990), 88-89.

[9] William R. Newman and Lawrence M. Principe, *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chemistry* (Chicago: U of Chicago P, 2002), 37-38.

wrote the *Kitāb al-Asrār*, his goal, in his own words, was to extract the essentials from his prior works and compile "one compact concise book on this subject."[10]

The *Kitāb al-Asrār* is organized into four parts, consisting of an introduction, required materials, equipment, and procedures. Al-Rāzī groups procedures by type of process (sublimation, calcination, softening) and substance categories (mercury, sulfur, metals, stones) and arranges the processes sequentially in the order needed. For example, directions for the sublimation of mercury precede the procedures which require it, such as the calcination of tin. However, when the last step of the tin procedure requires "crushing water," a strong solvent, the text refers the user to a later chapter on making solvents.[11] This cross-referencing avoids repetition and anticipates the user's need for more information, especially for reagents which are needed in more than one procedure. These internal citations show that al-Rāzī designed the manual as an integrated whole.

Each procedure contains the specific information required to perform it. The procedure for the sublimation of mercury specifies the required materials, quantities, preparation, containers, ovens, timing, and the desired endpoint. Detailed instructions, such as allowing the hot container to cool before collecting the residue on the sides, facilitate a larger yield of the final product. In order for any laboratory procedure to be repeatable, the practitioner should not have to guess the amounts, the timing, or whether the process is complete. Alchemic procedures are often vague, but al-Rāzī's laboratory manual anticipates the user's need for specific information.

The *Kitāb al-Asrār* is not only practical and systematic, but it also appears to introduce a new approach to laboratory science. Henry E. Stapleton and Julius Ruska, the historians who closely analyzed al-Rāzī's work in the 1920s and 30s, found that at least some of al-Rāzī's chemistry stemmed from a tenth-century body of alchemical texts written under the name of the eighth-century alchemist Jabir. However both Stapleton and Ruska are convinced that al-Rāzī's style was entirely new.[12] According to Ruska, "the gulf between the endless variety of forms of the Jabir manuscripts and the realistic matter-of-fact style of Rāzī's work is so great, that one can hardly notice any further relationship other than a common foundation."[13] Modern historians have not challenged this claim. Yet if Ruska is correct in characterizing al-Rāzī's book as something entirely new, it suggests that the concept of a laboratory manual and therefore the functional concept of the laboratory itself, began in the tenth century.

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[10] "...[ich] habe ihm ein kurzegefaßtes [*sic*], feines Buch über diesen Gegenstand zugeeignet." al-Rāzī, 83. (Unless otherwise stated, all translations are my own.)

[11] "...tränke es mit dem *zermalmenden Wasser*. Wir werden dieses erwähnen bei den scharfen Wässern in den Kapiteln des Lösens." The instructions referred to are located in that chapter on page 182. Al-Rāzī, 123, 182.

[12] Henry E. Stapleton, R. F. Azo, and M. Hidayat Husain, "Chemistry in Iraq and Persia in the Tenth Century A.D.," *Memoirs of the Asiatic Society of Bengal* 8 (1927), 343. Ruska, 12.

[13] "Der Abstand zwischen der unendlich vielgestaltigen Darstellung der Ǧābir-Schriften und der nüchtern sachlichen Form von Rāzī's Arbeiten ist so groß, daß man über die Feststellung einer gemeinsamen Basis hinaus kaum noch weitere Beziehungen wahrscheinlich machen kann." Ruska, 12-13.

The overall arrangement of the *Kitāb al-Asrār* into introduction, materials, equipment, and procedures sounds obvious, even intuitive. Yet there were alternative approaches. In medieval Europe, a variety of alchemical texts proliferated with a multitude of styles. Over the centuries, however, the simple functional approach never entirely disappeared. Al-Rāzī's laboratory manual was designed to last, supported by the enduring name recognition of its author.

Al-Rāzī was best known in Europe not as an alchemist, but as Rhazes, the author of authoritative medical texts. One list of his books names 89 on medicine, 21 on alchemy, and 74 on astronomy, philosophy, and other sciences.[14] Physicians became familiar with al-Rāzī in the universities where two of his works became standard texts: the *Nonus Almansoris*, and the twenty-five volume *Continens*, a compilation of Greek and Hindu medical texts accompanied by his own commentary.[15] Medical historian Donald Campbell lists Latin publications of *Continens* in 1486, 1500, 1506, 1509, and 1542.[16] The *Nonus Almansoris*, translated into Latin in 1481 and many times thereafter, was still required at the University of Frankfurt (Oder) after 1588.[17] Medical schools in Holland continued to require al-Rāzī's medical books into the seventeenth century.[18] Although alchemy was not a university subject in the Middle Ages, al-Rāzī's prestige as a learned physician, may have increased his credibility across his areas of expertise, especially since many alchemists were physicians or clerics.

References to al-Rāzī in popular culture indicate that he was also known to the public. *The Romance of the Rose*, a thirteenth-century poem by Guillaume de Lorris and Jean de Meun, enjoyed in both France and England for 300 years, names him as a medical authority.[19] In the fourteenth century, Geoffrey Chaucer referred to al-Rāzī in *The Canterbury Tales*, when he wrote, "Wel knew he th'olde Esculapius, And Deiscorides and eek Rufus, Old Ypocras, and Haly, and Galien; Serapion, Razes, and Avicen...".[20] Al-Rāzī joins Galen and Hippocrates again in an early seventeenth-century stone frieze of ten renowned medical authorities commissioned to celebrate the first pharmacy in the German county of Lippe. Clearly the public associated al-Rāzī with distinguished authorities of medicine.

Al-Rāzī was familiar to alchemists as well, and many mention him by name to give authority to their works either in connection with specific procedures or in a list of known authorities. Abufalah, an eleventh-century alchemist from Sicily, starts one process with: "A distinguished combinatory operation,

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[14] Abū Raihān Muhammad ibn Ahmad al-Bīrūnī (973-1048), "Al-Biruni als Quelle für das Leben und die Schriften al-Rāzīs," trans. and ed. Julius Ruska, *Isis* 5 (1923): 34-48.

[15] George Sarton, *From Rabbi ben Ezra to Roger Bacon*, vol. 2 of *Introduction to the History of Science* (Baltimore: The Williams and Wilkins Company, 1931; reprint, 1953), 609.

[16] Donald Campbell, *Arabian Medicine and its Influence on the Middle Ages*, vol. 1 (London: Kegan Paul, Trench, Trubner & Co., 1926; reprint, New York: AMS Press, 1973), 69.

[17] Stapleton, Azo, and Husain, 609. Campbell, 201-02.

[18] Robert P. Multhauf, *The Origins of Chemistry* (London: Oldbourne, 1966), 130.

[19] Guillaume de Lorris and Jean de Meun, *The Romance of the Rose*, trans. Charles Dahlberg, 3rd ed. (Princeton: New Jersey, 1995), 1, 271.

[20] Geoffrey Chaucer (c. 1340-1400), *Troilus and Cressida and the Canterbury Tales*, vol. 22 of *Great Books of the Western World*, ed. Robert Maynard Hutchins (Chicago: William Benton, 1952), 166.

tested by Rusis...".[21] In the thirteenth-century *Libellus de Alchemia*, ascribed to Albertus Magnus, one procedure begins: "A better way to sublime mercury is given by Rhases...".[22] The fourteenth-century *New Pearl of Great Price* by Petrus Bonus states: "Rhasis, in his *Seventy Precepts*, affirms that mercury is the root of all things."[23] Al-Rāzī is quoted in the *Speculum Alchymiae: The True Glass of Alchemy*, attributed to Roger Bacon (c. 1220-1292) and in Nicolas Flamel's fifteenth-century quest, *Écrits Alchemiques*.[24] Thomas Norton (c.1433-c. 1513), in *The Ordinall of Alchemy*, portrays al-Rāzī in an illustration and includes him in a list of named authorities.[25] Whether or not their citations were accurate, alchemists who wrote books recognized al-Rāzī as an authority in their field.

From the first Latin translations of his books in the twelfth century until the seventeenth century, al-Rāzī's fame was divided between the worlds of alchemy and medicine. Historians have also viewed him that way. The tenth-century compilation al-Nadīm's *The Fihrist*, separates al-Rāzī's medical works from his alchemical works, as does science historian George Sarton in 1927 in his *Introduction to the History of Science*.[26] Yet when one surveys al-Rāzī's body of work as a whole, the clear, organized methodology of the *Kitāb al-Asrār* is no longer an anomaly among alchemic texts, but the natural outcome of an analytic mind. For example, chapters from *Continens* listed in *The Fihrist* include divisions on "the potentialities of drugs and nutriments," "compounded drugs," and "weights and measures."[27] Viewed in its entirety, al-Rāzī's work anticipates European physicians whose writings incorporated both alchemy and laboratory medicine, such as Paracelsus (1493-1541) and Andreas Libavius (c. 1555-1616).[28]

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[21] Abufalah, *The Book of Em haMelekh*, in *The Jewish Alchemists: A History and Source Book*, trans. and ed. Raphael Patai (Princeton: Princeton UP, 1994), 110.

[22] Albertus Magnus, "A Description of Alchemical Operations, Procedures, and Materials," in *A Sourcebook in Medieval Science*, trans. Sister Virginia Heines, ed. Edward Grant (Cambridge, MA: Harvard UP, 1974), 599.

[23] Petrus Bonus, 229. This edition of *The New Pearl of Great Price* cites al-Rāzī at least thirteen times by my count, on pages 6, 80, 109, 112-13, 115, 229, 259 (twice), 279, 362, 365, 375, 382.The book was originally written in c. 1330 as *Pretiosa Margarita Novella*.

[24] Roger Bacon (c. 1220-92), *Speculum Alchymie: The True Glass of Alchemy*, in *Collectanea Chymica: A Collection of ten several treatises in chymistry, concerning the liquor alkahest, the mercury of philosophers and other curiosities worthy the perusal* (London: Pelican, 1684; Ann Arbor, Mich.: University Microfilms, 1963), 130. Nicolas Flamel (1330-1418), *Écrits Alchemiques*, ed. Didier Kahn (Paris: Les Belles Lettres, 1993), 39, 43.

[25] Thomas Norton, *Ordinall of Alchemy* in *Theatricum Chemicum Britannicum*, eds. Elias Ashmole and Allen G. Debus (London: n.p., 1652; reprint, New York: Johnson Reprint Corporation, 1967), 8.

[26] Muhammad ibn Ishāq al-Nadīm, *The Fihrist: A Tenth-Century Survey of Muslim Culture* vol. 2, trans. and ed. Bayard Dodge (New York: Columbia UP, 1970), 703-09, 863. George Sarton, *From Homer to Omar Khayyam* vol. 1 of *Introduction to the History of Science* (Baltimore: The Williams and Wilkins Company, 1927; reprint, 1953), 609.

[27] Al-Nadīm, 704.

[28] Paracelsus, Hermetic Chemistry, vol. 1 of *The Hermetic and Alchemical Writings of Aureolus Philippus Theophrastus Bombast, of Hohenheim, called Paracelsus the Great*, trans. and ed. Arthur Edward Waite (London: James Elliott, 1894; reprint, Boulder, CO:

European alchemists accessed the practical approach of the *Kitāb al-Asrār* in three ways: through its copies and translations, through the twelfth-century *Book of Alums and Salts,* and through the thirteenth-century text *Summa Perfectionis.* Ruska based his 1937 German translation of the *Kitāb al-Asrār* primarily on an Arabic manuscript dated 1561, which had been brought from Libya to the University of Göttingen library. He also referred to less complete Arabic manuscripts in Leipzig (1710), the Escorial, and Lucknow.[29] Ruska also refers to two Latin translations: the *Liber Ebu bacchar er Raisy* and the later *Liber Secretorum de voce Bubacaris* housed in the Paris National Library in a collection of manuscripts from the thirteenth to fourteenth centuries.[30] British archivist Dorothea Singer cites copies of the *Liber Secretorum* at Oxford in the fourteenth century and at Cambridge in the fifteenth century.[31] Historian Raphael Patai, noting the popularity of al-Rāzī's work among Jewish alchemists, describes a partial Hebrew translation in "a Yemenite Judeo-Arabic manuscript" now in Jerusalem as well as in Book Thirteen of the Gaster Manuscript, "a major seventeenth-century Hebrew alchemical manuscript."[32] The fact that the *Kitāb al-Asrār* was copied, recopied, translated, and archived in so many places at different times and in at least three languages shows that it was both accessible and attractive to medieval alchemists.

In addition to copies and translations, two of the most widely read alchemical texts in the Middle Ages owe much to the *Kitāb al-Asrār*. They are the twelfth-century chemical treatise *The Book of Alums and Salts* attributed to al-Rāzī and the thirteenth-century *Summa Perfectionis* attributed to Geber. These texts are examples of pseudepigraphia, the practice among medieval writers of attributing their text to a well-known author. Ruska surmised that the Arabic original of the *The Book of Alums and Salts* was written by an alchemist in Spain in the eleventh or twelfth century, pointing out that it is cited in the thirteenth century by both the Dominican encyclopedist Vincent de Beauvais (c. 1190-c. 1264) and Franciscan scholar Roger Bacon (c. 1214-92).[33] Its translation by Gerard of Cremona (d. 1187) made it accessible to the earliest European alchemists. The facts that the *The*

Shambhala, 1976), i. Bruce T. Moran, *Distilling Knowledge: Alchemy, Chemistry, and the Scientific Revolution* (Cambridge: Harvard UP, 2005), 8.

[29] Ruska, *Al-Rāzī's Buch Geheimnis der Geheimnisse*, 14-24.

[30] Julius Ruska, "Übersetzung und Bearbeitungen von al-Rāzīs Buch Geheimnis der Geheimnisse," *Quellen und Studien zur Geschichte Naturwissenschaften und der Medizin* 3 (Berlin, 1935), 159, 162. The translator and exact date for the Latin translation are unknown according to historian Moritz Steinschneider. Moritz Steinschneider, *Die Europäischen Übersetzungen aus dem Arabischen bis Mitte des 17. Jahrhunderts* (Graz, Austria: Akademische Druck- und Verlaganstalt, 1956), 48.

[31] Dorothea Waley Singer, *Catalogue of Latin and Vernacular Alchemical Manuscripts in Great Britain and Ireland Dating from before the XVI Century*, vol. 1 (Brussels: Maurice Lamartin, 1928), 107.

[32] Raphael Patai, *The Jewish Alchemists: A History and Source Book* (Princeton: Princeton UP, 1994), 420-22, 583.

[33] Ruska, "Pseudepigraphe Rasis-Schriften," *Osiris* 7 (1939): 40. The dates and descriptions for Bacon and de Beauvais are from: Holmyard, 113 and 118-19. Newman and Principe characterize the author of *De Aluminibus et Salibus* as "written by a much later follower [of al-Rāzī]," Newman and Principe, 39.

Book of Alums and Salts bore al-Rāzī's name, had content similar to the *Kitāb al-Asrār*, and was influential in the thirteenth century give this work, at the very least, a strong role in the spread of al-Rāzī's reputation and style. If it was adapted from the *Kitāb al-Asrār*, then it is the earliest example of this work's influence through its adaptations. However, there is an even stronger example.

Historian William R. Newman has recently documented a direct line of descent from the *Kitāb al-Asrār* to the *Summa Perfectionis* of Pseudo-Geber, an influential late thirteenth-century text. Although the author of the *Summa* attributed it to the eighth-century Islamic alchemist Jabir, westernized "Geber," scholars failed to find an Arabic text.[34] Newman identified the author as Paul of Taranto, a teacher and alchemist of the late thirteenth-century, in his book *The "Summa Perfectionis" of Pseudo-Geber: A Critical Translation and Study* which includes a chart tracing the *Summa's* evolution from the *Kitāb al-Asrār*.[35] The *Summa Perfectionis*, in turn, influenced major fourteenth-century alchemical works, including *Rosarium* attributed to Arnauld of Villanova, *Libellus de Alchemia* attributed to Albertus Magnus, *The New Pearl of Great Price* by Petrus Bonus, and *The Testamentum* attributed to Ramon Lull.[36] Thus the contents of the *Kitāb al-Asrār* interested alchemic writers who copied it, translated it, reworked it, and, knowingly or unknowingly, incorporated parts of it into their writings.

Examples of medieval texts illustrate the difference between the practical laboratory approach and the spiritual or allegorical alchemical style. Abufalah, an eleventh-century Islamic alchemist in Sicily, wrote a practical alchemic text which was later partially incorporated into the thirteenth-century work *The Gate of Heaven* by Gershon ben Shlomo of Arles.[37] His procedure to convert copper into silver reads: "Take of good green arsenic one weight, and grind it well with strong and good vinegar many times, and sublimate it until all of it becomes white..."[38] This style is comparable to a procedure from al-Rāzī's book which reads: "Take whichever of the two you will [sulfur or arsenic], then grind it with wine vinegar which contains a fourth of qali salt, and roast it one night over a gentle fire for sulfur or a medium fire for arsenic...".[39]

Today this kind of "recipe" instruction seems unremarkable except for the fact that the literature does not show straightforward laboratory procedures like this prior to al-Rāzī. The late thirteenth-century text, *Summa Perfectionis*, begins

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[34] Paul Kraus, who did extensive studies of Jabir's work, points out that as early as 1893 chemistry historian Marcellin Berthelot was convinced of the *Summa's* European origin: "But, on the other hand, he [Berthelot] proclaimed with great emphasis that the *Summa Perfectionis magisterii,* upon which the whole European development of experimental alchemy was based, were spurious writings which originated in the 14th century." Paul Kraus, "Julius Ruska," *Osiris* 5 (1938): 16.

[35] William R. Newman, trans. and ed., *The Summa Perfectionis of Pseudo-Geber: A Critical Edition, Translation and Study* (Leiden: E. J. Brill, 1991), 26, 65.

[36] Ibid., 58, 193-4, 199.

[37] Patai, 98.

[38] Ibid., 109.

[39] "Nimm von welchem der beiden du willst [G34] [*sic*], dann pulvere es mit Weinessig, worin ein Viertel Qalisalz [*sic*], und röste es eine Nacht in gelindem Feuer, wenn es Schwefel ist, und wenn es Zarnich ist, an einem mittleren Feuer." Al-Rāzī, 120.

an explanation of the sublimation[40] of mercury like this: "But now we will determine the entire goal of quicksilver's sublimation. The complete totality of that is the cleansing of its earthiness and removal of its wateriness."[41] Similarly, the *Kitāb al-Asrār* states: "Concerning the sublimation of quicksilver, there are two methods. One takes place in order to remove its moisture (wateriness), and the other serves to generate its dryness, so that it will become completely dry."[42] These texts are very clear in explaining the goal of the procedure to follow.

In contrast, the sixteenth-century alchemist Paracelsus uses a descriptive non-quantitative style: "In order that Mercury may be reduced to a precipitate, nothing more need be done than calcine it in the best aqua fortis; then let the granulated aqua fortis be extracted from it five times, more or less, until the precipitate acquires a beautiful red colour."[43] The *Compound of Alchemy* written by George Ripley in 1470-71 incorporates religious symbolism into the purification process:

> But when these to Sublymacyon continuall
> Be laboryd so, wyth hete both moyst and temperate,
> That all is Whyte and purely made spirituall;
> Than Hevyn uppon Erth must be reiterate,
> Unto the Sowle wyth the Body be reincorporate:
> That Erth becom all that afore was Hevyn,
> Whych wyll be done in Sublymacyons sevyn.[44]

In *The New Pearl of Great Price* (c. 1330) Petrus Bonus even gives al-Rāzī credit for an allegorical procedure: "The red slave, says Rhasis, has wedded a white spouse."[45] In alchemical literature, red represents sulfur, a masculine element, sometimes portrayed as a red king, which imparts its properties to mercury, the white queen.[46] The *Kitāb al-Asrār*, on the other hand, is all business:

> You take one ratl of mercury that has been solidified by covering it with sulfur (for redness) and an equal amount of vitriol, and half as much yellow

[40] Sublimation, which was used as a purification process, consisted of heating a substance to a vapor and then cooling it to recondense it back into a solid. Holmyard, 46, 56. It is only one of the alchemic processes, but it furnishes a common thread for purposes of illustration.

[41] Newman, 691.

[42] "Was die Hochtreibung des Quecksilbers anlangt, so gibt es davon zwei Arten. Die eine findet statt zur Wegnahme seiner Nässe (Wässerigkeit), die andere dient zur Erzeugung seiner Trockenheit, damit es ganz trocken wird." Al-Rāzī, 102.

[43] Paracelsus, 142.

[44] Holmyard, 187. George Ripley, *The Compound of Alchemy* in *Theatricum Chemicum Britannicum*, ed. Elias Ashmole and Allen G. Debus (London: n.p., 1652; reprint, New York: Johnson Reprint Corporation, 1967), 172.

[45] Petrus Bonus, 259.

[46] John Read, *Prelude to Chemistry: An Outline of Alchemy, Its Literature and Relationships* (London: G. Bell and Sons, 1936; reprint, Cambridge, MA, The M.I.T. Press, 1966), 92, 102. Compare Thomas Norton's *Ordinall of Alchemy*: "Then is the White Woman Married to the Ruddy Man." Thomas Norton, *Theatricum Chemicum Britannicum*, 90.

> sulfur as vitriol, grind it with the best wine vinegar a good hour, add an amount of roasted salt equal to the vitriol on it and, after its moisture is driven away, let it rise seven times.[47]

That is the voice of a laboratory manual.

In 1597 and again in 1606, German physician Andreas Libavius, published *Alchemia*, a massive text that expanded the processes of chemistry to include medicines, oils, and dyes, along with transmutation of metals.[48] In spite of their differences, *Alchemia* and the *Kitāb al-Asrār* share a fundamental structure. In his book *Chemists and the Word: The Didactic Origins of Chemistry*, Owen Hannaway characterized the structure of the chemistry textbook that began in the seventeenth century: "But all have a common form of organization: the definition of the art, a description of its instruments, a discussion of operations, followed by preparations—that is, the basic structure of *Alchemia*."[49] He is absolutely right. However, this structure goes back to 920 C.E. It is the structure of the *Kitāb al-Asrār*.

Chemistry historians have analyzed and praised al-Rāzī's chemical knowledge, classifications, and his organization of processes. What they take for granted is the functionality that now seems so natural in a laboratory manual, the book that the chemist holds in one hand or props open on the laboratory bench. Nevertheless, alchemy allows the historian to look beyond the immediate goals and theories of science, which are, with apologies to Kurt Vonnegut, stuck in time,[50] and see that the book supports the very reason for the laboratory's existence—to deliver reproducible results. In *The Structure of Scientific Revolutions*, Thomas Kuhn points out that when the boundaries of research shift and the efforts of previous investigations are abandoned, "part of that achievement always proves to be permanent."[51] The lasting achievement of the transmutation of metals may be the concept of the laboratory itself, embodied in a book.

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[47] "Du nimmst vom Quecksilber, das durch Aufstreuen von Schwefel (zur Röte) verfestigt ist, ein Ratl [*sic*], und vom Vitriol ebensoviel, und vom gelben Schwefel so viel wie die Hälfte des Vitriols, pulverst es mit bestem Weinessig eine gute Stunde, wirfst dann ebensoviel geröstetes Salz als Vitriol daruf und läßt es, nachdem seine Nässe weggenommen ist, siebenmal aufsteigen." Al-Rāzī, 107. When used as a unit of solid weight a *ratl* is equal to 360 grams. Ruska, *Al-Rāzī's Buch Geheimnis der Geheimnisse*, 63-4.

[48] Owen Hannaway, *The Chemists and the Word: The Didactic Origins of Chemistry* (Baltimore: Johns Hopkins UP, 1975), 81.

[49] Ibid., 155.

[50] Kurt Vonnegut, *Slaughterhouse Five or The Children's Crusade: A Duty-Dance with Death* (New York: Dell Publishing Co., 1969. The story begins: "Listen: Billy Pilgrim has become unstuck in time."

[51] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed. (Chicago: U of Chicago P, 1996), 25.

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