# THE *KITAB AL-ASRAR*: AN ALCHEMY MANUAL IN TENTH-CENTURY PERSIA

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> If I did not know that my days are numbered, and that my death is near, and if it were not for my concern that this service that I want to render out of friendship might be prevented by my death, I would not have brought all this together in my book and I would not have tried to bring it to such a state of perfection.
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> Al-Razi, *Kitab al-Asrar*, c. 920 CE[1]

Written near the end of al-Razi's long and prolific career, the *Kitab al-Asrar* or *Book of Secrets* has attracted attention for over a thousand years. Its subject is alchemy, the art of making gold, one of the many interests of Persian physician and teacher Abu Bakr Muhammad ibn Zakariya al-Razi (c. 865-923 CE). Nearly a century later, another Persian scholar al-Biruni (973-1048), himself an inexhaustible writer, catalogued the *Kitab al-Asrar* among 21 of al-Razi's works on alchemy, 89 on medicine, and 74 on astronomy, philosophy, and other sciences.[2] Many of these works disappeared during the Mongol invasions of 1220-1258 CE which destroyed both al-Razi's home city of Rayy and the Abbasid capital of Baghdad, whose hospital he directed.[3] Yet his reputation grew. In medieval Europe, physicians knew him as Rhazes, the author of two important medical school texts: the ninth volume of the *Kitab al-Mansuri*, called *Nonus Almansoris*, and the 25-volume *al-Hawi*, or *Continens*, "the most valuable of the nine volumes" in the University of Paris medical library in 1395 and still required at medical schools in Holland into the seventeenth century.[4]

At the same time Al-Razi's reputation as an alchemist flourished in a separate sphere, the writings of the alchemists themselves, who named him in connection with specific procedures and listed him with known authorities. Historian William R. Newman recently documented a direct line of descent from the *Kitab al-Asrar* through its Latin translations to the *Summa Perfectionis* of pseudo-Geber, a very influential late thirteenth-century text.[5] One of the alchemical texts influenced by the *Summa*, the fourteenth-century *New Pearl of Great Price* by Petrus Bonus, refers to al-Razi thirteen times in the course of its straightforward procedures.[6] Medieval alchemical literature is often cloaked in mysticism and allegory, obscuring

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its practical foundations. Yet a few alchemists simply wrote basic instructions on how to carry out transformative processes. This is the contribution of the *Kitab al-Asrar*.

The goal of the procedures in the *Kitab al-Asrar* is the transmutation of materials into gold and silver. Yet the systematic arrangement of its procedures and the specific methodologies they contain are those of a modern laboratory manual. In 1937, historian and linguist Julius Ruska (1867-1949) translated the *Kitab al-Asrar* from Arabic into German. I recently translated Ruska's text into English, combining historical research with my own laboratory experience to examine the *Kitab al-Asrar*'s historical context, systematic approach, and technical procedures. This article will analyze the organizational structure and procedural methodologies of the *Kitab al-Asrar* in order to show that the laboratory manual began at least a thousand years ago.

## Historians on al-Razi and Alchemy

Historians sometimes have difficulty separating the methods of alchemy from its goals, which were often suspect. Yet alchemy is where the laboratory began. Its theoretical foundation was based on the essential unity of matter, Aristotle's "common and ultimate substrate," whose properties were altered under changing natural conditions.[7] Alchemists combined natural substances in the laboratory, subjecting them to controlled heat and tedious procedures in order to artificially create conditions which would transform the properties of base metals into those of gold. Manipulation of conditions and transformation of matter are experimental activities which remain fundamental to the laboratory today. In his introduction to *Chemical Manipulation*, nineteenth-century chemist Michael Faraday points out: "Chemistry, if occupied only in the observation of such phenomena as are presented by Nature, would do little more than record the comparatively quiescent state of things which has followed the active exertion of the inherent powers of matter."[8] Laboratories turn up the heat, increase the pressure, and control the timing in order to create predictable changes under controlled conditions which do *not* occur in nature.

Historians have held mixed views on both the role of alchemy and the contributions of al-Razi to the development of chemistry. When German historian Karl Schmieder wrote his *History of Alchemy* in 1832, the manuscript of the *Kitab al-Asrar* which Ruska later translated had not yet come to Germany.[9] According to Schmieder, al-Razi's missing alchemical works, known only through references in Latin texts, were insignificant.[10] By 1893, French chemist Berthelot began to sort out the authorship of medieval texts for his book *La Chimie au Moyen Age*. He correctly attributed the *Liber Secretorum Bubacaris*, a Latin manuscript archived in Paris, as the translation of a text by al-Razi, although he did not identify the title of the original as the *Kitab al-Asrar*. With this knowledge, Berthelot's evaluation of al-Razi's work negated Schmieder's dismissal: "This work represents a veritable methodological treatise of actual chemistry, written about the year one thousand."[11]

Berthelot's statement turned out to be prophetic. In 1921, historian Julius Ruska, expert in languages and the history of Islamic science came across a complete manuscript of the *Kitab al-Asrar* while browsing through Arabic manuscripts at the University of Göttingen.[12] This manuscript, dated 1561, had been brought to Germany from the Coptic monastery Amba Buscai in Libya in 1878, over forty years earlier.[13]

Ruska's friend and colleague, historian Paul Kraus, points out that this find represented a keystone in the history of Arabic alchemy because the manuscript was authentic, complete, and the authorship was supported by al-Razi's biographers and early catalogs of his works.[14] Financial and career uncertainties in the early 1920s prevented Ruska from publishing a full translation for sixteen years, but he started his research almost immediately. In his 1927 *History of Science*, George Sarton labeled the second half of the ninth century "The Time of Al-Razi," because he was "simply the greatest clinician of Islam and of the whole Middle Ages... [also] a chemist and physicist."[15] Among his sources, Sarton cited two articles by Ruska on al-Razi dated 1923 and 1924.[16] At the same time, Henry E. Stapleton, principal of the Presidency College in Calcutta, published a few excerpts from the *Kitab al-Asrar* in English based on incomplete Arabic manuscripts from Leipzig, Germany; the Escorial Library near Madrid; Lucknow, India; and the medieval Latin translation in Paris, *Liber Secretorum Bubacaris*.[17] Stapleton, who was in correspondence with Ruska, deferred a thorough analysis of its significance and content to Ruska's forthcoming translation, but declared a strong thesis: "that in 900 A.D. such a degree of exact knowledge of chemical substances and apparatus was displayed that historians may henceforward be justified in antedating the birth of Scientific Chemistry by—in all probability—at least 900 years."[18] In 1937, Ruska, by then seventy years old and Director of the Research Center for the History of Natural Sciences in Berlin[19] achieved his goal of publishing a complete translation of the *Kitab al-Asrar*, based primarily on the Göttingen manuscript, but also referring to three other Arabic manuscripts, including one from Leipzig and photographic copies of manuscripts that Stapleton shared with him from Lucknow and the Escorial.[20]

Both Ruska and Stapleton maintained that the *Kitab al-Asrar* represented a break with its alchemic precedents. In the commentary accompanying his 1937 translation *Al-Razi's Buch: Geheimnis der Geheimnisse* (*Al-Razi's Book: Secret of Secrets*), Ruska states, "In any case, the credit goes to al-Razi for bringing alchemy to a strictly scientific format for the first time."[21] A year later, Kraus wrote: "In the course of his inquiries, Ruska was in a position to prove that the European authors owed almost nothing to Greek and everything to Arabic alchemy."[22]

Yet after World War II, the significance of early Islamic alchemy was still in doubt. In 1954, A. Rupert Hall wrote, "The theory of transmutation held by the later alchemists was originated by Jabir ibn Hayyan and al-Razi… It is enough to say… that it was never attached to any sound body of empirical knowledge and that its persistence was the greatest obstacle to the development of a rational chemistry."[23] Marie Boas in 1966 stated flatly, "Europe took nothing from the East without which modern science could not have been created."[24] On the other hand, some of their contemporaries recognized the research of Ruska, Kraus, and Stapleton. E. J. Holmyard, author of *Alchemy* in 1957, and Robert P. Multhauf, who wrote *The Origins of Chemistry* in 1966, took note of al-Razi's systematic methodology and his classification of chemical substances.[25] "Razi," states Holmyard, "in fact brought about a revolution in alchemy by reversing the relative importance of experiment and speculation."[26]

## Taking a Fresh Look at the Laboratory

Recent historians have referred to the *Kitab al-Asrar* briefly as "influential"[27] or "a straight-forward manual of chemical practice."[28] Not only are the modern references to al-Razi more cursory than in years past, but ever since Holmyard, authors have based their appraisals directly or indirectly on Ruska and Stapleton rather than applying fresh perspectives to al-Razi's work. Over the last thirty years, studies of laboratory texts seem to concentrate on early modern Europe. In 1975 Owen Hannaway, in his book *Chemists and the Word: The Didactic Origins of Chemistry*, analyzed *Alchemia* (1597 and 1606) by Andreas Libavius as the first chemistry textbook that shapes the transition between alchemy and chemistry.[29] British science historian David Gooding used the notebooks of nineteenth-century chemist Michael Faraday to examine how scientists construct knowledge from their interpretations of laboratory results.[30] William Newman and Lawrence Principe used the laboratory notebooks of Robert Boyle and American alchemist George Starkey to explore the relationship between alchemy and chemistry in *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry* published in 2002. However none of these works look at laboratory texts written before the seventeenth century. The *Kitab al-Asrar* is a primary source of laboratory procedures from the tenth century, yet in spite of a general consensus that al-Razi's work was ground-breaking, his work has not been analyzed for eighty years.

Recent laboratory social theory, although not specifically directed toward alchemy, provides new ways to look at the alchemist's laboratory. French social scientist Bruno Latour, who personally observed the dynamics of the laboratory over a two-year period at the Salk Institute in La Jolla, California, writes: "Laboratories are an excellent place in which to understand the production of certainty."[31] Latour sees the laboratory as an integral part of the economics, politics, and social agendas that surround it and he views the production of knowledge from research as a process, not of discovery, but of interpretation based on needs and expectations.[32] It is a long way from La Jolla to tenth-century Persia, yet the essence of the laboratory remains. Al-Razi's expectations were based on the conviction that one substance could be converted into another under specified conditions; therefore changes of color, ductility, and weight were evidence of this transformation. Criteria for laboratory safety, labor, and quantification expressed in *Kitab al-Asrar* were relative to the standards of society, as indeed they are today. Economic support, as always, makes one dependent on the expectations of others. Al-Razi was a physician, teacher, hospital director, and a writer with powerful patrons, including Prince Abu Salih Mansur ibn Ishaq, to whom he dedicated his renowned ten-volume medical treatise, the *Kitab al-Tibb al-Mansuri*.[33] Stapleton suggests that al-Razi may have given the *Kitab al-Asrar* to Mansur as well.[34] Like laboratories in every age, the alchemy laboratory required financing.

For the laboratory to satisfy external expectations it must build a high degree of credibility based on reproducible outcomes.[35] The quest for reproducibility is fundamentally another practical concern, codependent with issues of labor, safety, accuracy, and resources. As a priority, repeatability is nothing new. Petrus Bonus expressed frustration over the undependable methods of alchemic masters in *The New Pearl of Great Price* (c. 1330): "Amongst these persons are observed a great diversity of method, and a considerable variety even in the choice of their substance."[36] Similarly, a modern guide to laboratory accreditation advises: "When validating a method, it is also vitally important to assess the precision or reproducibility of the method."[37] This analysis will focus on how the *Kitab al-Asrar* addresses the issue of reproducibility, looking first at the organizational structure of the manual itself, and then at how the strategies of reproducibility are built into each procedure.

From time to time excerpts from more modern laboratory texts will illustrate how the methods in the *Kitab al-Asrar* fit into the larger picture of laboratory history. These examples range from *The New Pearl of Great Price*, a fourteenth-century alchemy manual, to Michael Faraday's *Chemical Manipulation*, written in 1827. I have also selected a modern laboratory manual, the 1962 edition of *Todd-Sanford Clinical Diagnosis by Laboratory Methods*, which was the standard clinical laboratory manual before the onset of massive automation and computerization that in some ways obscure, but do not change, the way laboratories arrive at certainty.[38] Here I find a certain affinity with al-Razi, because it was in this kind of laboratory amid flasks of fluids and the blaze of Bunsen burners, that I trained, worked, and wrote my first procedures.

## The Structure of a Laboratory Manual

Laboratory manuals have a formal structure: purpose, reagents, equipment, and procedure, reminiscent of the typical chemistry class laboratory notebook. For example, the *Todd-Sanford* chapter on syphilis testing is divided into reagents, equipment, and tests.[39] Al-Razi concludes his statement of purpose with: "My book encompasses three subjects: the knowledge of substances, the knowledge of equipment, and the knowledge of procedures."[40] The outline of the *Kitab al-Asrar* shows these three sections clearly: "What One Must Know about Substances," "What One Must Know about Equipment," and "About the Parts of the Procedures."[41] Historian Owen Hannaway observed a similar structure in the 1597 chemistry compendium *Alchemia* which was characteristic of many chemistry texts that followed it: "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*."[42] Although *Alchemia* does not have a separate section for chemical classification (al-Razi's "substances"), Lavoisier's *Elements of Chemistry* (1789) does, probably because he, like al-Razi, was developing a classification system.[43] The functional divisions of the laboratory manual facilitate repeatability by making information easy to locate and by assuring that the essential details are always included when writing up a procedure. These divisions have been important for a thousand years.

The procedure section of the *Kitab al-Asrar* comprises 83 percent of the text. It contains 389 procedures, which I have divided into four basic types: 175 primary procedures which directly produce an agent that changes metals into gold or silver, 127 preparatory processes such as softening or calcination, 51 reagent preparations (solvents, tinctures), and 36 sets of instructions for commonly needed operations such as mixing or dissolving (see Table 1). These four types are intermixed, but their arrangement is systematic. The procedures for spirits (mercury, sal ammoniac, sulfur, and arsenic) are almost all primary procedures producing gold or silver. The many calcination procedures for metals and stones, such as "Calcination of Silver through Letting it Rust," have a basic organization of three or four alternative intermediate processes followed by one primary process.[44] Most of the reagent preparations are gathered in the sections on making solutions for dissolving ("Dissolving with Sharp Waters") or for tinting ("The Procedures of Water").[45] The preparatory processes, such as mixing, dissolving, or solidifying are also grouped together. Near the end, the section on animal and vegetable substances, like the spirits at the beginning, are almost all primary procedures, producing gold or silver. It would not take long for an alchemist at work to find the section required for the next step.

The procedures to prepare mercury, sal ammoniac, sulfur, and arsenic come first because they are needed in later procedures and their contents are carefully arranged. For example, a procedure for the sublimation of sulfur or arsenic requires the untreated ingredients bitter salt or Andarani salt and sal ammoniac, which are described in the section on chemicals. It also calls for "mercury sublimated to whiteness," a process described in the previous section, and for "sharp water of lime, that is called *crushing water*," which is described in a subsequent section on "sharp waters" or commonly used solvents.[46] This section is comparable to the Appendix in *Todd-Sanford* which has procedures for making commonly used culture media, stains, and reagents.[47] This cross-referencing saves space by ensuring that reagents used in many different procedures only need to be described once.

*Table 1* A Classification of the Procedures in the *Kitab al-Asrar*

| *Type of Procedure* | *Purpose* | *Count* | *Percent* | *Example* |
|---|---|---|---|---|
| Primary | Produces a substance that transforms metals into gold or silver | 175 | 45 | Sublimation of mercury |
| Intermediate | Prepares materials required for primary procedures | 127 | 33 | Calcination of silver through burning |
| Reagent | Produces a chemical used in other procedures | 51 | 13 | Liquids used to dissolve or color |
| Preparation | Instructions for a method used in other procedures | 36 | 9 | Mixing through pulverizing and roasting |
| Total | | 389 | 100% | |

## Assuring Reproducibility

Yet organized and highly integrated procedures alone do not assure reproducibility. Strategies for reproducibility must be built into every procedure. For the purpose of analysis, the following discussion will divide them into physical requirements, operational requirements, and verification requirements. Physical requirements include the materials that the laboratory needs to construct an artificial test environment, such as chemicals, equipment, and controlled heat. Operational requirements are the procedures which provide clear, practical, and safe methods for using these materials. Verification requirements specify standards for using the materials and methods in order to ensure repeatable results, such as timing, temperature, quantification, and endpoints. Together, these requirements reduce the variable components of the testing system and bring the system closer to achieving reproducibility, the *sine qua non* of laboratory testing.

### Physical Requirements: Chemicals, Equipment, and Controlled Heat

Chemicals are the first physical requirement. Even though modern commercial suppliers provide chemicals labeled with a purity rating, *Todd-Sanford* points out that, "Purity of chemicals is a matter of degree" and discusses how to select the appropriate grade.[48] Similarly, al-Razi provides guidelines for his students to judge the quality of raw chemicals for themselves in the first section of the *Kitab al-Asrar*: "What one must know about Substances."[49] Although some procedures use organic matter such as plants, blood, and hair, 90 percent of the procedures are based on inorganic substances, which he divides into six classifications: "spirits, metals, stones, vitriols, boraxes, and salts."[50] Living in the Persian city of Rayy gave al-Razi access to all of these chemicals. Caravans traversing the Silk Road filled Rayy's bazaars with imported goods, while springs in the Elburz Mountains provided the city with pure water.

Rayy was a commercial crossroads, situated on both a north-south trade route and the east-west road between Baghdad and Samarqand (Figure 1). Moreover, the tenth century was a time of expansion for the Persian mining industry. Islamic historian Alessandro Bausani writes: "Deposits of silver, iron, copper, tin, lead, sulphur (near Mount Demavend), lapis lazuli (Badakhshan and Azerbaijan), rubies (for which Badakhshan was famous), and turquoise (near Nishapur) were all mined."[51] The map in Figure 1 shows the location of Rayy on major trade routes and the places named in the *Kitab al-Asrar*. The many substances al-Razi uses in his procedures were readily available to the chemist who had only to select them carefully.


*Figure 1* Persia of the *Kitab al-Asrar*
This map shows places named in the *Kitab al-Asrar* and the major trade routes that crossed through Rayy, superimposed on a map of modern Iran. Al-Razi also refers to India and China to the east and Yemen, Syria, Cyprus, and Egypt to the west.

Al-Razi introduces the question of quality very early, in "Part Two: About Distinguishing the Good and the Bad Varieties."[52] He gives five methods for selecting the best chemicals for the laboratory: color, texture, smell, point of origin, and testing for purity. Color and texture are the most frequently used. For example, the dense yellow sulfur is the most desirable, whereas the white and black varieties are "not suitable."[53] The best kind of arsenic sulphide is "pure red and flakey."[54] Smell helps to distinguish salts; for example, Chinese salt "smells like hard-boiled eggs."[55] Al-Razi is particular about point of origin, revealing a wide range of available sources: the best talc is from Yemen, the best iron oxide is from Istahr, the best red vitriol from Cyprus, the best borax from Zarawand, the best malachite from Kerman.[56] For mercury, the alchemist's most critical ingredient, al-Razi recommends selecting some that is white and soft and then pressing it through a cloth to make sure no black residue is left behind.[57] In addition to purchased chemicals, his procedures assume that the alchemist has ready at hand basic substances such as wine vinegar, distilled vinegar, distilled water, honey, and eggs.

Equipment is the second physical requirement, described in "What one must know about Equipment."[58] Stating his assumption that the tools for metalworking, such as bellows, fire tongs, and crucibles are already well-known, al-Razi concentrates on equipment for working with nonmetals, including alembics, beakers, flasks, and grinding plates. Like later chemists, al-Razi prefers glass for many purposes. Concerned with the quality of the glass, Al-Razi states: "There are various kinds.... The best of them is Syrian, white, pure, as clear as rock crystal."[59] Since the art of glass blowing was invented in Syria in the first century BC, al-Razi would have been able to obtain a variety of glass containers.[60] He specifies using glass vessels for producing urine salts, combining iron filings and vinegar to produce iron rust, and for dissolving various substances.[61] In addition, three procedures require glass mortars and two specify glass funnels lined with cotton for filtration.[62]

Controlled heat is an important part of producing predictable chemical reactions. The modern hospital blood bank laboratory, for example, uses heat blocks at 37 degrees Celsius (normal body temperature) for facilitating some antibody reactions, room temperature of 20-25 degrees Celsius for others, and a refrigerator at 4-6 degrees for cold-reacting antibodies.[63] The *Kitab al-Asrar* describes four kinds of ovens, for different levels of heat: the *tabistan*, *tannur*, *atun*, and *nafikhu-nafsih*, a self-ventilating oven, which burns coal at a high heat fanned by the wind.[64] Al-Razi describes it in detail:

> It stands on three feet and is placed on a saucer, whose walls have holes through them. In the middle of its base there is a hole, through which the ashes fall out. Coals are poured into its lowest part, and that which must be calcined is placed on them and buried in the

coals and covered over with coals. Place it where the wind blows through it. Its fire is exceedingly strong, it calcines the metals and combines them and smelts them.[65]

Controlled heat is not limited to ovens however. Small quantities of material are heated over a naphtha lamp. Long-term even heating is achieved by incubation in a pile of manure, where the inherent bacterial activity generates an even heat for one to three months.[66] Al-Razi frequently uses this dependable medium to dissolve solids that resist faster methods. A procedure for the sublimation of glass reads, "Bury it 40 days in dung, so that it becomes a pure water, purer than tears,"[67] and a process for making strong solvents from vitriols reads, "bury it for three weeks in dung. It dissolves into yellow water without residue."[68] Apothecaries as well as alchemists used manure through the sixteenth century to provide a standard even heat for the digestions and fermentations needed to make their medicines.[69]

### Operational Requirements: Clear, Realistic, and Safe

While physical requirements define the materials themselves, operational requirements describe how to use them. Procedures that are clear, realistic, and safe are vital to reproducible results. Clarity helps ensure that laboratory procedures will be understood and followed properly. *Food and Drink Laboratory Accreditation*, a modern manual on regulatory requirements, states: "Remember to keep it simple! … Staff will not follow complicated procedures."[70] Confusing instructions compromise reproducibility and waste precious materials and labor when the elements of a botched experiment have to be thrown away. Consider the difficulties one faces in following this alchemic procedure attributed to Raymond Lull in *The New Pearl of Great Price* (c. 1330) by Petrus Bonus: "At the first distillation take only 1½ part and, distil it again, and then its 4th part, which also distil a third time; of this again take 2 parts for the fourth distillation, in which take a little more than the whole; distil this 8 or 9 times."[71] Compare this procedure from the *Kitab al-Asrar* which reads: "Take copper filings, mix them with a quarter the amount of yellow arsenic sulfide, place it in a clay-coated jar and roast it one night in the oven."[72]

Al-Razi's clear instructions include explicit warnings against conditions that put the experiment at risk: "One must watch, however, that the fire does not go out and the ashes do not get cold, before it has dissolved and solidified."[73] "Then take black naphtha and add an equal amount of sal ammoniac and distill it; repeat the task with it and watch that it does not ignite."[74] "Put it in hot ashes, but these must not be too hot so that the flask does not shatter."[75] These warnings help the beginner avoid disaster. The difficulty with replicating his procedures today would not lie as much in the clarity of the instructions as it would with duplicating the chemicals and equipment he used.

The second operational requirement is practicality. A procedure that demands heavy physical labor, many repetitions, or a long duration, is unlikely to be performed the same way twice. The concept of heavy labor is relative to societal standards, but there are also human limitations to consider. One procedure in the fourteenth-century alchemy text *The New Pearl of Great Price* states that "The time required for the whole work is stated by Rhasis to be one year."[76] Actually even the longest intervals in the *Kitab al-Asrar* are far shorter, such as a series of three forty-day incubation periods for dissolving hard stones like turquoise. Digging pits for such incubations is the heaviest labor required, but at least these are not works of precision. Some procedures require hours of grinding materials on a stone to pulverize them or combine them. However, physical labor and repetitions in the *Kitab al-Asrar* appear to be within achievable limits. In contrast, alchemy historian E. J. Holmyard points out that some medieval alchemists recommended distilling and redistilling materials hundreds of times.[77] When a procedure has hundreds of repeated steps, reproducibility is virtually impossible.

The last operational necessity is safety. Like labor, safety is relative to the expectations of society as a whole. The 1962 *Todd-Sanford*, for example, is lax by today's standards, advocating mouth pipetting, wiping up mercury spills, and never mentioning protective gloves while working with body fluids in a hospital diagnostic laboratory.[78] Today the mercury, lead, and arsenic compounds so casually handled by al-Razi, Libavius, Faraday, and many chemists since, are highly regulated by state and federal agencies. Interestingly, in his medical work *al-Hawi* al-Razi questioned the safety of mercury enough to administer it experimentally to an ape. He concluded that its ill effects were minor, limited to "severe pains in the stomach and intestines."[79] Immediate effects, not long-term environmental exposure are a threat to repeatability, and al-Razi does not neglect them.

The *Kitab al-Asrar* contains seven specific references to safety. In the procedure for initial treatment of sulfur and arsenic sulfide, found in Part One, al-Razi instructs the alchemist to heat the substances in a remote outdoor area and not to return them to the laboratory until after the smoke turns white, because at that point, "it will not harm you."[80] In addition to keeping the toxic fumes out of the workplace, the instruction appears to show concern for protecting the public as well, by recommending that the procedure be carried out in "a desert…or a place free from inhabitants."[81] The instructions for purifying sulfur and arsenic sulfide caution the alchemist to "protect your hand and your nose, because it is a poison."[82] The procedure for softening iron using borax goes a step further, advising the alchemist to plug his nostrils with cotton soaked in oil of violets and to avoid touching it because the poison acts in one hour.[83] The same precaution is advised in Part Three for working with "sharp waters" (strong solvents), recommending the addition of either rose oil or violet oil to the cotton. A different procedure for making "sharp water" from sal ammoniac, copper acetate, lime, and arsenic sulfide advises strict caution because it "exerts a powerful effect on you."[84] The emphasis is on protecting the worker from immediate harm. This is quite comparable with the 1962 laboratory manual that recommends "fireproof hose connections for Bunsen burners" and yet ignores the risk of contagious disease.[85]

### Verification Requirements: Quantification and Endpoints

Even more critical to reproducibility than physical and operational requirements are measurable and observable specifications for verification such as time and temperature, weights and measures, and clear-cut endpoints, the vital indicators of a successful outcome. If physical requirements describe what is needed and operational requirements explain how to carry out the procedures, verification requirements specify exact testing conditions so that the results of the process are the same every time it is performed. This concept is so fundamental to the concept of the laboratory that biologist Edward Wilson made it the primary defining property of real science: "The diagnostic features of science that distinguish it from pseudoscience are first, repeatability."[86]

The shortest time interval specified in the *Kitab al-Asrar* is one hour, occurring in many procedures such as "take it out every hour and examine what adheres to it" and "grind it while roasting a good hour."[87] It is significant that al-Razi uses the hour only to describe the length of time to perform a particular process, such as grinding, roasting, shaking, or soaking, where the exact duration is not critical, and he never uses time alone to define when a procedure is complete. That is, instead of stipulating simply, "pound it with mustard for several hours," he adds the words "until it turns black," so that the alchemist can tell when he has pounded the mercury long enough.[88]

When al-Razi uses time to specify the frequency of a process, rather than its duration, he specifies the three most easily determined times of day, as in "every day for three hours, one hour at the beginning, one in the middle, and one at the end," or "every day, morning, noon, and evening."[89] He does not use more difficult frequencies, such as four, five, or six times a day. Occasionally he specifies a long duration in hours, such as "apply heat under the aludel twelve hours for each ratl" or "light a gentle fire under the lamp for ten hours."[90] These may have been estimated as the length of one day or night.

The procedures also specify time spans of days, weeks, and months which can be reproduced without instruments. In his medical case histories, al-Razi documented the time when his patients' symptoms appeared or subsided and the frequency of treatments. For example, in the case of a woman suffering from residual fever after smallpox, he records the results of a regimen of "dried apricots at day-break and barley-water at noon during a fortnight. The maturation of urine appeared after forty days, and her recovery was complete at the end of fifty days."[91] The systematic recording of time intervals in his medical writings suggests that he observed the forty-, fifty-, or sixty-day intervals in his alchemy procedures with equal care.

Temperature in the *Kitab al-Asrar* is relative. The procedure for calcination of lapis lazuli, calls for a "gentle fire, like a bird incubator," hot ashes provide a medium heat, and the most powerful fire is the "fire of the oven for casting iron."[92] The manual also provides general principles, such as, "the fire for roasting for solidifying dissolved substances is a strong fire, whereas the fire for roasting for melting is a gentle fire."[93] Fire is specified as directional, on all sides for some purposes, and from below for others.[94] Alternative methods for controlling heat include manure, naphtha lamps, and the sun. "Put it in the sun in the most heat possible," reads one procedure.[95] Time and temperature were functional concepts, although both defied synchronization into the nineteenth century. On the other hand, standardization of weights was important wherever trade predominated.

Weights were in use throughout the Abassid Caliphate, to facilitate business transactions and tax collection such as the cane sugar and dates that Persia sent to the treasury in Baghdad.[96] There are three methods of quantification for weight and volume in the *Kitab al-Asrar*: quantitative weights and measures, proportional quantities, and semi-quantitative estimates. The most common unit of measurement is the *ratl*, both a unit of weight or of volume (as is the English ounce). According to Ruska, the word *ratl* is equivalent to 360 grams of weight, or between one and two liters of liquid. The currants, cane sugar, and dates that Persia sent to the treasury in Baghdad were measured in *ratls*.[97] The *ratl* is divided into twelve *uqia* or ounces, so that one ounce is thirty grams.[98]

A typical quantitative procedure from the *Kitab al-Asrar* reads: "Then take vitriol, copper acetate, cinnabar, and sal ammoniac, one uqia of each, pour a ratl of distilled vinegar on it and bury it in manure."[99] Al-Razi does not mention a balance specifically, but he almost certainly had one because fifty of his procedures start with weighed materials and three require reweighing materials throughout the process to monitor their weight change. Al-Razi also uses the *dirham* and the *mithqal* to quantify metals, which Ruska puts at four grams and six grams respectively.[100] The silver dirham was a coin used as a rate of exchange. According to Italian historian Alessandro Bausani, in tenth-century Persia, "one *dirham* or drachma would purchase between 11 and 18 lbs of meat or honey, or up to 50 cakes of barley."[101] Al-Razi specified the most standardized weights available, the measurements used in tax collection and commerce.

Almost 80 percent of al-Razi's procedures use proportional measurements (Table 2). These methods measure all ingredients relative to the first: "Take what you will of copper filings, amalgamate them with three times as much mercury, add an equal amount of alum as copper and half as much sal ammoniac as alum."[102] A comparable twentieth-century example reads: "Bloor's reagent. 3 volumes of 95 percent ethanol and 1 volume of ethyl ether."[103] This approach may not sound as precise as a procedure that specifies units of measure, but in fact it would successfully keep all components in proportion and facilitate adjustments to the availability of chemicals or how much of the end product was desired. In 1789, however, French chemist Antoine Laurent Lavoisier (1743-1794) presented a strong argument in favor of proportions which may help explain why al-Razi and other alchemists used them so much.

*Table 2* Use of Actual Weight versus Use of Proportions in the *Kitab al-Asrar*

| *Type of Procedure* | *Purpose* | *# times in Kitab* | *% with proportion* | *% with weights* | *% none stated* |
|---|---|---|---|---|---|
| Primary | Produces a substance that transforms metals into gold or silver | 175 | 80 | 18 | 2 |
| Intermediate | Prepares materials required for primary procedures | 127 | 95 | 5 | 0 |
| Reagent | Produces a chemical used in other procedures | 51 | 75 | 24 | 2 |
| Preparation | Instructions for a method used in other procedures (dissolving, softening) | 36 | 14 | 3 | 83 |
| Total | | 389 | 78% | 13% | 9% |

Lavoisier advocated the use of proportional measurements in his work *Elements of Chemistry* in order to enable chemists to duplicate experiments internationally. He suggested that each chemist use their local standard weight as a unit and use decimals for fractions. "By this means the chemists of all countries will be thoroughly understood by each other, as, although the absolute weights of the ingredients and products cannot be known, they will readily and without calculation, be able to determine the relative proportions of these with utmost accuracy; so that in this way we will be possessed of an universal language for this part of chemistry."[104] For centuries before Lavoisier, alchemists used proportions in their written procedures, very likely for the same reason—the desire to repeat the processes of others in the absence of standardization.

Semi-quantitative estimates, the third method of measurement al-Razi uses, work well for procedures that do not involve mixing chemicals. These procedures usually specify a familiar object on which the laboratory investigator can base an estimate: "On the lowest portion of the open crucible is a hole; so big that the little finger passes through it."[105] Other semi-quantitative measurements describe making a hole that a needle can pass through or sprinkling an entire surface with oil "until there is no part of its surface remaining that the oil has not touched."[106] A comparable modern procedure for preparing a thick blood smear for microscopic examination reads, "Thick film preparations are made about the size of a dime—not thick enough to slough off when dry."[107] Although they sound deceptively easy, because semi-quantitative measurements are not exact specifications, only technique gained by supervised practice and hands-on experience can assure success. The ultimate verification of a procedure, however, is the achievement of a specified end point.

The end point is the most important verification requirement in laboratory procedures. In the laboratory, a detectable end point indicates when a process is complete or when it is time to proceed to the next step. It assures repeatability by showing when the required conditions have been met. An end point in chemistry can be defined as "a point marking the completion of a process or stage of a process."[108] Color change is one of the most common endpoints in chemistry. When Faraday refers to carrying out a process until the flame turns blue or the litmus paper turns red, he is using color as an end point.[109] Forensic laboratories regularly start a bomb investigation with a color test, such as the diphenylamine test which turns blue to indicate the presence of certain explosives.[110] *Todd-Sanford* ends a titration for ammonia: "Endpoint is a blue-gray or a dirty blue."[111] Even with automated instrumentation in clinical chemistry the final reading is usually based on color change read by a spectrophotometer and conveyed to a computer.

Color change is also the most common end point in the *Kitab al-Asrar*. Most procedures conclude with a phrase such as "until it turns black," "until it [the smoke] begins to come out white," "red as liver," "red as blood," or "white as snow."[112] Al-Razi also frequently uses changes in consistency: "until it is like foam," "like honey," "as thick as tar," and most often, "an impalpable fine white powder."[113] Carrying out a heating process until the mixture starts to smoke or ceases to smoke is another common visual end point in the *Kitab al-Asrar*.[114] Occasionally the procedure may recommend checking for solubility by placing the powder on the tip of the tongue.[115]

Flammability is used as an end point four times in the *Kitab al-Asrar*. When distilling oils, the procedure stipulates: "Do this with it several times, until it ignites no fire."[116] The distillation of naphtha instructs: "Make naphtha into a paste with an equal amount of sal ammoniac and distill it. Do this with it, until it distills like water and absolutely does not ignite a fire."[117] The use of flammability as an end point shows that al-Razi recognized it as a chemical property, along with color, smell, consistency, and solubility. Other procedures use test tablets or weight change to detect the success of the desired reaction,[118] for example: "the indicator for that is that you sprinkle some of it on to a heated silver test tablet, it does not blacken the tablet and flows over it and does not smoke."[119] Weight change is an end point in three procedures. One instruction reads: "grind it and weigh it and repeat the procedure until it remains unaltered at one weight that does not diminish."[120] A procedure for distilling a solution made with hair states: "Then weigh the remaining water, so that you know what has been taken from it."[121] A defined end point is an essential strategy for repeatability. It indicates that the procedure is complete and successful. Ninety-five percent of al-Razi's procedures have specified end points.

The *Kitab al-Asrar* presents a series of procedures which the alchemist must carry out under specified conditions which collectively constitute strategies for reproducibility. These conditions included selecting chemicals, combining them in defined proportions, and subjecting them to controlled heat for a set period of time in order to achieve a fixed end point. When combined, these strategies make a repeatable result possible by imposing a template on the vagaries of nature. They are used in laboratory manuals up to the present day.

## Conclusion: "The Production of Certainty"[122]

A modern definition of a testing laboratory reads: "An organization that measures, examines, tests, calibrates or otherwise determines the characteristics or performance of products, materials, equipment, organisms or physical phenomena."[123] Laboratories test virtually everything we touch, eat, or drink. They diagnose diseases, convict criminals, and determine the nutritive content of baby food. Despite occasional revelations of scandals and errors, the laboratory as an institution has developed a high degree of credibility through an increasing trend toward standardization and accreditation, based on the use of standard operating procedures contained in a laboratory manual. "The manual summarizes the rules of operation, providing direction and uniformity in laboratory testing," states a modern guide to laboratory management.[124] The *Kitab al-Asrar* is such a laboratory manual.

Yet the very economy of words that characterize the *Kitab al-Asrar* as a working manual makes its roots more difficult to trace. Ruska found some clues to al-Razi's chemistry in a body of texts attributed to the eighth-century alchemist Jabir, although Ruska noted the difference in style: "the gulf between the endless variety of forms of the Jabir manuscripts and the realistic matter-of-fact style of Razi's work is so great, that one can hardly notice any further relationship other than a common foundation."[125] Some historians have credited al-Razi with important new chemical distinctions including, for example, his categorization of vitriols as a distinct group.[126] However, his stylistic innovation is arguably even more significant. By separating the extraneous from the essential al-Razi defined laboratory functions.

As a laboratory manual, the *Kitab al-Asrar* only mentions medicines once, but some of its unwritten infrastructure may be illuminated in chemistry-relevant sections of *al-Hawi* such as "potentialities of drugs and nutriments, and all of the substances required for medicine," compounded drugs," or "weights and measures."[127] In contrast to the *Kitab al-Asrar*, al-Razi names his sources in *al-Hawi*, including extracts from Greek and Hindu authors while adding his own observations.[128] The utility of a laboratory manual lies in its very terseness, but a study of al-Razi's massive medical works in parallel with the *Kitab al-Asrar* might reveal more about what he knew and where he learned it, and clarify the nature of his innovations.

Challenging questions remain. What were the connections between al-Razi's original writing of the *Kitab al-Asrar* in c. 920 CE and its first known translations in the thirteenth century? If one further defined elements of laboratory manual discourse, when and where would they be discovered outside the *Kitab al-Asrar*? The components of laboratory manuals discussed in this article might be more closely refined and sought both in texts contemporary with and later than the *Kitab al-Asrar*, looking at laboratories of the past in order to understand why the laboratories of today have become so very important. The laboratory's external connections also have roots in the past. Historically as much as today, the search for patronage engages laboratories in economic, political, and social controversies. As Latour observes, "there is no outside to laboratories,"[129] because the community determines what the laboratory should seek and the laboratory's findings become a part of the community's reality.

The fact that al-Razi's laboratory sought to make gold should not distract us from seeing the *Kitab al-Asrar* as a focused laboratory procedure manual. In the ancient theoretical framework of material unity, transformation of one substance into another was not an unreasonable goal. Kuhn points out that, "Out-of-date theories are not in principle unscientific because they have been discarded."[130] Substances do transform—in the furnaces of burning stars, where nuclear fusion sequentially assembles a series of elements beginning with helium, carbon, and oxygen, culminating, as the star dies, in the formation of iron, lead, mercury, silver and gold in a sequence that science writer Timothy Ferris so aptly calls "the virtuosity of stellar alchemy."[131]

Al-Razi described the sequence of changes in the laboratory, which take place as he combines, dissolves, distills, and solidifies selected substances under specified conditions of heat and timing in order to obtain repeatable transformations of form, color, and properties. At a student's request, he condensed the essential elements of his procedures into one manual. Beginning with three sections, substances, equipment, and procedures, he built in strategies for predictable success. This is what we have come to expect in a laboratory manual.

> So I have put together this my book for him and with it gave him something that I have never once given any king or ruler. I have explained to him what is essential in the science of the chemical arts from all my other books on this subject and compiled one compact,

precise book on this subject for him, the title of which is *The Book Secret of Secrets*. With it, the (state of) metals committed to the process will be raised, and (the elevated metals) broken down and returned to their original state. Therefore I describe these procedures. (Al-Razi, *Kitab al-Asrar*, c. 920 CE)[132]

## Notes

1. "Wüsste ich nicht, daß meine Tage gezählt sind, und daß mein Tod nahe ist, und bestünde nicht die Besorgnis, es möchte, was ich ihm Freundliches erweisen will, durch meinen Tod vereitelt werde, so hätte ich ihm nicht dies alles in meinem Buch zusammengestellt und hätte mich nicht bemüht, es in solcher Vollendung auszuführen." Abu Bakr Muhammad ibn Zakariya al-Razi, *Kitab al-Asrar*, in *Al-Razi'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), 83. Unless otherwise stated all translations are by the author.
2. Al Abu Raihan Muhammad ibn Ahmad al-Biruni, "Al-Biruni als Quelle für das Leben und die Schriften al-Razis," trans. and ed. Julius Ruska, *Isis* 5 (1923), 34-48.
3. Yvon Houdas, *La Médecine Arabe aux Siècles d'Or: VIIIème-XIIIème Siècles* (Paris: L'Harmattan, 2003), 78. G. Le Strange, *The Lands of the Eastern Caliphate: Mesopotamia, Persia, and Central Asia from the Moslem Conquest to the time of Timur* (London: Frank Cass & Co., 1905; reprint, New York: Barnes & Noble, 1966), 216 (page citations are to the reprint edition).
4. Edward Theodore Withington, *Medical History from the Earliest Times: A Popular History of the Healing Art* (London: The Scientific Press, 1894), 146. 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 (page citations are to the reprint edition).
5. William R. Newman, trans. and ed. *The Summa Perfectionis of Pseudo-Geber: A Critical Edition, Translation and Study* (Leiden: E. J. Brill, 1991), 65.
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), 229 (page citations are to the reprint edition). This edition of *The New Pearl of Great Price* cites al-Razi at least thirteen times by my count, on pages 6, 80, 109, 112-113, 115, 229, 259 (twice), 279, 362, 365, 375, 382. The book was originally written in c. 1330 as *Pretiosa Margarita Novella.*
7. Aristotle, *Meteorology*, vol. 1 of *Great Books of the Western World*, ed. Robert Maynard Hutchins (Chicago: William Benton, 1952), 445, 482.
8. Michael Faraday, *Chemical Manipulation: Being Instructions to Students in Chemistry on the Methods of Performing Experiments of Demonstration or Research, with Accuracy and Success* (London: John Murray, 1842), 1.
9. Ruska, *Al-Razi's Buch Geheimnis der Geheimnisse*, 22.
10. Karl Christoph Schmieder, *Geschichte der Alchemie* (Halle: Verlag der Buchhandlung des Waisenhauses, 1832), 94-95.
11. "Cet ouvrage représente un véritable traité méthodique de chimie positive, écrit vers l'an mil [*sic*]." M. Berthelot, *La Chimie au Moyen Age* (Paris: Imprimerie Nationale, 1893), 306.
12. Paul Kraus, "Julius Ruska," *Osiris* 5 (1938), 9.
13. Ruska, *Al-Razi's Buch Geheimnis der Geheimnisse*, 22.
14. Kraus, "Julius Ruska," 13.
15. Sarton, *From Homer to Omar Khayyam*, 587.
16. Ibid., 610.
17. H. E. Stapleton, R. F. Azo, and M. Hidayat Husain, "Chemistry in Iraq and Persia in the Tenth Century A.D.," *Calcutta: Memoirs of the Asiatic Society of Bengal* 8 (1927), 369.
18. Ibid., 317.

19. Ibid., 11.
20. This translation was published in Julius Ruska, *Al-Razi's Buch Geheimnis der Geheimnisse*, Quellen und Studien zur Geschichte der Naturwissenschaften und der Medizin, Band 6 (Berlin: Verlag von Julius Springer, 1937).
21. "Dann aber bleibt auf alle Fälle für Razi das Verdienst, die Alchemie zum ersten Mal in eine streng wissenschaftliche Form gebracht zu haben." Ruska, *Al-Razi's Buch Geheimnis der Geheimnisse*, 13.
22. Kraus, "Julius Ruska," 15.
23. A. Rupert Hall, *The Scientific Revolution 1500-1800: The Formation of the Modern Scientific Attitude*, 2nd ed. (London: Longmans, Green and Co., 1962), 309-310.
24. Marie Boas, *The Scientific Renaissance 1450-1630* (New York: Harper & Row, 1966).
25. E. John Holmyard, *Alchemy* (Middlesex, England: Penguin Books, 1957; reprint, New York: Dover Publications, 1990), 88 (page citations are to the reprint edition). Robert P. Multhauf, *The Origins of Chemistry* (London: Oldbourne, 1966), 130.
26. Holmyard, *Alchemy*, 88-89.
27. William R. Newman, "Alchemy, Assaying, and Experiment," in *Instruments and Experimentation in the History of Chemistry*, ed. Frederic L. Holmes and Trevor H. Levere (Cambridge: The MIT Press, 2000), 37.
28. William H. Brock, *The Chemical Tree: A History of Chemistry* (New York: W. W. Norton & Co., 2000), 22.
29. Owen Hannaway, *The Chemists and the Word: The Didactic Origins of Chemistry* (Baltimore: The Johns Hopkins University Press, 1975), 81, 89.
30. David Gooding, *Experiment and the Making of Meaning: Human Agency in Scientific Observation and Experiment* (Dordrecht, Netherlands: Kluwer Academic Publishers, 1990).
31. Bruno Latour, *Pandora's Hope: Essays on the Reality of Science Studies* (Cambridge, MA: Harvard University Press, 1999), 30. The Salk Institute study is described in: *Laboratory Life: The Construction of Scientific Facts* (Princeton, NJ: Princeton University Press, 1986).
32. Latour, *Laboratory Life*, 129.
33. Max Meyerhof, trans. and ed., "Thirty-Three Clinical Observations by Rhazes (Circa 900 A.D.)," *Isis* 23 (1935), 324. Ruska, *Al-Razi's Buch Geheimnis der Geheimnisse*, 4. According to Meyerhof, "This was the Samanid Prince Abu Salih Mansur ibn Ishaq, Governor of the Eastern and Southern provinces of Persia, killed in 302 A.H. (925 A.D.)."
34. Stapleton et al., "Chemistry in Iraq and Persia," 318.
35. Latour, *Pandora's Hope*, 30.
36. Petrus Bonus, *New Pearl of Great Price*, 110.
37. Sandra Wilson and Geoff Weir, *Food and Drink Laboratory Accreditation: A Practical Approach* (London: Chapman and Hall, 1995), 107.
38. Israel Davidsohn and Benjamin Wells, eds., *Todd-Sanford Clinical Diagnosis by Laboratory Methods* (Philadelphia: W. B. Saunders, 1962).
39. Ibid., 839-877.
40. "Dies mein Buch umfaßt drei Gegenstände: die Kenntnis der Stoffe, die Kenntnis der Geräte und die Kenntnis des Verfahrens." Al-Razi, 84.
41. Ruska, *Al-Razi's Buch Geheimnis der Geheimnisse*, ix-xiii.
42. Hannaway, *Chemists and the Word*, 155.
43. Antoine Laurent Lavoisier, *Elements of Chemistry*, vol. 45, *Great Books of the Western World*, ed. Robert Maynard Hutchins (Chicago: William Benton, 1952), 53-86.
44. "Die Verkalkung des Silbers durch das Rostenlassen." Al-Razi, 131-133.
45. "Die Lösung mit den scharfen Wässern." Ibid., 181. "Die Verfahren der Wässer." Ibid., 201.
46. "Darauf nimm ebensoviel zur Weiße hochgetriebenes Quecksilber." "Tränke es mit dem scharfen Wasser der Nura das *Zermalmendes Wasser* heißt." The instructions for making the "crushing water" are located in a later chapter. Ibid., 115, 182.
47. Davidsohn and Wells, *Todd-Sanford Clinical Diagnosis*, 929.

48. Ibid., 394.
49. Al-Razi, 84. Al-Razi appears to be the first to use the three-part classification of animal, vegetable, and mineral. Holmyard, *Alchemy*, 89. Holmyard also provides a good diagram of al-Razi's classification system on page 91.
50. "Geister, Metalle, Steine, Vitriole, Boraqe und Salze." Al-Razi, 84.
51. Alessandro Bausani, *The Persians: From the Earliest Days to the Twentieth Century* (Florence: Sansoni, 1962; English translation: London: Elek Books Limited, 1971), 86.
52. "Zweiter Abschnitt. Von der Unterscheidung der guten und schlechten Arten." Al-Razi, 84.
53. "Nicht geeignet." Ibid., 85.
54. "Eine rote, von reinem Rot, blättrig, is vortrefflich für unser Werk." Ibid., 85.
55. "Ein Geruch nach gekochten Eiern." Ibid., 90.
56. Ibid., 87, 89.
57. "Wenn mann es durch ein Tuch preßt, darf nicht etwas dem Kuhl (Augenpulver) Ähnliches darin zurückbleiben." Ibid., 85.
58. "Was man von der Geräten wissen muß," Ruska, *Al-Razi's Buch Geheimnis der Geheimnisse*, viii.
59. "Das Glas. Es gibt verschiedene Arten... Das beste davon ist das syrische, weiße, reine, das dem Bergkristall (Billaur) an Reinheit gleicht." Ibid., 87.
60. Holmyard, *Alchemy*, 45.
61. Al-Razi, 91, 139, 186.
62. Ibid., mortar: 210, 219; funnel: 190, 222.
63. Davidsohn and Wells, *Todd-Sanford Clinical Diagnosis*, 291.
64. Al-Razi, 93-99.
65. "Es steht auf drei Füßen und wird auf einem Untersatz aufgestellt, dessen Wände durchlöchert sind. In der Mitte seines Bodens befindet sie ein Loch, aus dem die Asche herausfällt. In seinem unteren Teile werden Kohlen geschüttet, und das, was verkalkt werden soll, wird darauf gesetzt und in die Kohle eingegraben und mit Kohle zugedeckt. Du stellst ihn hin, wo ihn die Winde treffen. Sein Feuer ist äußerst stark, es verkalkt die Metalle und vereinigt sie und schmelzt sie." Al-Razi, 99. "Calcines the metals" means that the strong heat transformed the metal into a fine powder. Holmyard, *Alchemy*, 277.
66. Terence Young, "From Manure to Steam: The Transformation of Greenhouse Heating in the United States, 1870-1900," *Agricultural History* 72 (1998), 586.
67. "Grabe es dann 40 Tage in Mist ein, so wird es zu reinstem Wasser, reiner als die Träne." Al-Razi, 198.
68. "Und es dann drei Wochen im Mist eigräbst. Es löst sich zu gelbem Wasser ohne Rückstand." Ibid., 202.
69. Friedrich Dobler, "Der Firmus als Wärmequelle in der alten Pharmazie," *Pharmaceutica Acta Helvetiae* 32 (1957), 67.
70. Wilson and Weir, *Food and Drink Laboratory Accreditation*, 70.
71. Petrus Bonus, *New Pearl of Great Price*, 355.
72. "Nimm Feile des Kupfers, vermische sie mit ihrem Viertel gelbem Zarnich, tue sie in einen verlehmten Krug und röste sie eine Nacht im Ofen (Tannur)." Al-Razi, 134.
73. "Man muß jedoch aufpassen, daß das Feuer nicht ausgeht (E und die Asche nicht kalt wird, bevor es sich gelöst hat und fest geworden ist"). Ibid., 95-96. Note: In Ruska's translation, E refers to words which are only found in the Escorial manuscript of the *Kitab al-Asrar*.
74. "Dann nimm schwarzes Naft und tue ebensoviel Salmiak dazu und destilliere es; wiederhole damit die Arbeit und achte darauf, daß es sich nicht entzündet." Ibid., 122.
75. "...tue es in heiße Asche, doch darf diese nicht zu heiße sein, damit die Flasche nicht zerspringt." Ibid., 173.
76. Petrus Bonus, *New Pearl of Great Price*, 115.
77. Holmyard, *Alchemy*, 52.
78. Davidsohn and Wells, *Todd-Sanford Clinical Diagnosis*, 392, 402.
79. Withington, *Medical History from the Earliest Times*, 148.

80. "denn es schadet dir (jetzt) nicht." Al-Razi, 112.
81. "in der Wüste oder anderswo (L oder an einen Ort frei von Bewohnern)." Ibid.
82. "hüte deine Hand und deine Nase, denn es ist ein Gift." Ibid., 118.
83. "denn es ist ein Gift einer Stunde." Ibid., 167.
84. "Es ist ein sehr scharfes Wasser, das dir eine kräftige Wirkung ausübt." Ibid., 183.
85. Davidsohn and Wells, *Todd-Sanford Clinical Diagnosis*, 928.
86. Edward O. Wilson, *Consilience*: *The Unity of Knowledge* (New York: Vintage Books, 1998), 58.
87. "[du] nimmst ihn dann jede Stunde heraus und betrachtest (E was an ihm hängen geblieben ist)." Al-Razi, 109. "Pulvere dies unter Rösten eine gute Stunde." Ibid., 131.
88. "[du] es mit Senf einige Stunden zerstoßest, bis es schwarz geworden ist." Al-Razi, 100.
89. "Jeden Tag drei Stunden, eine Stunde an seinem Anfang, eine in seiner Mitte und eine an seinem Ende." Ibid., 132. "Schüttle es jeden Tag morgens, mittags und abends." Ibid., 119.
90. "[du] erhitzest unter dem Uthāl für jedes Ratl zwölf Stunden lang." Ibid., 103. "Zünde unter der Lampe ein gelindes Feuer an, zehn Stunde lang." Ibid., 108.
91. Case history by al-Razi, in Meyerhof, "Thirty-Three Clinical Observations by Rhazes," 338.
92. "An einem gelinden Feuer wie die Brutwärme des Vogels." Al-Razi, 108. "Erhitze ihn in einem mächtigen Feuer, dem Feuer des Ofens der Eisengießer." Ibid., 174.
93. "Der Unterschied zwischen dem Feuer der Röstung des Erweichens und dem Feuer zur Röstung des Verfestigens ist daß das Feuer der Röstung der gelösten Dinge ein mächtiges Feuer ist, während das Feuer der Röstung des Erweichens ein gelindes Feuer ist." Al-Razi, 168.
94. "Damit ihr Feuer von allen Seiten wirke." Ibid., 191. "Darunter geheizt." Ibid., 95.
95. "Bring ihn an die Sonne...in die großtmögliche Hitze." Ibid., 174.
96. Bausani, *The Persians*, 85.
97. Ibid.
98. Ruska, *Al-Razi's Buch Geheimnis der Geheimnisse*, 64.
99. "Dann nimm Vitriol, Kupfergrün, Zinnober und Salmiak, von jedem einzelnen eine Ūqia, gieße ein Ratl destillierten Essig darauf und vergrabe es im Mist." Al-Razi, 128.
100. Ruska, *Al-Razi's Buch Geheimnis der Geheimnisse*, 64.
101. Bausani, *The Persians*, 85.
102. "Nimm Feile des Kupfers was du willst, amalgamiere sie mit drei ihresgleichen Quecksilber, füge ebesoviel Alaun wie Kupfer hinzu und so viel wie die Hälfte des Alauns Salmiak." Al-Razi, 137.
103. Davidsohn and Wells, *Todd-Sanford Clinical Diagnosis*, 429.
104. Lavoisier, *Elements of Chemistry*, 88.
105. "An der untersten Stelle des oberen Bechers ist ein Loch; so groß, daß der kleine Finger hindurchgeht." Al-Razi, 195.
106. "So daß der Kopf einer Packnadel durchgeht." Ibid., 109. "Und gehst [du] mit einer Besprengung von Öl darüber weg, so daß von seiner Oberfläche keine Stelle übrig bleibt, die das Öl nicht berührt hat." Ibid., 100.
107. Davidsohn and Wells, *Todd-Sanford Clinical Diagnosis*, 936.
108. End point: "a point marking the completion of a process or stage of a process; especially: a point in a titration at which a definite effect (as a color change) is observed" (Merriam-Webster online Dictionary s.v. end point). www.m-w.com/dictionary/endpoint, accessed 10 September 2008. Here, I use the term in the first, more general, sense.
109. Faraday, *Chemical Manipulation*, 603, 273.
110. Ashraf Mozayani and Carla Noziglia, *The Forensic Laboratory Handbook: Procedures and Practice* (Totowa, NJ: Humana Press, 2006), 98.
111. Davidsohn and Wells, *Todd-Sanford Clinical Diagnosis*, 453.
112. "Bis es schwarz geworden ist." Al-Razi, 100. "Wenn es [der Rauch] aber weiß herauszukommen beginnt." Ibid., 112. "Rot wie Leber." Ibid., 140. "Rot wie Blut." Ibid., 151. "Weiß wie der Schnee." Ibid., 115.
113. "Bis es wie Schaum wird." Ibid., 133. "Wie Honig." Ibid., 205. "Wie der Teer." Ibid., 213. "Bis es (G dir gefällt und) ein unfühlbares weißes Streupulver geworden ist." Ibid., 130.

114. Examples: "Bis der Rauch (E ganz) herauskommt." Ibid., 160. "Bis sein Rauch aufhört." Ibid., 198.
115. "Du erhälst ein unfühlbares Pulver, das auf der Spitze der Zunge schmilzt." Ibid., 154.
116. "Bis es wie Wasser destilliert und sich durchaus nicht Feuer an ihm entzündet." Ibid., 221.
117. "Mache das Naft zu Teig mit ebensoviel Salmiak und destilliere es. Tue dies mit ihm, bis es wie Wasser destilliert und sich durchaus nicht Feuer an ihm entzündet." Ibid., 221.
118. Ruska states that the exact construction of the tablet is not clear. Ruska, *Al-Razi's Buch Geheimniss der Gerheimnisse*, 55.
119. "Das Kentzeichen davon ist, daß du von ihm auf eine erhitze Probetafel von Silber streust, es diese nicht schwärtzt und über sie läuft und nicht raucht." Al-Razi, 108.
120. "Pulvere es und wäge es und wiederhole das Verfahren damit, bis es unverändert auf einem Gewicht stehen bleibt, das sich nicht vermindert." Al-Razi, 154. The two other examples are: Al-Razi, 190, 211.
121. "Dann wäge den Rest des Wassers, damit du weißt, was darin zugenommen hat." Al-Razi, 211.
122. Latour, *Pandora's Hope*, 30.
123. *New Zealand Code of Laboratory Management Practice*, Issue 2, December 1988, in Harvey E. Schock, ed., *Accreditation Practices for Inspections, Tests, and Laboratories* (Philadelphia: American Society for Testing and Materials, 1988), 129.
124. Judith A. O'Brien, *Common Problems in Clinical Laboratory Management* (New York: McGraw-Hill, 2000), 131.
125. "Der Abstand zwischen der unendlich vielgestaltigen Darstellung der Gabir-Schriften und der nüchtern sachlichen Form von Razi's Arbeiten ist so groß, daß man über die Feststellung einer gemeinsamen Basis hinaus kaum noch weitere Beziehungen wahrscheinlich machen kann." Ruska, *Al-Razi's Buch Geheimnis der Geheimnisse*, 12-13.
126. Vitriols was a old term for metal sulphates, especially iron and copper, often characterized by their bright blue or green color. Vladamir Karpenko and John A. Norris, "Vitriol in the History of Chemistry," *Chemické Listy* 96 (2002), 997-998.
127. Muhammad ibn Ishaq al-Nadim, *The Fihrist: A Tenth-Century Survey of Muslim Culture* vol. 2, trans. and ed. Bayard Dodge (New York: Columbia University Press, 1970), 704. Reference to making medicines in the *Kitab al-Asrar*: al-Razi, 111.
128. Sarton, *From Homer to Omar Khayyam*, 609.
129. Bruno Latour, "Give Me a Laboratory and I will Raise the World," in *Science Observed*, K. Knorr and M. Mukay, eds. (Beverly Hills: Sage, 1983), 166.
130. Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed. (Chicago: The University of Chicago Press, 1996), 3.
131. Timothy Ferris, *Coming of Age in the Milky Way* (HarperCollins: New York, 2003), 276.
132. "So habe ich also für ihn dies mein Buch verfaßt und ihn mit etwas beschenkt, womit ich nicht einmal von den Königen und Fürsten beschenkte. Ich habe ihm von der chemischen Kunst auseinandergesetzt, was ihm alle meine andern Bücher über diesen Gegenstand entbehrlich macht, und habe ihm ein kurzgefaßtes, feines Buch über diesen Gegenstand zugeeignet, dessen Titel *Buch des Geheimnisses der Geheimnisse* ist. Es werden mit ihm die Metalle (in ihrem Rang) erhöht durch das, was es vom Verfahren anvertraut, und es vernichtet (das erhöhte Metall) und führt es in den ursprünglichen Zustand zurück. Dieses Verfahren also beschreibe ich." Al-Razi, 6.