

Chapter One

ANALYTICAL OBJECTIVES, OR: WHAT ANALYTICAL CHEMISTS DO

"Unless our knowledge is measured and expressed in numbers, it does not amount to much."
—Lord Kelvin



Chapter 1 URLs

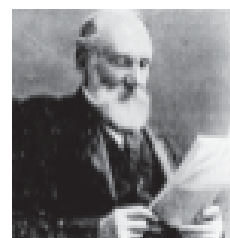
Learning Objectives

WHAT ARE SOME OF THE KEY THINGS WE WILL LEARN FROM THIS CHAPTER?

- Analytical science deals with the chemical characterization of matter—what, how much?, p. 2
- The analyst must know what information is really needed, and obtain a representative sample, pp. 6, 9
- Few measurements are specific, so operations are performed to achieve high selectivity, p. 11
- You must select the appropriate method for measurement, p. 12
- Validation is important, p. 15
- There are many useful websites dealing with analytical chemistry, p. 16

Analytical chemistry is concerned with the chemical characterization of matter and the answer to two important questions: what is it (qualitative analysis) and how much is it (quantitative analysis). Chemicals make up everything we use or consume, and knowledge of the chemical composition of many substances is important in our daily lives. Analytical chemistry plays an important role in nearly all aspects of chemistry, for example, agricultural, clinical, environmental, forensic, manufacturing, metallurgical, and pharmaceutical chemistry. The nitrogen content of a fertilizer determines its value. Foods must be analyzed for contaminants (e.g., pesticide residues) and for essential nutrients (e.g., vitamin content). The air we breathe must be analyzed for toxic gases (e.g., carbon monoxide). Blood glucose must be monitored in diabetics (and, in fact, most diseases are diagnosed by chemical analysis). The presence of trace elements from gun powder on a perpetrator's hand will prove a gun was fired by that hand. The quality of manufactured products often depends on proper chemical proportions, and measurement of the constituents is a necessary part of **quality assurance**. The carbon content of steel will influence its quality. The purity of drugs will influence their efficacy.

In this text, we will describe the tools and techniques for performing these different types of analyses. There is much useful supplemental material on the text website, including Excel programs that you can use, and videos to illustrate their use. You should first read the Preface to learn what is available to you, and then take advantage of some of the tools.



Lord Kelvin (William Thomson, 1824–1907)

Everything is made of chemicals. Analytical chemists determine what and how much.

1.1 What Is Analytical Science?

The above description of analytical chemistry provides an overview of the discipline of analytical chemistry. There have been various attempts to more specifically define the discipline. The late Charles N. Reilley said: "Analytical chemistry is what analytical chemists do" (Reference 2). The discipline has expanded beyond the bounds of just chemistry, and many have advocated using the name *analytical science* to describe the field. This term is used in a National Science Foundation report from workshops on "Curricular Developments in the Analytical Sciences." Even this term falls short of recognition of the role of instrumentation development and application. One suggestion is that we use the term *analytical science and technology* (Reference 3).

The Federation of European Chemical Societies held a contest in 1992 to define analytical chemistry, and the following suggestion by K. Cammann was selected [*Fresenius' J. Anal. Chem.*, **343** (1992) 812–813].

Analytical Chemistry provides the methods and tools needed for insight into our material world . . . for answering four basic questions about a material sample:

- **What?**
- **Where?**
- **How much?**
- **What arrangement, structure or form?**

These cover qualitative, spatial, quantitative, and speciation aspects of analytical science. The Division of Analytical Chemistry of the American Chemical Society developed a definition of analytical chemistry, reproduced in part here:

Analytical Chemistry seeks ever improved means of measuring the chemical composition of natural and artificial materials. The techniques of this science are used to identify the substances which may be present in a material and to determine the exact amounts of the identified substance.

Analytical chemists serve the needs of many fields:

- **In medicine,** analytical chemistry is the basis for clinical laboratory tests which help physicians diagnose disease and chart progress in recovery.
- **In industry,** analytical chemistry provides the means of testing raw materials and for assuring the quality of finished products whose chemical composition is critical. Many household products, fuels, paints, pharmaceuticals, etc. are analyzed by the procedures developed by analytical chemists before being sold to the consumer.
- **Environmental quality** is often evaluated by testing for suspected contaminants using the techniques of analytical chemistry.
- **The nutritional value of food** is determined by chemical analysis for major components such as protein and carbohydrates and trace components such as vitamins and minerals. Indeed, even the calories in food are often calculated from its chemical analysis.

Analytical chemists also make important contributions to fields as diverse as forensics, archaeology, and space science.

An interesting article published by a leading analytical chemist, G. E. F. Lundell, from the National Bureau of Standards in 1935 entitled "The Analysis of Things As They Are", describes why we do analyses and the analytical process (*Industrial and Engineering Chemistry, Analytical Edition*, **5**(4) (1933) 221–225). The article is posted on the text [website](#).

A brief overview of the importance of analytical chemistry in society, with examples that affect our lives, and the tools and capabilities, is given in the article, "What Analytical Chemists Do: A Personal Perspective," by Gary Christian, *Chiang Mai Journal of Science*, 32(2) (2005) 81–92: http://it.science.cmu.ac.th/ejournal/journalDetail.php?journal_id=202

Reading this before beginning this course will help place in context what you are learning. A reprint of the article is posted on the text website.



What Analytical Chemists Do

1.2 Qualitative and Quantitative Analysis: What Does Each Tell Us?

The discipline of analytical chemistry consists of **qualitative analysis** and **quantitative analysis**. The former deals with the identification of elements, ions, or compounds present in a sample (we may be interested in whether only a given substance is present), while the latter deals with the determination of how much of one or more constituents is present. The sample may be solid, liquid, gas, or a mixture. The presence of gunpowder residue on a hand generally requires only qualitative knowledge, not of how much is there, but the price of coal will be determined by the percent of undesired sulfur impurity present.

Qualitative analysis tells us what chemicals are present.

Quantitative analysis tells us how much.

How Did Analytical Chemistry Originate?

That is a very good question. Actually, some tools and basic chemical measurements date back to the earliest recorded history. Fire assays for gold are referred to in Zechariah 13:9, and the King of Babylon complained to the Egyptian Pharaoh, Ammenophis the Fourth (1375–1350 BC), that gold he had received from the pharaoh was "less than its weight" after putting it in a furnace. The perceived value of gold, in fact, was probably a major incentive for acquiring analytical knowledge. Archimedes (287–212 BC) did nondestructive testing of the golden wreath of King Hieron II. He placed lumps of gold and silver equal in weight to the wreath in a jar full of water and measured the amount of water displaced by all three. The wreath displaced an amount between the gold and silver, proving it was not pure gold!

The balance is of such early origin that it was ascribed to the gods in the earliest documents found. The Babylonians created standard weights in 2600 BC and considered them so important that their use was supervised by the priests.

The alchemists accumulated the chemical knowledge that formed the basis for quantitative analysis as we know it today. Robert Boyle coined the term *analyst* in his 1661 book, *The Sceptical Chymist*. Antoine Lavoisier has been considered the "father of analytical chemistry" because of the careful quantitative experiments he performed on conservation of mass (using the analytical balance). (Lavoisier was actually a tax collector and dabbled in science on the side. He was guillotined on May 8, 1793, during the French Revolution because of his activities as a tax collector.)

Gravimetry was developed in the seventeenth century, and titrimetry in the eighteenth and nineteenth centuries. The origin of titrimetry goes back to Geoffroy in 1729; he evaluated the quality of vinegar by noting the quantity of solid K_2CO_3 that could be added before effervescence ceased (Reference 4). Gay-Lussac, in 1829, assayed silver by titration with 0.05% relative accuracy and precision!



Robert Boyle coined the term "analyst" in his book *The Sceptical Chymist* in 1661.



Antoine Lavoisier used a precision balance for quantitative experiments on the conservation of mass. He is considered the "father of quantitative analysis."