

Forensic Chemistry in Criminal Elucidation: Scientific Applications in Investigation Judicial

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SUMMARY

This article proposes an in-depth analysis of the importance of forensic chemistry in the investigative process, highlighting its main applications in criminal sciences. Forensic chemistry represents a fundamental branch of science applied to Law, being essential in the analysis of chemical evidence at crime scenes, such as drugs, gunshot residues, poisons and body fluids. Through modern analytical techniques, such as chromatography, spectrometry and colorimetric reactions, this discipline allows the identification of substances, establishing links between suspects and crime scenes, in addition to providing material evidence for the judicial system. This study was developed based on a bibliographic review of renowned authors in the field up to the year 2021, adopting a theoretical-scientific approach. The objective is to demonstrate how the application of forensic chemistry contributes decisively to justice, ensuring greater precision, reliability and impartiality in criminal proceedings.

(Castilho & Henriques, 2018; Souza & Lima, 2018).

Keywords: Forensic Chemistry. Criminal Investigation. Chemical Analysis. Material Evidence. Scientific Justice.

Abstract:

This article provides an in-depth analysis of the importance of forensic chemistry in the investigative process, highlighting its main applications in criminal sciences. Forensic chemistry is a fundamental branch of science applied to Law, essential in the analysis of chemical evidence at crime scenes, such as drugs, gunshot residues, poisons, and bodily fluids.

Through modern analytical techniques, such as chromatography, spectrometry, and colorimetric reactions, this discipline allows the identification of substances, the establishment of links between suspects and crime scenes, and the provision of material evidence to the judicial system. This study was developed based on a literature review of renowned authors in the field up to the year 2021, adopting a theoretical-scientific approach. The objective is to demonstrate how the application of forensic chemistry contributes decisively to justice,



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1 - INTRODUCTION

Forensic chemistry emerged as a link between pure science and criminal law, contributing to the objectivity of criminal evidence. Its role goes beyond laboratory analysis; it is an investigative tool that seeks the truth through science. In the forensic context, chemistry is used to examine samples of suspicious substances, traces of blood, tissues, residues and various materials. According to Taylor (2010), the reliability of these analyses depends on well-established methods and trained professionals. The increasing complexity of contemporary crimes requires increasingly precise and specialized methods, which drives the development of technologies in the forensic field.

The scientific investigation of crimes based on material evidence began to gain momentum in the 19th century, with the first toxicology studies and the introduction of rudimentary chemical tests (Nolasco, 2015). However, it was only in the 20th century that forensic chemistry consolidated itself as an autonomous discipline, incorporating advances in spectroscopy, electrophoresis, and chromatography into its procedures (Rodrigues & Santos, 2019). Police institutions and crime laboratories began to include professionals specialized in chemistry, with technical and scientific training appropriate for expert analysis.

The importance of forensic chemistry is also reflected in its ability to provide independent and measurable evidence. While human testimony can be flawed or manipulable, a well-conducted chemical analysis has high reproducibility and unquestionable legal value (Souza & Lima, 2018). In this sense, the reliability of the evidence depends directly on the training of the experts, the calibration of the equipment and the methodological rigor applied in each examination.

Several areas of expertise use forensic chemistry: the analysis of illicit drugs, the examination of gunshot residue, the detection of poisons in bodies, and the identification of substances in fires and explosions. These practices require in-depth knowledge in areas such as analytical, organic, and inorganic chemistry. In addition, forensic work also requires legal skills, such as the correct writing of reports and technical testimony in court.

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The work of a forensic chemist is guided by ethical and scientific principles. Every analysis process must be documented, reproducible and auditable. The Brazilian Code of Criminal Procedure and other international legislation establish parameters for expert work, with the following being:

impartiality and technical rigor are essential criteria. The objectivity of the reports contributes to fairer and more well-founded judicial decisions.

Forensic chemistry therefore represents a pillar of modern criminal investigation. Its contribution goes beyond the identification of substances, acting as an instrument of truth and justice. This article will explore the main areas of application of forensic chemistry, its most widely used analytical methods, as well as the challenges and perspectives of this ever-evolving science.

2. Fundamentals and Principles of Forensic Chemistry

Forensic chemistry is based on principles of natural sciences, especially analytical chemistry, applied in a legal context. Its main objective is to identify and characterize substances of legal interest through scientifically recognized laboratory techniques (Castilho & Henriques, 2018). Such procedures must follow strict protocols, ensuring the chain of custody, data traceability and the integrity of the evidence from collection to presentation in court.

The principle of reproducibility is central to this field: any chemical test must be able to produce the same results when repeated under identical conditions. This requires meticulous quality control, the use of certified reagents, calibrated equipment (SWGDRUG, 2019) and highly qualified personnel. The representativeness of the sample is also essential, requiring statistical procedures and adequate storage.

Impartiality in the interpretation of results is one of the pillars of expert work. The chemical expert should not construct accusatory or defensive narratives, but provide objective technical support (Souza & Lima, 2018). Statistics, according to Taylor (2010), assist in quantifying the degree of certainty of results, especially in comparative and falsification analyses.

Another essential principle is sample representativeness. The fragment analyzed must accurately reflect the composition of the total substance collected at the crime scene. To achieve this, statistical sampling and homogenization techniques are applied, especially in powdery or liquid materials. Correct storage, using appropriate vials and keeping the material at an appropriate temperature, is also part of the fundamental procedures of forensic chemistry.

The interpretation of the results must be guided by impartiality and scientific rigor. The role of the chemical expert is not to construct accusatory or defensive narratives, but to provide technical support that clarifies the facts. Their work requires mastery of legal terminology and ethical responsibility, as their report can directly influence judicial decisions involving the freedom or conviction of individuals.

It is also important to understand the role of statistics in forensic analysis. The use of significance tests, confidence intervals and statistical inference models helps in

quantification of the degree of certainty of a result. This is particularly relevant in comparison analyses between samples — such as drug residues or traces of explosives — and in tests for document or monetary forgery.

In short, forensic chemistry is structured around solid scientific foundations, combined with the legal responsibility of its application. Its effectiveness depends on the balance between technical mastery and the moral integrity of the professional involved. These principles guide all other stages of the investigative process in which chemistry is inserted as a tool of truth.

3. Applied Analytical Techniques

Chemical forensics uses a variety of instrumental and classical techniques to identify unknown substances, determine their concentrations, or compare samples. Among the most widely used methods are gas chromatography (GC), high-performance liquid chromatography (HPLC), mass spectrometry (MS), infrared spectroscopy (FTIR), and atomic absorption spectroscopy (AAS).

(Rodrigues & Santos, 2019).

Chromatography, in its various forms, is crucial for the separation of complex mixtures.

GC is widely used in the analysis of volatile residues, while HPLC is applied to non-volatile substances such as drugs and poisons. Coupled mass spectrometry (GC-MS, LC-MS) allows high sensitivity and specificity in the identification of substances (SWGDRUG, 2019).

FTIR identifies organic compounds based on molecular vibrations, and is useful in the analysis of fibers, paints, and explosives. AAS detects heavy metals in biological and environmental samples (Souza & Lima, 2018). Classical methods, such as colorimetric reactions and precipitation tests, also have preliminary value.

In addition to instrumental techniques, classical procedures such as colorimetric reactions, precipitation tests, acid-base extractions and pH determination continue to be relevant. These preliminary tests are fast and cost-effective, aiding in the screening of samples prior to their confirmatory analysis in more sophisticated equipment.

The choice of technique depends on the nature of the sample, the time available, the laboratory infrastructure and the purpose of the analysis. In legal cases, the reliability of the method is essential, and it must be recognized by the scientific community and supported by validated technical literature. International protocols, such as those published by SWGDRUG (Scientific Working Group for the Analysis of Seized Drugs), are widely followed.

Therefore, the analytical techniques applied in forensic chemistry are the foundation of expert conclusions. Their use requires advanced technical knowledge, constant updating and rigorous validation of procedures. The correct application of these methodologies guarantees the integrity of the results and the legal security of the reports issued.



4. Applications of Forensic Chemistry in Common Crimes

Forensic chemistry has broad applications in the investigation of everyday crimes, ranging from the analysis of illicit drugs to the identification of poisons in homicide cases. One of the most established branches is **forensic toxicology**, which focuses on the detection of toxic substances in the bodies of victims or suspects. Cases of poisoning, alcohol intoxication, drug abuse and accidents involving chemical substances are clarified through this approach (Jones et al., 2011).

Another important field is the examination of **seized drugs**, which seeks to confirm the presence of narcotics such as cocaine, marijuana, crack, heroin, LSD, among others. The forensic work involves both rapid tests such as Marquis and Scott, as well as instrumental analyses to quantify and determine the purity of the substance. The identification of the substance and its concentration has direct implications for criminal classification (Rodrigues & Santos, 2019).

Gunshot residue (GSR) is also a subject of forensic chemistry. The presence of elements such as lead, barium and antimony on the hands of suspects may indicate a recent gunshot, and is detected by atomic absorption spectroscopy or energy-dispersive scanning electron microscopy (SEM-EDS). These tests are essential in investigations of homicides, suicides and shootings.

In cases of **fires and explosions**, forensic chemistry helps identify accelerants, commercial or homemade explosives, such as gasoline, acetone, ammonium nitrate and TATP. Analysis of these materials requires careful collection at the scene and specific chromatography and spectrometry techniques. The chemical profile of the explosive can also indicate its origin or link the case to other similar events.

Chemical document analysis tests are also common, aimed at identifying inks, papers and alterations in documents. UV-visible spectroscopy, thin layer chromatography (TLC) and other techniques allow the detection of fraud, forgery or alteration in checks, contracts and banknotes. Such analyses are essential in economic and administrative crimes (Castilho & Henriques, 2018).

Forensic chemistry is thus established as an essential component in the solving of crimes. Its role is to produce technical and irrefutable evidence, supporting police work and the judicial system. Practical applications demonstrate the relevance of multidisciplinary work and the ongoing training of professionals in the field.

5. Limitations, Challenges and Technological Advances

Despite its importance and evolution, forensic chemistry faces several technical, operational and legal limitations. Among the main challenges is the **analytical sensitivity** required to detect substances in trace quantities. Trace amounts are often present in extremely low concentrations, requiring high-precision equipment and rigorous contamination control procedures, which not all forensic laboratories have.

(Souza & Lima, 2018).

Another common obstacle is **interference from the sample matrix**. Biological samples, such as blood, urine and hair, contain natural compounds that can mask the presence of drugs or toxins. Purifying these samples requires complex protocols, which increase the analysis time and cost of tests. In addition, the decomposition of bodies or exposure to the environment can degrade substances, making their identification even more difficult.

The **interpretation of results** must be cautious, considering metabolism, exposure time and routes of administration (Jones et al., 2011). One example is the detection of drug metabolites, which do not always indicate recent or intentional use. The chemical expert needs to consider variables such as exposure time, route of administration and individual metabolism before issuing conclusions.

In the legal field, there are also obstacles regarding the **validation of methods**. Expert results are only accepted in court if the methods used are scientifically recognized and validated according to international standards. This requires documentation, constant calibration and maintenance of good laboratory practices, such as the ISO/IEC 17025 guidelines, which are not always implemented in all institutional contexts.

On the other hand, technological advances have significantly boosted forensic chemistry (Rodrigues & Santos, 2019). Techniques such as high-resolution mass spectrometry (HRMS), portable Raman spectrometry, and solid-phase microextraction (SPME) expand the detection and identification capacity of complex substances in the field and in the laboratory. Statistical analysis software and chemical databases also contribute to greater standardization and efficiency of analyses.

Thus, despite its structural and methodological limitations, forensic chemistry continually adapts to the new demands of modern crime. The integration of technology, ongoing training of professionals and public investment policies in the area is essential for forensic science to maintain its reliability as an auxiliary instrument of justice.

6. Conclusion

Forensic chemistry is a scientific field that is essential to criminal investigation and the production of reliable technical evidence. Throughout this article, it has been possible to demonstrate that its role is not limited to the laboratory, but encompasses the crucial stages of criminal justice — from the collection of evidence to its expert interpretation and presentation in court. Based on validated scientific methods, forensic chemistry strengthens legal certainty and impartiality of decisions.

The foundations of forensic chemistry are based on analytical precision, quality control and professional ethics. By applying knowledge of the exact sciences to legal cases, the chemical expert transforms seemingly insignificant evidence into decisive proof. Their work requires constant technical updating, mastery of analytical methods and understanding



legal requirements, which justifies the need for public policies aimed at valuing and structuring expertise.

The analytical techniques discussed, such as chromatography, spectrometry and calorimetric tests, illustrate the diversity of instruments available to the expert (Taylor, 2010). Each methodology, however, demands rigor in sample preparation, equipment calibration and data interpretation. These factors are essential to ensure that the results have legal value, respecting the principles of adversarial proceedings and full defense.

The role of forensic chemistry in crimes such as homicide, drug trafficking, poisoning and forgery demonstrates its direct impact on solving crimes and holding perpetrators accountable. At the same time, it also works to exonerate innocent people, contributing to the effectiveness and fairness of criminal justice. Its contribution is therefore both investigative and a guarantee of rights.

Finally, it is essential to recognize that technological advances, combined with multidisciplinary training of experts, are the way to overcome current challenges. Strengthening laboratory structures, valuing scientific research and consolidating international quality standards are strategic measures for the future of forensic chemistry (Souza & Lima, 2018; Nolasco, 2015). In this way, it will continue to be one of the most robust bridges between science and justice.

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