Forensic science and fingerprints

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Introduction

This course covers how science can make fingerprints easier to study, how they are used in court and some of the questions about the extent to which fingerprint identification is sound and scientific.

Visible fingerprints can be photographed conventionally but an important scientific problem is how to make 'latent' fingerprints, which are not visible to the naked eye, available for examination. Two scientific approaches are described. The first is the use of chemical change; that is, the transformation of one substance into another, in this case often accompanied by a colour change. The second uses light, and other types of electromagnetic radiation, to interact with the fingerprints and make them visible. The fingerprints can then be photographed, ready to be compared by experts with a database of fingerprints or with fingerprints taken from a suspect. Assuming that a successful match is found, fingerprint evidence can then be used in an attempt at individualisation.

This OpenLearn course provides a sample of level 1 study in Science

Learning Outcomes

After studying this course, you should be able to:

- demonstrate knowledge and understanding of some of the basic facts, language, concepts and principles relating to the principles and significance of fingerprint matching
- demonstrate knowledge and understanding of some of the links between forensic science and the legal system
- draw together information from different sources and make logical deductions as a result
- demonstrate an understanding of how forensic scientists operate and use scientific evidence in a legal context.

1 Introduction to fingerprints

In this section you will learn the principles used in classifying and matching fingerprints (often called 'marks').

Question 1

From your general knowledge, do you know what is special about fingerprints that makes them so useful to forensic science?

Answer

The skin on the ends of human fingers has ridges which form patterns that are unique to an individual.

Question 2

What do forensic scientists mean by 'individualisation'?

Answer

Individualisation is the process of unambiguously connecting a single individual or object to a crime scene.

The use of fingerprints in the identification of criminals is the most frequently applied technique in forensic science. As the main method of establishing identity from traces left at crime scenes, fingerprint matching is currently presented in court in the UK five times more often than is DNA matching. You will learn that fingerprint evidence is usually very sound and is one of the most reliable forms of identification, though there are challenges to its use and human errors can be made. However, these problems and errors do need to be put in the context of the outstanding history of success in using fingerprints in individualisation.

Perhaps the earliest recorded examples of what might today be cited as the forerunners of forensic science appeared in ancient China and Assyria. Thousands of years ago the Chinese and Assyrian people used fingerprints to establish the identity of clay artefacts, and later on documents, by labelling them with a unique and identifiable mark - the finger (or thumb) print.

The Chinese also used thumbprints on legal documents and on criminal confessions. As far as is known this was a simple and informal classification of the fingerprints, rather like a signature. But it is perhaps the first sign of recognition that a person's fingerprints are unique to that person - something that is still considered to be true today and forms one of the foundations of individual identification. The process of 'matching' individuals and things to a crime scene that grew from fingerprint analysis is still the basis of much of forensic science.

Systems for the classification of fingerprints had been developed during the 19th century by several investigators. The discovery that most fingerprints were invisible to the naked eye but could be made visible by the use of powders was also developed during the 19th century. There were disputes about who was first in the field (as often happens in science). In 1892 a cousin of Charles Darwin, Sir Francis Galton, published *Finger Prints* (Figure 1), the first major text on fingerprints and their use in solving crime.

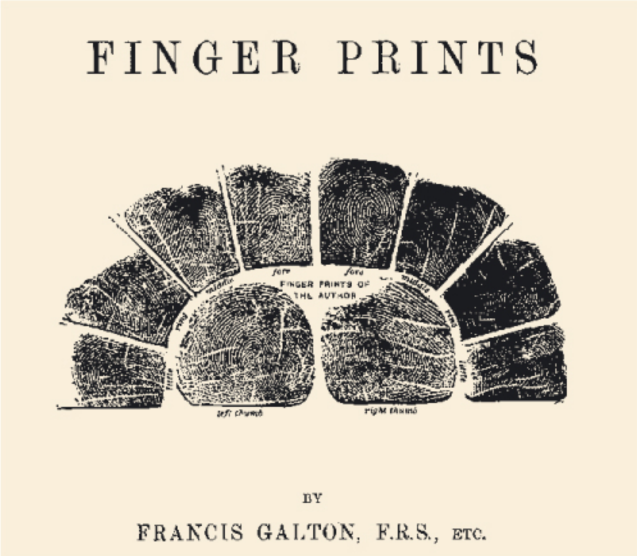

Figure 1 The title page of Sir Francis Galton's book Finger Prints, published in 1892.

Galton, a researcher into heredity, was initially asked to resolve a dispute between two investigators about who had made certain discoveries first. In the process he became fascinated with fingerprints and decided to conduct his own studies that led to his book. In the book, as well as some original insights, he used data and conclusions that had been previously discovered - including the critical one that fingerprints did not change over a lifetime - but he brought it all into one place and established the field of fingerprint use in solving crimes. As a result of Galton's book the British Government in 1894 officially adopted fingerprinting as a supplementary system to visual evidence for the identification of individuals.

Since Galton's days fingerprints have been used all over the world in identification with great success and methods for their visualisation have been constantly improved.

One reason for the enduring usefulness of fingerprints in the administration of criminal justice is that it is very difficult to remove or hide fingerprint patterns. In the 1920s and 1930s in the USA, some prominent gangsters, including the FBI's 'Public Enemy Number One' John Dillinger, attempted to make their fingerprints unrecognisable through self-mutilation. Dillinger had minor plastic surgery to change his appearance and probably at the same time had his finger tips scarred. Sadly for him, enough of his fingerprints remained to enable him to be identified from his fingerprints held on file.

Activity 1: Looking at and taking fingerprints

This activity should take from a few minutes up to an hour or so.

a. If you have a magnifying glass or a hand-lens, you may like to look at each of your fingertips to see the range of patterns in the ridges. You may also like to look at those of another person in the same way and compare them with yours.
b. You may also find it interesting to take your own fingerprints and see what kind of features yours show. It can be messy and if you do not have an inkpad, you can buy kits for children that will suit your purposes very well. The kits can also contain dusting powder, brushes and notes on fingerprinting.

2 Fingerprints in identification

The matching of fingerprint details has actually changed rather little since Galton's day. In images of fingerprints, it is important to remember that the ridges are normally shown in black (or sometimes another colour) on a white or light background. This is the way that dirty fingers leave prints on light coloured surfaces and how inked fingers transfer prints to paper for the storage of fingerprint data, as it is the ridges that touch the surface.

2.1 The use of fingerprints in identification and the classification of fingerprints

The following extract from *Forensic Science* (2nd edition, 2008) was written before July 2007. Since it was written, a new and expanded database has replaced and incorporated NAFIS. The new database IDENT1 continues to do what NAFIS did but has additional services and capabilities. In particular, it combines the England and Wales data with Scottish finger- and palm-print data. Fingerprints can now be matched for the first time across the three countries of England, Scotland and Wales. A new addition is the palm-print database. Scotland had a palm-print database previously but the searchable database including England and Wales only became available in late 2007. It is intended that in the future IDENT1 will encompass a wider range of biometric data such as iris (eye) scans and facial imaging. The information in the below extract concerning the use of fingerprint data is still useful as at present the fingerprint analysis using IDENT1 is essentially the same as it was with NAFIS. The additional palm-print capability is not covered in this course.

Reading 1

Task 1

Please read the following extract from Chapter 4 of *Forensic Science* by Andrew Jackson and Julie Jackson (2nd edition, 2008), which describes the NAFIS fingerprint database; then answer the questions below.

View document

Question 1

1. When is a fingerprint first formed in a person and how does it change throughout a life?
2. What supports the assertion that no two fingerprints are identical?

Answer

1. Fingerprints are formed in the foetus at about 28 weeks. They are formed of 'friction ridge skin' and so do not change throughout life and are maintained for some time after death.

2. The most compelling evidence to date is that no two identical fingerprints have ever been found, despite there being probably hundreds of millions on file throughout the world. Even identical twins who share the same DNA do not have identical fingerprints.

Question 2

1. What are the three most common patterns in fingerprints?
2. In England and Wales there was a system called NAFIS which has now been superseded by IDENT1. Answer the following question assuming that IDENT1 has just incorporated NAFIS without changing the policy on fingerprints. If a person had their fingerprints taken in 2006 in connection with a crime but was not charged or cautioned in connection with the offence, will their fingerprints be on the IDENT1 database?
3. Why do you think that national fingerprint databases need to store '10-print' sets of fingerprints, rather than one or two fingerprints?

Answer

1. The three basic ridge patterns are loops, arches and whorls.
2. NAFIS was a national fingerprint collection for England and Wales holding about 5 million ten-print sets. After 2001 there was no need to remove a person's fingerprints from NAFIS, even if they were not cautioned. As the database has been carried forward unchanged to IDENT1, this does not necessarily mean that such a person's fingerprints will definitely be on the database but there is a good possibility that they will be on it.
3. As no two fingerprints are identical - even those on our own hands - all ten fingerprints must be on file if an individual fingerprint from a crime scene is to be connected to an individual.

2.2 Certainty and uncertainty in identifications by fingerprint matching

You may have gained the impression that fingerprint analysis is almost foolproof and that the experts, whose opinion is validated by other experts, always make an unambiguous identification. By convention, the experts at the moment do give a yes/no answer to questions of the type: 'Can this fingerprint found at the crime scene definitely be associated with individual X and no-one else?' In court their evidence is usually presented as a definite attribution of fingerprints found at the crime scene to a person who has had access to that crime scene. In almost all cases their opinion is unchallenged and the evidence is accepted by both the prosecution and the defence. At various times in the last few years, following errors in fingerprint attributions, there have been calls for the way that fingerprint evidence is presented to be changed away from a yes/no (binary) presentation to a 'probabilistic' system. A probabilistic presentation would attempt to give the probability or odds that a fingerprint was left by a particular person.

Question 3

When a fingerprint is submitted to the national database did the NAFIS system and now IDENT1 give a probability of a match, a single definite match or several possible matches?

Answer

The NAFIS system gave, and now IDENT1 gives, 15 potential matches and the relevant fingerprint expert then analyses all potential matches and states that either one or none of the matches is correct.

In the past in the UK, and in some jurisdictions today, a minimum number of *matching characteristics* needed to be demonstrated to establish a match between two fingerprints. As our ability to visualise fingerprints has become so much greater and use of technology has improved, a mechanical, quantitative measure like '16 matching characteristics' asks as many questions as it answers. Among them is the vital question of whether there are any major *differences* between the prints as well as the matches. The ideal solution is to be able to compare the whole of a print with one on a database with complete reliability. That is not yet completely possible; although the automatic (computerised) matching programs are now very accurate, in the UK, expert opinion on the attribution is always needed in court.

There have been one or two high-profile cases recently where the fingerprint evidence has been shown to be unreliable or wrong and these have raised more generalised concerns about reliability. The following case study illustrates some of the problems.

Case study 1 Shirley McKie: mistaken fingerprint evidence

The very complex case of Scottish ex-police officer Shirley McKie shows some possible consequences for criminal justice if fingerprint attributions cannot be established to the satisfaction of both the defence and the prosecution.

The events started in 1997 when a woman, Marion Ross, was found murdered in her home in Kilmarnock, Scotland. In the subsequent police investigation Detective Constable McKie was assigned to help in the case.

A number of fingerprints were found at the crime scene and at the house of a suspect. The Scottish Criminal Records Office (SCRO) was called in by Strathclyde Police to analyse the prints. A small, decorative tin containing money was found in the home of an early suspect, David Asbury, who had previously done some work for Ross. A latent print on the tin from the suspect Asbury's home was identified as having been made by the victim, Ross. One latent print on a Christmas gift tag from the murder scene was identified as belonging to Asbury (Figure 2). The 16 points of identification (matching characteristics) are shown on each print. You can get an idea of how difficult fingerprint matching is from these prints.

One print from a bathroom doorframe at the crime scene was initially unassigned and SCRO looked at the prints of all those who had potentially been at the crime scene. They claimed a match with a print from DC McKie. However, McKie denied having ever been inside the crime scene, Ross's house.

In the next step Asbury was arrested and charged with murder. The fingerprint evidence tying him to the crime scene (but not necessarily at the time of the murder) was used in the trial. The evidence of Ross's print on the tin found in Asbury's house was critical as he could not explain how it got there and he claimed that Ross had never been to his house. These print attributions comprised the only physical evidence used against Asbury in his trial in 1997. McKie testified under oath that she had not been at the crime scene, even though one of her prints was said to have been found there. The crucial point to note is that those who believed her denial asserted that the rest of the fingerprint evidence was undermined. Despite this Asbury was found guilty and sentenced to life imprisonment.

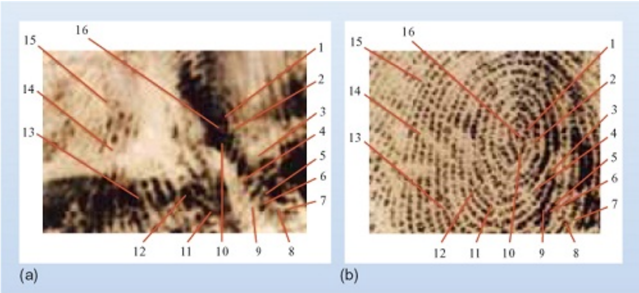

Figure 2 (a) Latent print found on a gift-tag at the crime scene, assigned to Asbury. (b) Known print from Asbury. The 16 matching characteristics are labelled in each print.

In March 1998 McKie was arrested following a dawn raid on her house and she was charged with perjury for denying that she was at the crime scene, despite the apparent fingerprint evidence that she was there. In May 1999 McKie was unanimously found not guilty of perjury in the Scottish High Court of Judiciary. Several fingerprint experts from the USA and England had independently decided that the supposed match between the crime-scene fingerprint and McKie was definitely incorrect and testimony was given in the court to that effect. The Court rejected the SCRO's fingerprint evidence of a match. This marked the beginning of a long battle for McKie who sued her employers over her arrest and in 2003 lost her case and faced costs that almost forced her into bankruptcy. An anonymous donor subsequently paid her costs which allowed her to continue her campaign.

A consequence of the wrong assignment of the fingerprint initially attributed to McKie was that the fingerprint evidence that helped to convict Asbury was now considered questionable by defence lawyers and the question of who left the now-disputed fingerprint at the crime scene was open. It could conceivably have been left by a so-far unidentified killer. Also, was the attribution of Ross's print on the tin certain? Given these uncertainties, Asbury was freed in August 2003 after the judges accepted that fingerprint evidence against him was unreliable. There has been no final resolution of the murder of Ross.

There are many other twists and turns but McKie sued the Scottish Executive (SE) and in February 2006, before the case was heard, McKie accepted £750 000 compensation from the SE in full settlement of her compensation claim, without admission of liability by the SE.

In a report to the Scottish Parliament former Chief Inspector of Constabulary in Scotland, William Taylor, reported that he found that the Scottish Criminal Records Office's fingerprint bureau was not fully effective and efficient after an inspection he carried out in 2000. He told Members of the Scottish Parliament (MSPs) that there was much good work at the SCRO but suggested that there was an introverted culture where experts thought that their way was the best way. He said, 'The way in which you [i.e. SCRO fingerprint experts] were made an expert was not as good as it should have been, the quality assurance processes were not as good as they should have been'.

In February 2007 a Scottish parliamentary report into the McKie case heavily criticised the management of the fingerprint bureau of the SCRO. MSPs were also critical of the justice minister over McKie's compensation deal and in addition they cleared the fingerprint officers involved of acting maliciously. The report concluded that significant weaknesses still need to be addressed. This report may or may not be the end of the story. There are still strong calls for a judicial enquiry into the whole affair.

Question 4

The technical details of the various fingerprint comparisons in the McKie and Asbury cases are beyond the scope of this course. Based upon the extract from Forensic Science you read earlier in the course, what are the features of fingerprints that the experts would have been looking for in a detailed comparison?

Answer

First of all the expert will classify the major pattern as a loop, whorl, or arch. They will then look for categories of loops, whorls or arches. For example, a loop can be radial or ulnar depending on the direction of flow of its ridges. A whorl can have several different forms including a central pocket whorl or a double loop whorl. Arches can be plain or tented. The expert will also try to assign the print to a particular finger - essential when making a comparison with a known print. The next stage is to examine the detailed features or minutiae. There are actually many of these but examples would include ridge ending, bifurcation, lake and short independent ridge.

2.3 Context and potential error in fingerprint analysis

There have been a number of research articles that reveal the potential for personal error in the decisions of fingerprint experts. For example, in 2006 researchers in the School of Psychology at the University of Southampton published a paper in the peer-reviewed journal *Forensic Science International,* in which they presented some fingerprints to experts and asked them to confirm that they did not match a set of reference fingerprints. What the experts were not told was that the prints they were given had previously been positively identified as a match with the reference prints by the experts themselves. In the experiment carried out by the Southampton psychologists, the experts were much less certain of their attributions and most of them contradicted their own previous judgements. The authors of the paper concluded that the *context* of the examination of fingerprints is important in affecting their judgement.

Although the Southampton study was a small-scale one, it illustrates that a process dependent on individual judgement is always going to be subject to some degree of human error. The aim is always to minimise that error and one method is to use other experts to validate the first expert's opinion. The Shirley McKie case (Case Study 1) shows that this is not always foolproof. Although that case is unusual, it is exceptions such as this that help to establish the *scientific* credibility of fingerprint analysis, since learning from errors helps to improve the system. The likelihood of making matches in an unambiguous way is therefore enhanced.

There are people who say that fingerprint matching, when carried out by an expert, is not an example of a scientific method because it is dependent on personal judgement and is based on an assertion that fingerprints are unique that is not subject to the scientific standards of falsifiability. When the matching is completely automated and complex mathematical formulas are used to make the comparison, matching may be accepted by critics as a science. At present the distinction between science and a highly skilled art is of academic interest, but is not likely to challenge the use of fingerprint matching in court or to undermine its usefulness.

Now read Case Study 2 relating to mistaken identification of fingerprints found in connection with the Madrid bombings in 2004.

Case study 2 The Madrid bombings and the mistaken identification of Brandon Mayfield

On 11 March 2004 a series of bombs devastated Madrid, Spain, killing 191 people and wounding 2050. The bombings were widely assumed to be inspired by Al Qaeda but there appears to have been the involvement of several disparate groups and individuals. The trial of 28 accused ran from February to July 2007. At the end of October 2007, the Audiencia Nacional de España delivered its verdicts. Of the 28 defendants in the trial, 21 were found guilty on a range of charges from forgery to murder.

In the early stages of the investigation a blue plastic bag containing detonators was found near the scene of the bombings at a railway station. A print was taken from the bag and the FBI in the USA was sent a digital copy of the print. An American lawyer Brandon Mayfield, who had converted to Islam, was identified by the FBI as a match to the fingerprint. Mayfield was never charged with a crime but was arrested by the US authorities as a material witness with possible information about the Madrid bombing.

Court records reveal the process that led to Mayfield's arrest in May 2004 and his two-week detention in the Multnomah County Jail in Oregon, USA. According to the record, Mayfield's prints were among the best 15 matches found by the FBI fingerprint computer, which holds the prints of some 45 million persons. Those matches were then compared by FBI examiners to the digital image of the partial print sent by the Spanish authorities, who finding 15 matching characteristics concluded that the print was 'a 100 per cent identification' with Mayfield (Figure 3).

Even as the FBI homed in on Mayfield, Spanish authorities were disputing the FBI's fingerprint analysis on the Madrid bag and the identification was not accepted in Spain. An independent fingerprint expert brought in by the FBI appeared, according to the court records, to confirm the FBI's attribution of the print to Mayfield. But Mayfield's lawyer said the expert's report had cautions that were not included in the FBI's affidavit (a sworn statement of evidence or fact that can be used in court without the author necessarily being present).

Although not included in the FBI's affidavit the expert's report included concerns that the quality of the print copy that was received from Spain was poor and that the image possibly included an overlay of another print. The expert said that it was important to see the original image to make a definitive identification.

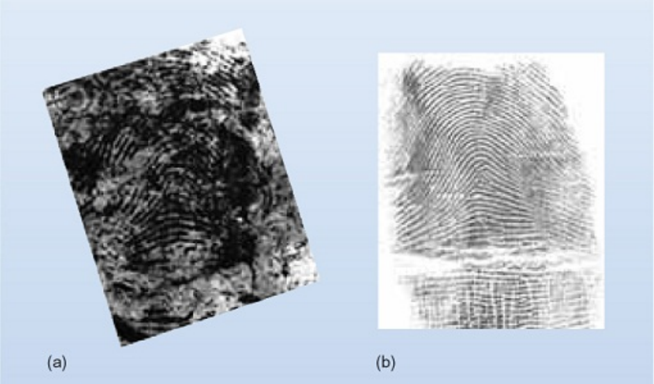

Figure 3 (a) Image of the fingerprint on the plastic bag that was found near the scene of the March 2004 Madrid bombings. (b) Brandon Mayfield's fingerprint.

It was soon recognised that an error had been made and Mayfield was released. The US attorney said the error was regrettable but that as soon as the misidentification came to light, federal authorities 'moved immediately' to have Mayfield released. The US Inspector General's Office (an office within the Department of Justice that can investigate waste, fraud and abuse within the US justice system) released a 273-page report in 2006 on the Mayfield affair. The report acknowledges that there was an 'unusual similarity' between the fingerprints, confusing three FBI examiners and a court-appointed expert. But the report also concluded that FBI examiners failed to adhere to the bureau's own rules for identifying latent fingerprints and that the FBI's 'overconfidence' in its own skills prevented it from taking the Spanish police seriously.

The errors in this case appear to have come from the use of a substandard image combined with elements of human error.

2.4 The use of new technologies in fingerprint matching

The process of matching fingerprints found at crime scenes with reference fingerprints from potential suspects or others known to be present at the scene, is a highly skilled activity. Unambiguous and unchallengeable individualisations are most likely to result from complete, well-defined prints recovered from the crime scene. Problems are more likely to arise when a partial, smudged or otherwise distorted print is left at the scene, as was apparent in the Mayfield case where the initial US attribution of prints was erroneous.

Question 5

The old UK system of requiring 16 matching characteristics to establish identity between a crime scene print and a file (reference) print has now been abandoned and there is no quantitative standard. Can you suggest one or two reasons why that may have happened?

Answer

One particular reason for the change is that a mechanical match of the previous kind does not answer the question of whether there are points of difference (discrepancies) between the prints as well as the matches. Another, related reason is that the formulaic match can give a false sense of certainty when there may in fact be some doubts as to the match. Another reason, which was seen in the McKie and Mayfield cases, is that once a potential match is found the examiner may feel that the job is done and that other possibilities need not be explored.

New methods of image enhancement are being developed. For example, the DCS-3 system is now part of IDENT1. The DCS-3 system comprises a high-resolution digital camera, various light sources and filters and complex software and it can be used to enhance fingerprints in a variety of ways to help the expert to examine the print in more detail. One example is shown in Figure 4 where a latent fingerprint on a vehicle is first visualised by fluorescent light (a) and photographed using DCS-3 (b) and that image is then digitally enhanced to give a final black and white image (c) which is best for detailed examination.

Figure 4 Fingerprint on a vehicle bonnet photographed and enhanced using the DCS-3 system. (See text for details.)

Although these image-enhancing methods are very useful, courts need to be reassured that the enhancement does not materially alter the features of the print. The DCS-3 system has built-in safeguards to ensure accuracy. In the electronic manipulation of the Madrid bombing fingerprint (Case Study 2) some of the detail was apparently lost or obscured, thus compromising the comparison. In all of forensic science the aim is minimum interference with samples left at crime scenes, as every new step introduces potential errors or changes.

3 The development of latent fingerprints

Question 6

Which two methods were mentioned earlier in section 1 for making latent fingerprints visible?

Answer

It is possible to use either a chemical reaction, usually one which produces a colour change, or to use light or another type of electromagnetic radiation to make the fingerprints visible.

To understand these two methods, you will need to know more about electromagnetic radiation. This is detailed in the following sections.

3.1 The electromagnetic spectrum

Electromagnetic radiation is defined as energy in the form of waves that have both electrical and magnetic properties. The electromagnetic spectrum covers a continuous range of wavelengths. The energy of electromagnetic radiation depends on the wavelength of the radiation. The shorter the wavelength, the higher the energy associated with that radiation.

Figure 5 illustrates the range of the electromagnetic spectrum and the uses to which the radiation is put. At the highest energy (shortest wavelength) are gamma rays which are produced during some nuclear radioactive decay processes (including nuclear fission in nuclear weapons). Gamma rays are highly destructive to life and penetrate most matter. At the lowest energy (longest wavelength) in the spectrum are radio waves which are used to transmit radio and television signals across large distances.

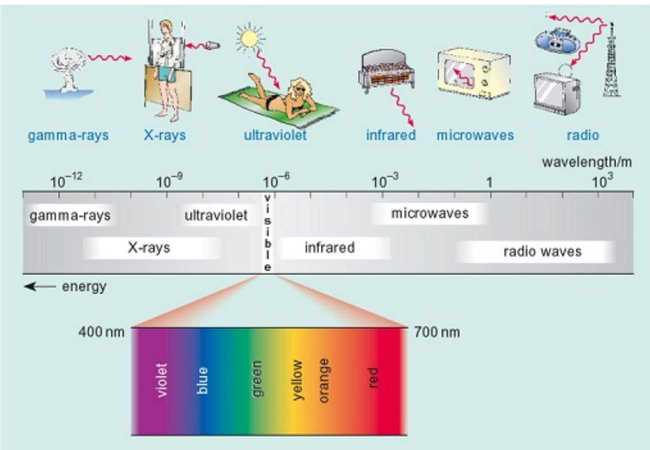

Figure 5 The electromagnetic spectrum.

In Figure 5, the value of the wavelength of the electromagnetic radiation is between about 10^{-12} m and 10^{3} m (i.e. between 0.000 000 000 001 and 1000 metres). Note that the highest energy radiation has the shortest wavelength. Gamma rays (10^{-12} m) are very high energy while radio waves ($1\text{-}10^{3}$ m) are very low energy.

Question 7

Using the information in Figure 5 arrange the following types of radiation in order of increasing *energy* : infrared; ultraviolet; microwave; visible.

Answer

Figure 5 shows that the wavelength of electromagnetic radiation decreases from radio waves, on the right of the figure to gamma rays, on the left of the spectrum. The shortest wavelength radiation has the highest energy. Therefore the energy increases from the lowest energy of the four in the question, microwave, to infrared and then to visible and finally to the highest energy of these, ultraviolet radiation.

3.2 Interactions of light and matter

Light, or visible radiation, interacts with parts of our eyes and is translated by our brains into the perception of colours.

Question 8

Using Figure 5, what is the approximate wavelength of the visible region of the electromagnetic spectrum and which regions lie on either side of it?

Answer

The 'visible spectrum' is radiation with a wavelength of about 500 nm and it lies between the infrared and the ultraviolet regions of the spectrum.

Wavelengths starting at about 7×10^{-7} m (700 nm) are perceived as the colour red. As the wavelength decreases to about 4×10^{-7} m (400 nm), the colour we perceive changes from red through to violet. Daylight is composed of all of the radiation in the visible region, which results in 'white' light.

When light, or any other form of electromagnetic radiation, interacts with any kind of matter, including living matter, the light can be:

- reflected
- absorbed
- transmitted (pass through unchanged)
- absorbed at one wavelength and emitted at another (longer) wavelength.

These phenomena are exploited in many ways in forensic science and analytical science generally. They are especially useful because different materials will interact highly specifically with radiation of different wavelengths.

If you are wearing a blue piece of clothing and are looking at it in daylight, the principles of the scientific use of radiation can be seen. When the daylight (visible radiation) hits your blue clothes, all (or most of) the colours except blue are absorbed (by the blue dye) and the blue light is reflected back into your eyes (Figure 6).

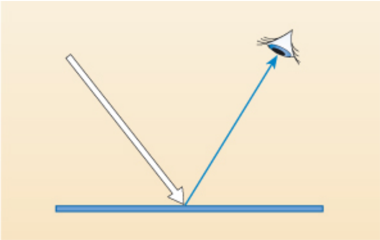

Figure 6 Reflection of light. If white light is directed onto a blue material, all the wavelengths apart from blue are absorbed by the blue dye. The blue light is reflected.

Different-coloured materials absorb and reflect different wavelengths. Consider what happens when a piece of coloured glass is held in front of your eyes.

Question 9

If that coloured glass appears to you to be blue, what do think is happening to the daylight that is falling on it?

Answer

All of the different wavelengths except blue are either absorbed (or possibly reflected back) and the blue light passes through - is transmitted - and is detected by your eyes, as shown in Figure 7 below.

The process by which light is absorbed at one wavelength and emitted at another, longer wavelength is called fluorescence. This principle is used in 'optical brighteners' in washing powders. These emit light in the blue region of the visible spectrum which reduces the appearance of 'yellowing' in white material and the emitted light increases the amount of light reaching the eye, making white garments washed in them appear bright and white.

Question 10

In order that they can emit blue light, which wavelengths will the optical brighteners need to absorb?

Answer

The absorbed light must have a shorter wavelength than visible blue light, which, from Figure 5, is ultraviolet radiation. (You may already know that sunlight contains some ultraviolet (UV) radiation. It is that which causes sunburn if the skin is exposed to sunshine for too long.)

So, by a complex process, the molecules of the optical brighteners absorb radiation in or near the ultraviolet region. Some body fluids can also fluoresce, as you will see later.

These interactions of electromagnetic radiation with matter - reflection, absorption, transmission and fluorescence - are exploited in many ways in forensic science in a set of techniques collectively called spectroscopy.

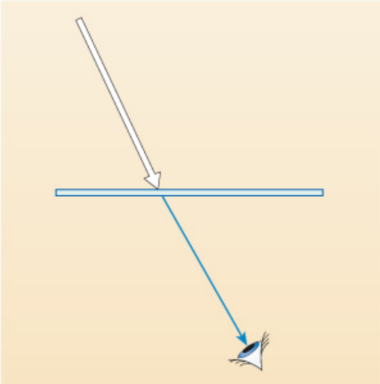

Figure 7 Transmitted light. A transparent material appears blue by transmitted light when all wavelengths are absorbed except blue, which passes through the material.

In spectroscopy, matter is exposed to radiation and the pattern of absorption, transmission, reflection or fluorescence emission of this radiation by the material is measured and interpreted. The patterns obtained can reveal a great deal about the chemical and physical structures of substances.

In fingerprint analysis the observation of fluorescence can be used to visualise some fingerprints that are otherwise invisible to the eye. This technique involves shining ultraviolet radiation onto the sample. Since biological fluids, such as semen, saliva, urine and others fluoresce, and any of these fluids could find their way onto the fingertips that leave fingerprints at crime scenes, an 'invisible' or latent fingerprint may be revealed by fluorescence (Figure 8). It can then be photographed for later comparison with prints from suspects and others.

Figure 8 A fingerprint on a mug has been made visible in fluorescent light. To see the fluorescence clearly it is necessary to work in a dark room using UV light. To avoid damage to eyes from the UV radiation, protective goggles need to be worn.

3.3 Chemical tests

As well as using the interactions of radiation with matter to help in the identification of materials, forensic scientists make extensive use of chemical tests. Chemical reagents are used to produce a chemical change that results in a change of colour, or some other detectable change. A simple test that can give an indication of the presence of a substance is called a *presumptive test.* Presumptive tests are often the first kind of test used in looking for a substance but they do not give definite results of the type needed in court.

If you have ever collected wild, field or horse mushrooms you may know a simple colour test. The poisonous mushroom *Agaricus xanthodermus* can look like a small edible horse mushroom. If in doubt about whether it is an edible variety, mushroom hunters cut the base of the stem or look for the colour when they pull it from the ground. The cut or damaged stem of *Agaricus* turns a bright chrome-yellow (Figure 9). The yellow stain is formed by a chemical reaction between a substance in the mushroom and the oxygen in the air. Field and horse mushrooms do not show a yellow colour when the stems are cut or damaged.

Figure 9 The yellow stain on the stems of Agaricus xanthodermus damaged as they are pulled from the ground.

Box 1 briefly summarises some basic chemical concepts with which you should already be familiar. Read through it quickly and check that you can answer the questions correctly.

Box 1 Some basic chemistry revised

Atoms

Atoms are the building blocks of all chemical substances. An atom contains three components: negatively charged electrons surrounding a positively charged nucleus containing neutrons and positively charged protons. The different types of atom are called chemical elements and each element has its own symbol.

Question 11

What are the names of the elements represented by the following symbols: Ag, Al, C, Cl, Cu, Fe, H, N, Na, O, S?

Answer

They are, in order: silver, Ag; aluminium, Al; carbon, C; chlorine, Cl; copper, Cu; iron, Fe; hydrogen, H; nitrogen, N; sodium, Na; oxygen, O; and sulfur, S.

Molecules: molecular and structural formulas

Molecules are electrically neutral collections of atoms bound together in specific proportions. Each molecule has a particular geometric arrangement of atoms. One way of describing molecules is to use their molecular formula, such as the familiar H_2O for a water molecule. The geometry of molecules can be shown approximately in a structural formula. In water the three atoms are held together by two single bonds (Figure 10). A single bond is composed of two electrons shared between two atoms, holding them together.

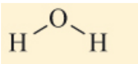

Figure 10 The structural formula of water.

Ions

Molecules are neutral. Ions are charged. The source of all positive ions is the nucleus of an atom which contains one or more protons, each proton in the nucleus having a single positive charge. The nucleus of a hydrogen atom is a single proton, the hydrogen ion, H^+. Negative ions are formed when one or more electrons are added to neutral atoms or molecules. Neutral atoms and molecules have exactly equal numbers of protons and electrons. The electrical charge of an electron is exactly equal in magnitude and is opposite in sign to that of a proton, so in terms of electrical charge an electron neutralises a proton.

Balancing equations

A chemical equation describes a chemical change. A chemical equation has on the left-hand side the formulas of the molecules, atoms or ions that are changed during the chemical reaction - the reactants - and has on the right-hand side the formulas of the new molecules, ions or atoms formed by the chemical change - the products. A balanced equation is one in which there are the same number of atoms of each type on each side of the equation. If there are charges involved, the number of charges also needs to be the same on each side.

Question 12

For the three reactions below, which of the equations are balanced chemical equations?

- $$C + O_2 = CO_2 \quad \text{(Equation 1)}$$

  $$CH_4 + 2O_2 = 2CO_2 + 2H_2O \quad \text{(Equation 2)}$$

  $$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O \quad \text{(Equation 3)}$$

Answer

Equations 1 and 3 are balanced, having equal numbers of C, H and O atoms on each side. Equation 2 with one carbon atom on the left-hand side and two carbon atoms on the right-hand side is not balanced. There are also too many oxygen atoms on the right-hand side of Equation 2. The removal of the 2 in front of the CO_2 will balance the equation.

Two types of chemical change are particularly important in diagnostic tests; these are acid-base reactions and redox reactions.

Acid-base reactions

Acid-base reactions involve water, H_2O. Although most water does exist in this form, a very small proportion of the H_2O molecules break up to form ions, i.e. *ionise*, according to the following chemical equation:

$$H_2O = H^+ + OH^- \quad \text{(Equation 4)}$$

H^+ and OH^- are called ions as they bear an electrical charge. The hydrogen ion, H^+ , is positive. The OH^- ion, called a hydroxide ion, has a negative charge. An acid is a substance that has a greater concentration of hydrogen ions than water. The concentration of hydrogen ions in water is often measured in pH units. On the pH scale, 7 denotes neutral, 0 is very acidic and 14 is very alkaline. An alkali has a greater concentration of OH^- ions than water.

Question 13

The pH of the fluid in a human stomach varies between about 1 and 4. Is the environment in our stomachs acidic or alkaline?

Answer

The environment in our stomachs is very acidic. Any pH less than 7 is acidic.

Chemical substances called bases can react with acids to form new compounds by neutralising the hydrogen ions. This is called an acid-base reaction. You are probably familiar with the use of the term 'litmus test' to mean a diagnostic test that gives a quick answer. Litmus is a substance that in the presence of acids is red and in the presence of hydroxide ions or bases is blue. So dipping a piece of blotting paper impregnated with litmus into a liquid and seeing whether it turns red or blue can be used as a simple test for an acid or base, but other tests would be needed to identify exactly how acidic or basic, i.e. to determine the pH.

In the same way that litmus changes colour when it comes into contact with acids or bases, other substances can change colour when the pH is changed and this colour change can be used in conjunction with other chemical and biological reagents to give colour tests that are diagnostic for particular biological fluids.

Redox reactions

The second kind of chemical reaction that is used extensively in forensic science, and analytical science in general, is the redox reaction. Redox is a contraction of 'reduction and oxidation' and refers to reactions in which one molecule or ion is oxidised and the other reduced. One simple definition of oxidation is the addition of oxygen to a substance. There are lots of examples of an oxidation reaction where oxygen in the atmosphere reacts with something to form a new substance. For example, burning coal, which is carbon, causes it to combine with oxygen to form carbon dioxide (Equation 1) and burning methane gas (CH_4) in air produces carbon dioxide and water (Equation 2). In our bodies, glucose ($C_6H_{12}O_6$) reacts with the oxygen that we breathe in to produce the carbon dioxide that we breathe out and water (Equation 3).

The definition of oxidation in terms of addition of oxygen is not appropriate for all oxidation reactions, and oxidation is better understood in terms of the *loss of electrons.* Rusting of iron metal (Fe) is another familiar example of an oxidation reaction. Here, each iron atom loses three electrons to form an iron(III) (ferric) ion as shown in Equation 5, where the symbol e^- is used to denote an electron and $3e^-$ means three electrons. The symbol Fe^{3+} means that the iron nucleus has three more protons that it has electrons.

$$Fe = Fe^{3+} + 3e^-$$ (Equation 5)

> **Question 14**
>
> If an oxidation is loss of electrons, what do you think a reduction might be?
>
> Answer
>
> A reduction is where something gains electrons, such as that shown in Equation 6 where an aluminium ion is reduced to metallic aluminium. (This is the energy-intensive process used to make aluminium metal.)

$$Al^{3+} + 3e^- = Al$$ (Equation 6)

Another redox reaction, in which the copper atom is oxidised by the silver ion which is correspondingly reduced, is shown in Equation 7.

$$Cu + 2Ag^+ = Cu^{2+} + 2Ag$$ (Equation 7)

What this equation shows in chemical language is that if you dip, say, a copper coin into a solution containing silver ions then the copper atoms are oxidised by losing two electrons and the silver ions are simultaneously reduced with each one gaining an electron. The result is that the copper coin becomes silver plated. This is the principle behind Sheffield plating in which copper items such as candlesticks are coated in silver. A similar principle is used in a technique called 'physical developer', where oily or greasy fingerprints may be visualised by the deposition of metallic silver in a redox reaction (Equation 8).

$$Ag^{+} + e^{-} = Ag \qquad \text{(Equation 8)}$$

Question 15

Is the reaction of the silver ion to form silver metal in Equation 8 an oxidation or a reduction?

Answer

The addition of an electron to the silver ion is a reduction, because the silver has gained an electron.

3.4 Final activities

Finally, before you read the following extract from *Forensic Science* about the ways in which latent fingerprints are developed, there are just a few more terms with which you will need to be familiar.

> Autoradiography is a way of photographing materials that contain radioactivity, so that the parts that are radioactive can be seen.
>
> Polymerisation is the linking together of small molecules to make a long chain of regular repeated segments - a polymer. Polythene, for example, is a polymer of the simple molecule ethane, and polystyrene is a polymer of styrene. Polymers often have very different properties from the simple molecules from which they are composed.
>
> Fat, grease and oil are different versions of similar substances and the words are used interchangeably in the book.

View document

Please complete Activity 2 as you are working through the above extract from Chapter 4 of *Forensic Science* by Andrew Jackson and Julie Jackson (2nd edition, 2008).

Activity 2 Summary of fingerprint visualisation techniques

Download and complete the following table as you read about the different techniques used to make latent prints visible. Once you have finished reading the extract, check your completed table with the version below.

View document

Answer

Click here to see the completed table.

View document

The flow charts in the *Forensic Science* extract you have just read show the sequence of processes that forensic scientists go through when visualising latent fingerprints in blood on porous surfaces and latent fingerprints on non-porous surfaces. Charts like this are critically important for people trying to recover fingerprints from crime scenes. As you see, various different routes can be taken, depending mostly on the type of article being tested, and the tests must be used in the correct order until a sufficiently good print has been recorded.

Question 16

If you were responsible for collecting fingerprint evidence at a major crime scene suggest what methods of visualisation you would choose if one of the likely objects for study was a small fragment of glass, not stained with blood or contaminated with grease.

Answer

The protocols that can be followed for a small fragment of glass, such as from a mirror or window, are shown in Figure 4.7 of the extract you've just read. The first step would be to make a visual examination and photograph the fragment (step 1). If the glass is dry, testing could proceed immediately; if not it would be necessary to let it dry at room temperature (step 2). The glass could then be dusted with a fingerprint powder, such as aluminium powder, and photographed or lifted with special adhesive tape or gelatine lifters (step 7 and p. 99 of the extract). An alternative route, which might be taken since this is a major crime scene where the maximum information possible is needed, would be to shine a laser or high-intensity light on the sample and photograph any fluorescence visible (step 3). If this did not give a good record, then the next step would be to subject it to vacuum metal deposition with metallic zinc or gold, or both. The results of this experiment would also be photographed (step 4). Then the fingerprint powder would be used (step 7). If the glass had needed drying, superglue fuming (step 8) would probably not be a success. Similarly small particle reagent (step 9) is unlikely to be successful since it is best used on wet or waxy surfaces.

Conclusion

- The uniqueness of fingerprints combined with the ease with which they are left on a surface when touched makes them an invaluable aid to those seeking to solve crimes.
- Fingerprints are relatively easy to find at crime scenes and latent prints may be visualised using a logical sequence of tests, some chemical and some physical.
- The chemical tests include oxidation and reduction reactions, called redox reactions, and acid-base reactions.
- The physical methods for visualising latent fingerprints include fluorescence of contaminants induced by illumination with high intensity light or lasers, and the application of powders that adhere to grease or dirt present on the print.
- In general, fingerprint use in identification is very reliable, although every attempt must be made to remove or minimise errors.
- There are various databases of fingerprints. In England, Scotland and Wales the new system IDENT1 was introduced in 2007.

References

Jackson, A. and Jackson, J. (2008) *Forensic Science*, 2nd edn, Harlow, Pearson Education.

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Figure 3: Taken from *Seattle Times*, 7 June 2004

Figure 4: Esther Neate, Neate Imaging Services

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Figure 9: Rogers Plants Limited.

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Figures 4.6 and 4.7 freom Bowman. V. (ed) (2005) Fingerprint Development Handbook (2nd edn.). Reproduced under the term of the click-use library.

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