Examination of clue materials in the Physics Division of a forensic science laboratory

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The application of the methods and techniques of physics to produce evidence - objective and circumstantial - to elucidate pertinent questions/doubts for the judicial and social justice is, in general, termed as Forensic Physics. The methods and techniques of physics have wide and varied applications in the scientific evaluation of a large variety of physical clues of crime. In a general write-up, such as this one, the description of whole range of methods and techniques of physics used in forensic applications of science would be incompatible with its intended use. Hence, an effort has been made here to describe, briefly, the examinations taken up in the Physics Division of a typical forensic science laboratory in India.

The following types of clue materials are examined, in general, in the Physics division:

- Fractured surfaces
- Erased Identification marks
- Tool marks
- Wires, and Cables
- Glass: broken panes/articles, and small fragments
- Soil, Dust, and Dirt
- Paint
- Fabric, and Textile
- Footprint
- Building materials

and other sundry items, which are not entertained by other divisions in the laboratory

Most of the examinations conducted in the physics division are comparative in nature. These are aimed at providing a physical evidence of the presence of a suspect at the scene of crime, or showing that an object which can be linked with him in some other way, was used in the commission of the crime. That is, these examinations establish a relation between the crime and the perpetrator.

Fractured Surfaces

If any thing gets broken or torn into pieces during the commission of a crime, and if one of the pieces is found at the scene of crime and the other can be linked with the suspect, then the fitting together of the broken edges of these pieces may provide the most incontrovertible evidence to link criminal with the crime. The uniqueness of the randomly generated irregular contours of the broken edges can be inferred intuitively or a statistical concept of random breaking to prove the uniqueness of broken edges can be developed. However, computer generated fractal surfaces, as models of evidence physical matches, have also been used to assess the degree of uniqueness of the broken edges in terms of the complexity of the fractal surfaces.

In general, any material that breaks with a randomly irregular edge can provide this type of evidence. The mechanical fitting (like jigsaw puzzle) of randomly broken irregular edges of screw drivers, chisels, pliers, cast metal, door handles, wood, plastics, fabrics, paper, adhesive tapes, idols, bamboo sticks etc. have provided valuable evidences in many cases. It is not uncommon for tools used in burglaries to break during forced entry. Large or small fragments of the tool may, therefore, be found at the scene of crime and prove to be a very valuable piece of evidence. Broken pieces of a tool might also be found inside a lock on which picking or prying was attempted. The converse situation should also be kept in mind, i.e. a broken tool left by the burglar at the scene of crime can be matched with fragments of that tool which may be found in the suspect's home or workshop or in his clothing. In fact, many house burglaries have bean worked out on the basis of physical fits of broken surfaces.

In a case of burglary, the recovered ornaments were found wrapped in a piece of *saree* and a torn *saree* was found in the burglarized premises. The irregular torn sides of the two pieces of the *saree* fitted exactly, which established their source correspondence. The boarder design, weave pattern, and print of the pieces of *saree* were also found to match. In another case of rape and murder, a piece of broken bangle was recovered from the footboard of a bus, during investigation. Broken pieces of bangle were also found at the place where the dead body of the victim was lying. Examination of the design of the bangle and physical fits between the broken pieces showed that the piece recovered from the footboard of the bus originally formed a part of the bangle worn by the victim lady. Similarly, broken lamp glass, broken off door handles, etc. may be left at the scene of a road accident and if the suspected vehicle still carries the corresponding broken part, no further proof of its having been involved is necessary. If the head lamp glass is shattered, a patient matching of pieces from the road and pieces remaining on the lamp may be rewarding. Occasionally, a fixture, which has been attached to a vehicle, machine or a building for a long time, is stolen. It is sometimes possible in such cases to link the fixture found in a thief's possession with its original point of attachment.

Erased Identification marks

Many manufactured items such as bicycles, motorcycles, automobiles, guns, etc. are inscribed with a serial number or a monogram or other inscription for their identification. These marks are effaced or obliterated by the criminals to defeat identification of the stolen property. Generally, the identification marks are obliterated or removed by filing, chiseling, grinding, filling in, painting over or obscuring otherwise.

The identification marks may be of various types, e.g. punched marks, engraved marks, cast marks, painted or printed marks. A majority of serial numbers is punched by stamping the number into the metal by striking a die bearing the number forcibly into the metal with a hammer or a press. The metal crystals in the stamped zone are placed under a permanent strain that extends to a short distance beneath the original numbers. Engraved marks are of two types; those made with an engraving tool (mechanical engraver), and those made with an electric engraver. The first type of mark is found on articles of plate and jewelry, while the second type is used for engraving identification marks on common articles of very hard metals like stainless steel etc. All the engraved marks are made by removing the metal, and the underlying metal is not seriously disturbed. Cast marks are raised above the surface but sometimes are also found to be depressed. They form the part of the mould used in casting and thus appear on the casting. These marks are used to identify the particular casting employed; they do not identify the individual article. The punched, engraved, and cast marks are effaced or obliterated by filing, chiseling, grinding, or filling in. The identification marks may also be made by painting or printing on the surface. Such marks may be obliterated by painting over or by obscuring otherwise. The recovered items of theft are sent to the laboratory for restoration of the incriminating marks.

The restoration of erased punched marks is a matter of routine in a forensic science laboratory. When suitable etching reagent is applied on the surface, the strained zone (beneath the original punched marks) dissolves at a faster rate as compared to the unaltered metal; and thus an etched pattern appears in the form of the original marks. Different metals require different etching reagents. A solution consisting of concentrated hydrochloric acid (120 ml), crystalline cupric chloride (90 gm), and water (100 ml) generally works well for steel surfaces. One may often come across problems of restoration on surfaces like pure metals, aluminum alloys, copper alloys, etc. Copper and aluminum alloys may require different etching solution. Pure metals are more difficult to treat than alloys. The restoration of effaced/obliterated punched mark, depends much on the availability of the zone of strain for etching, if the zone of strain is removed completely the etching does not help. Some times the numerals are restored partially and one can figure out the numbers if the characteristic portions (key points) of the partially restored numerals are legible. Magnetic crack detectors have also been used successfully for the restoration of punched marks in iron and steel. The change in permeability in the zone of strain causes the iron particles (suspension in oil) of the detector to trace out the numbers. The chances of redevelopment of obliterated engraved marks and cast marks are small, since a little or practically no alteration to the metal crystal structure is produced in the process of marking by these methods. However, in the case of electrical engraving, the metal is heated and fused to some extent. The fused area reflects light differently when the surface is polished. Thus, specular reflection at correct angle may show the erased numbers as dark shadow on the bright background. The etching process is of help in the case of engraved marks on plated articles, because preferential etching of the two metals is possible. Most of the time, the erased cast marks are unsuitable for restoration. However, oblique light illumination is of help sometimes, if the numbers are not completely removed. The etching method is useful for the restoration of filled in identification marks also. For the restoration of obliterated painted identification marks, the possible lines of attack are careful treatment with solvents, infrared photography/viewing, ultraviolet fluorescence/photography, shadowgraphy with soft x-ray, and careful grinding off the hard, upper painted surface.

In a case, on receiving the information that a foreign mini bus had been smuggled into India over land and was plying, the officers of Land Customs searched the garage where the bus was kept and the same was seized. According to the owner of the garage the bus was purchased at a sale conducted by the Customs authorities. It was alleged that the original engine and chassis numbers of the mini bus had been changed to those of the vehicle bought in auction. Forensic scientists examined the engine and chassis numbers of the bus. It was discovered that on the original engine number of the bus another number was punched. Chemical etching restored the original number. It was observed that the plate bearing the original chassis number was removed and a new numberplate was fixed on the bus. However, the original chassis number could also be located at another place on the body of the bus. It was established that the bus was different from that sold by the Customs. Thereupon, the Customs confiscated the bus and imposed personal penalties on the owner of the garage.

The identification marks in wood, if made by cutting with a chisel or knife or burnt in with branding iron, cannot be restored when they are erased by removal of the surface. If the marks are punched in, the underlying wood fibers are bent or broken by the punch and can be rendered visible. The simplest and the most effective method of development is to play a jet of steam on to the erased surface. The steam softens the wood and causes the bent fibers to spring back and broken fibers to swell. As a result the mark can be deciphered. Strong alkali also causes the broken fibers to swell. Marks on plastics can often be developed by specular reflection. Treatment with deeply colored solution or dye solution is of much help in the restoration of marks on soft plastics. The erased identification marks on leather are generally restored by cleaning the surface with chloroform and examining it under ultraviolet for fluorescence of paints or under infrared for carbon particles etc. In some cases, the differential absorption of strong caustic soda solution by loose and compressed leather surfaces brings out the erased marks.

The restoration of effaced/obliterated identification numbers or marks on different articles is the exclusive job of an expert. The judgement and experience of the expert plays an important role in the successful restoration. The know-how is important since etching and the treatment with chemicals etc. are once-and-for-all processes in which the mark may appear only fugitively and the use of unsuitable reagents may spoil the chance of success.

Tool marks

When tools like pliers, cutters, jimmy, knife, chisel, drill or hammer, etc. are used on comparatively softer surfaces, they leave their impressions like a fingerprint through which their identity can be established. In a burglary, for example, there may be available the impression of the jimmy used to open a safe, a drawer or a door, Similarly in a wire theft case, the cut-marks of the cutter may be available on the cut-ends of the known and questioned wires.

Tool impressions are produced, generally, by two types of instruments; those which touch the area only once (single stroke or one time application) in producing the impressions, such as an axe, a hammer, or pliers; and those which are used repeatedly (repeated strokes or multiple application) over the same area, like a saw or a file. The impressions produced by instruments in single stroke are further classified as indentations (or compression) marks; and scratch (or friction) marks.

Indentation or compression marks are produced by a single application of the tool in an area of contact; for example, the impression produced as a result of a simple blow of a hammer. The value of these marks lies in the fact that they may reproduce the outline of the instrument edge and reveal its approximate dimensions. For a positive identity of a particular tool, we have to look for an individual flaw or imperfection on the surface of the striking edge and the evidentiary value depends upon the amount and number of such characteristics. Scratch marks or friction marks are found as a series of scratches or striae consisting of grooves and ridges produced by the defects in the edge of the instrument as it moves across or through a softer surface. All edged tools have irregularities that can easily be seen under magnification. Such irregularities are characteristics of a particular instrument.

The importance of a tool mark as evidence lies in its uniqueness. The edge of an instrument, howsoever new, is never completely regular and free from individuality . As the instrument ages, it receives adventitious damage which alters the contour of the edge and increases its uniqueness. Since the edge is unique, the marks produced by the edge are also unique. The tool-marks are examined and compared with the stereo, and comparison microscopes. Test impressions are made in the laboratory with the suspected tool, and the characteristics of the test impressions are compared with those of the impression found at the scene of crime. When the test and the crime impressions match, it is concluded that the same tool made both the impressions. However, it is not always possible to demonstrate this satisfactorily. Sometimes, one may have to be contented by proving that the impression was made by a tool of the type in question.

In a case of theft of copper wire, a large number of wire samples, cutting instruments, and control wire samples were examined. Most of the wire samples were found to be telegraph wire, and the use of a pair of pliers for cutting some of the control and questioned wire samples could be established on the basis of the comparison of tool marks.

For the instruments, which can be applied at various angles with respect to the surface receiving the impressions, a perfect line by line match is rarely obtained. The criteria for convincing match are drawn from experience, common sense, and the law of probability. A satisfactory match is possible if the angles of application in the case of crime and test impressions are within 15 degrees. It is difficult to identify tools via their tool marks, if they produce impressions in repeated strokes. Nevertheless, the tool marks produced by such instruments should be examined and compared carefully. Sometimes characteristic features are observed and it is possible to establish the use of a given instrument in commission of the crime.

Wires, and Cables

The theft of telegraph and traction wires and cables is very common throughout the country. It has become a lucrative trade as there is a large shortage of copper and it fetches handsome money in the black market. Nowadays, steel cored copper or aluminum wires are used but miscreants do not spare these also, as the market value of these metals is by no means less attractive. The telegraph and transmission lines are spread throughout the country and they pass through many remote and not easily accessible areas. The miscreants select such vulnerable places for their activities. The theft of underground cables is also not uncommon. The cable is cut at two points and is pulled out by means of some sort of winding machine. In the course of investigation, control samples are collected (for reference) from the two cut ends of wire at the scene of occurrence; a search is made for the stolen wire, and the cutting tools. The bundles of the stolen wire may be recovered as such or it may be seized at some stage of its usual disposal, e.g. small cut pieces, semi-molten mass containing remnants of wire pieces, or smelted mass.

The control (reference) samples of wire and the recovered samples are examined in the laboratory to establish the commonness of their origin. Such comparison of wires may, sometimes, be involved in the cases of theft of electrical equipment also, if the wires attached to the equipment are cut/snapped by the criminals. The parameters generally studied for the comparison of wires are: diameter, material, electrical resistance, mechanical properties, physical matching of the cut ends, die marks on the surface of the wire, tool marks, and trace element profile. In the case of cables, diameter of the cable with the insulation, structure of the cable, number of strands and core, material of strands and cores, diameter of each strand and core, trace element profile of each strand and core, and nature (material) of the insulation are examined.

The diameter is measured with the help of an accurate micrometer at different places on the wires, and an average in computed for comparison. The density, a physical property that depends upon the composition and also on the manufacturing process, is a reliable parameter for the comparison of material of the wire. However, the chemical composition (quantitative) of the wires may also be determined and compared. The electrical resistance of telegraph and transmission wires and cables is an important parameter, which should invariably be measured and compared. The mechanical properties like tensile strength etc. may also be studied if the facilities are available. In general, the samples referred to the laboratories are rarely suitable for such tests.

If the cut ends of the control and the seized wires match with each other, and a mechanical fit is observed, it proves the continuity of the wires. Such a matching of the ends is generally observed in cases where the wires have been removed by breaking or by partial cutting followed by breaking. In case of cables, the examination of the plastic insulation may also, at times, give good results. In the manufacturing process wires are drawn through die, which imparts a series of striations on the surface of the drawn wires. The prominence and position of the striations on the control and seized wires are compared under a microscope to find out if the two pieces of wire could be parts of one wire. If a cutting instrument is also recovered, it is often required to establish that the wires were cut with the seized instrument. A number of test cuttings are made with the questioned instrument for comparison with the tool marks present on the control (reference) wires. If it is found that the tool marks on the control wires match with those on any of the several test-cuttings, it can be established that the instrument in question had been used to cut the wire. Trace element composition is a reliable parameter to compare the control and questioned wires and to find out their source correspondence. The purity of the metal, and the percentage of the constituents of an alloy are selected and controlled by the manufacturer, but there is no control over the very low concentration impurities (trace elements) which enter the products through the raw materials, processing equipment, and other sources such as supply of air, water, etc. Thus, the population of the trace elements in samples from different sources is bound to differ while the samples from the same source are expected to show a very good correspondence in their trace element profile. The results of trace analysis of the samples, if properly evaluated, may prove the commonness of origin of the samples or otherwise. If molten metal mass is recovered, the trace analysis of the samples is the only way out. However, one must be careful about the possibility of additional impurities introduced in the molten metal during the process of melting the stolen wire. The trace element profile of the wire can be analyzed using various instrumental techniques like Atomic Emission Spectroscopy, Atomic Absorption Spectroscopy, Neutron Activation Analysis etc.

In a case, four pieces of multi-stranded cables (control and questioned) were received for examination. Each sample consisted of seven strands twisted together. On the basis of the physical examinations, and trace element profile of each strand of all the samples, the source correspondence between the control and the questioned cables was established.

Glass

Glass as a physical clue is encountered in various crimes such as burglaries, road accidents, vandalism, assaults, etc. A projectile (stone, bullet etc,) penetrating the window glass produces a familiar fracture pattern in which some cracks radiate outward from the point of impact while others encircle the point of impact. The radiating lines are known as radial fracture (primary fracture), and the circular lines are called concentric fracture (secondary fracture). The secondary ones run between the primaries dividing the broken glass into rough triangles or truncated triangles, the apices of which are directed towards the point of impact. The fractured window glass may reveal information that can be related to the force and direction of impact. Such information may be useful for reconstructing the events of a crime.

If the cross sections of broken pieces of glass are examined, faintly curved linear stress marks will be seen, with their opposite ends nearly asymptotic to one face and perpendicular to the other. These marks are known as rib marks. It is an invariable rule that in radial cracks, the rib marks are asymptotic to the face on which the blow was delivered and perpendicular to the other. In concentric cracks, the rib marks are usually much less clearly developed, but in so far as they are visible, they nearly always run the other way, i.e. they meet the side receiving the blow perpendicularly. These facts often enable one to determine the side from which the window was broken. In certain cases, straight lines are observed in the cross section of the broken pieces of glass. These are called hackle marks. These marks indicate that the fracture is sudden and explosive in nature. The impact surface can be determined by hackle marks as well.

If the glass pane is struck by a small rapidly-moving projectile (say a bullet) and particularly if the glass is fairly thick, some glass will be punched out at the point of impact, leaving a crater shaped hole which is invariably wider on the exit side. Generally, entrance side of the hole is smooth and the exit side is rough due to flaking. Such fractures are known as cone fractures. In the case of a cone fracture caused by a bullet, additional information concerning the direction of impact is given by the distribution of the flaking about the crater. A shot fired perpendicular to a windowpane will give a crater of uniform flaking. If the shot is fired at an angle from the right, the left side of the glass will suffer more flaking than the right side and vice versa.

In the case of multiple fractures on a glass pane, the sequence of impact may be determined because a fracture always terminates at an existing line of fracture. For example; if there are two fractures on a single window pane, the order of occurrence of the fractures may be determined from the fact that the cracks, specially the radial cracks, of the second fracture are interrupted and end-stopped at points where they intersect the cracks of the first fracture.

The most conclusive evidence of the source of a piece of glass is the mere fit of its broken edges in the parent glass. If a match can be found over a reasonable length, e.g., a quarter inch or more, it is a virtual proof that the questioned fragment was broken from the exact spot.

In a case of burglary the window was alleged to have been broken by the intruder. The household goods were heavily insured and the owner filed a claim after completing the formalities. A question was raised whether the alleged break in was genuine or was it fabricated in order to claim insurance by breaking the window from the inside. The broken pieces of windowpane and the window frame having part of the glass pane were sent for forensic examination. All the pieces were carefully and patiently assembled and put together with the help of transparent adhesive tape. The point of impact and the radial and concentric fractures were reconstructed. The cross sections of the radial fractures were examined, where rib marks were observed. The rib marks on the radial fractures showed that the window was broken from in side the room. The point of impact was near the upper latch of the window.

When a sheet of glass is broken, although most of the broken glass travels in the direction of the applied force, many fine chips are thrown backwards also. The phenomenon of backward fragmentation is the source of most of the glass fragments that are available on the clothing of a suspect. Establishment of identity of these fragments with the glass of the broken window may help in identifying the criminal. In addition, if the damage is due to a firearm, backward fragmentation may also help in providing an estimate of the range of firing even beyond the powder range to a limited extent. It may be mentioned here that when a tempered glass breaks it does not shatter but rather fragments into small pieces. This glass is made by introducing internal stress through rapid heating and cooling of the glass surface. This is used, nowadays, for window of cars for safety. The laminated glasses are also in use for many purposes. A layer of plastic is sand-witched between two layers of ordinary glass to make the assembly strong.

The glass fragments are generally examined for their thickness and its variation, color and general appearance, ream patterns, surface patterns, ultra-violet fluorescence, density and refractive index, and other identifying characteristics like trace element profile. The properties, which have been used with fairly universal success for comparison of glass pieces, are density and refractive index. The chance of two glasses taken at random being identical in density is small. The same applies to the refractive index also. The probability of agreement of both density and refractive index of two glass selected by chance is very small, even though these properties of glass are correlated. A rapid method of comparing densities of glass is floatation. The control glass particle is immersed in a liquid; a mixture of bromoform and bromobenzene, the composition of the liquid is carefully adjusted so that the glass chip remains suspended in the liquid. Now, questioned glass piece of approximately the same size and shape as the control is added to the liquid. If both the particles remain suspended in the liquid, their densities are equal. Once the glass pieces are distinguished by density determination, their different origins are immediately inferred. However, comparable density results require comparison of their refractive indices. The refractive indices are determined by Beck line method, by varying the refractive index of the immersion fluid till the Beck line disappears. An effective way to vary the refractive index of the immersion liquid is by adjusting the temperature of the liquid. A special apparatus, known as Hot-stage accomplishes this.

In a hit-and-run case, small pieces of glass found in the clothing of the victim were compared with the glass pieces from a broken parking light of the suspect's car. On the basis of the design present on the surface of the glass pieces, and their densities and refractive indices, they were found to be indistinguishable. It provided corroborative evidence, which led to successful investigation of the case.

If the two samples have comparable densities and refractive indices, further characterization/comparison may be achieved by their trace element profile. Recent advances in analytical capabilities for the trace element characterization of glass fragments have provided a high degree of discrimination between glass fragments that was previously not available. The Inductively Coupled Plasma-Mass Spectrometry, and Energy Dispersive x-ray fluorescence are the techniques of choice today, for such studies. The elemental composition data can also be used for classification of glass samples into their product-use type.

Soil, Dust, and Dirt

The presence of soil at most of the crime scenes and its transferability between the scene and the criminal, makes it a valuable physical clue in the investigation of crime. Soil or dried mud found adhering to a suspect's shoe, pant cuffs, or vehicle when compared with soil sample collected from the place of occurrence of the crime, may provide associative evidence that can link the suspect or object to the scene of crime.

The soil at different points varies in some detectable manner. It varies so much from point to point as compared with its variation from region to region that it is useless to attempt its comparison unless the control (known) sample is collected at almost the exact spot from which the questioned (unknown) sample is thought to have come. Thus, mud on a shoe should be compared with mud from the shoe print, if possible. If the approximate location is known but not the exact spot, it is necessary to collect samples in a definite geometric pattern throughout the small region in question and compare all of them with the questioned sample.

In a case of theft, a portion of the wall in a *cutcha* house was dug to remove ornaments hidden there. A *khurapa* (digging implement) was seized from the possession of a suspect. The soil collected from the *khurapa* was compared with the soil collected from the scene of the theft. The soil samples taken from the two sources were found to be similar. When confronted with this evidence the suspect confessed and the stolen property could be recovered.

The methods generally used to examine soil samples are: macroscopic and microscopic examinations, particle size distribution, loss on ignition and color of ash, turbidity test, density gradient analysis, trace element analysis, differential thermal analysis etc. Generally soil can be differentiated and distinguished by their gross appearance. A side by side visual comparison of the color and texture of soil samples is easy to perform and provides a sensitive property for distinguishing soils from different locations. Low power microscopic examination of soil reveals the presence of minerals, botanical fragments, and other foreign material. Further high power microscopic examination help in characterizing various minerals and rocks present in the sample. Accurately weighed samples of soil are ignited in a furnace (temperature range 500-900°C) to study the loss on ignition and color of ash. After the soils are ashed, they are weighed again to determine the loss on ignition due to the burning of organic material and the loss of combined water in clay. The color of ash is due largely to the iron content and it is affected considerably by the temperature of ashing. For density gradient analysis, the soil samples are dried thoroughly and crushed on a clean plate of glass by means of a rubber stopper to eliminate all aggregates made up of caked soil particles. When the soil is pulverized, it is sifted through a clean 100-mesh sieve on to a clean paper. The fine fraction of the soil, which passed through the sieve, is taken for the density distribution analysis. Accurately weighed sample of the soil is gently placed on the surface of a column of liquid made to have a gradient of density from top to bottom. Each particle sinks down in the liquid until it reaches the liquid fraction where the density of the liquid is equal to that of the particle. Thus, soil particles sink down to their own density zone in the density gradient tube and a particle density distribution is set up. Different samples of same soil show remarkable similarity in density distribution pattern while different soils have markedly different patterns. The density gradient analysis is quite reliable technique for comparison of soil samples. The trace element composition of different soil sample is expected to vary from one sample of soil to another to a considerable extent. Hence, multi-elemental analysis techniques like Atomic Emission Spectroscopy may, at times give significant results. Differential Thermal Analysis may be used to show similarities or differences between, without necessarily identifying chemically, highly complex substances such as clay. When such a substance is heated, physical or chemical changes occur at certain temperatures, and at each change there are energy gains or losses. These will manifest themselves as discontinuities in the otherwise smoothly rising temperature graph of the substance as the heat is applied to it. These changes are recorded and compared.

In a case of murder, the dead body was disposed off in a muddy pond. The accused carried away thick stains of mud on his trouser, which was recovered from his house. The mud from the relevant place in the pond and the mud from the trouser were found to be similar on the basis of macroscopic and microscopic examinations, and the particle density distribution. The accused confessed his association with the crime.

In general, airborne particles, which are macroscopic, microscopic or sub-microscopic in size, are known as dust. It may be very characteristic of a particular place. This applies specially to places such as flourmills, building sites, workshops, coal cellars and the like. A person who has worked at or visited such places carries on his clothes dust characteristic of that place and a close examination of the dust will reveal his occupation or his visit to that place. He may also leave traces in the form of dust from shoes or clothes which are characteristic of him and the same can act as a guide in tracing him. In dust, there could be such particles whose occurrence can be connected directly with a crime.

Laboratory examination of the dust, which is sometimes very tedious and comprehensive, is done first under the microscope. Thereafter, any characteristic particles, if located and separated are examined further by suitable chemical or physical analytical methods. For example, filings and other metallic particles can be easily identified by spectrochemical methods, and the clay minerals can be identified by x-ray diffraction technique.

Paint

As a physical clue material, paint is frequently encountered in hit-and-run, burglary, art forgeries, and other offences. A paint chip or a paint smear may be transferred to the victim or left at the scene of accident, or paint smear could be transferred on to a tool during house breaking. There are numerous possibilities and situations under which a transfer of paint from one surface to another could occur; it may be in the form of chips/flakes, smears or dust. In obtaining control paint specimens, one should attempt to get adequate and representative specimens. It should be borne in mind that the prime consideration is to obtain all the paint layers in their proper sequence. Paint should never be scrapped or shaved from a surface since this may practically destroy layer structure or remove only the top layer.

The methods generally used to examine paint samples are microscopic examination, solubility test, ultraviolet fluorescence, pyrolysis gas chromatography, infrared spectroscopy, and elemental analysis. Questioned and known samples of paint are compared side by side under a stereomicroscope for their color, texture and layer structures, etc. The cross section of paint flakes is examined to determine the number of paint layers, the color of each layer, the sequence of the layers, and the thickness of the layers. Good correspondence of these factors between two paint flakes may be almost positive proof of a common origin, if there are sufficient (say four or more) number of layers. Occasionally, it is possible to prove the absolute identity of the paint flakes by showing an exact fit for the broken edges of the known and unknown paint samples. Similarly, the presence of characteristic markings on the surface of the paint flakes is quite helpful in establishing the identity of the paint flakes.

In a burglary, the entrance was gained by cutting a hole through the back door with sharp instrument. A suspected person was arrested in the vicinity who had in his possession a large knife. Although, it was not possible to prove by tool mark comparison that the knife was the instrument used, a small piece of paint was found adhering to the blade of the knife. This paint compared with the paint on the door of the house, layer by layer. The door had been painted several times. This was very conclusive evidence, as it would be difficult to find another house having a door with such an arrangement of paint layers.

The reaction of paint flakes to a variety of solvents is examined as a screening test. Small quantities of control and questioned paint samples are placed in spot tiles side by side and their reaction to a number of reagents like strong acids and bases, acetone, ethyl acetate etc. are observed simultaneously. Difference in their reaction to the reagents establishes their non-identity. Paints, which are indistinguishable to the naked eye, can often be differentiated by examination under ultra-violet radiation. The minerals or metallic components of paint originally introduced as dryers, pigments, etc. can be determined by instrumental methods of analysis like atomic emission spectroscopy, neutron activation analysis, x-ray fluorescence, and x-ray diffraction. A comparison of inorganic constituents of the paint samples may provide strong evidence of their source correspondence. Pyrolysis gas chromatography is an invaluable technique for distinguishing most of the paint formulations. Paint chips as small as 25 microgram are pyrolysed (decomposed by heat) and sent through gas chromatograph for separation of the constituents and their characterization. It is difficult to identify the products absolutely, but the results show whether the paints have similar formulation or not.

Infrared spectroscopy is another analytical technique, which provides information about the binder composition of paint samples. Binders absorb infrared radiation selectively to yield spectrum that is highly characteristic of the specimen. Paint, in the form of smear or dust is much more difficult to characterize and identify as compared to flake/chip. Nevertheless, modern instrumental analysis techniques may yield definitive results in the case of dust/smear of paint also.

Fabric, and Textile

Fabric and textile as physical evidence may be found at crime scenes, where the criminal happened to tear his clothes in crawling through a broken window and leaving portions of fabrics on the jagged edges of the glass or on a brick projection, etc. The victim of assault may also tear fabrics from the clothes of a criminal. Conversely, the material may originate from the victim's clothing or from a garment, rug or sack, etc, which the criminal used during the commission of the crime. The criminal may deliberately tear a piece of cloth from a larger piece for some criminal act. The fragments of cloth which can be fitted directly to the clothing of a victim or a suspect form a strong piece of evidence and are of great significance.

The attributes examined and compared to determine whether two or more pieces of cloth had a common origin or not, are: dimensions, shape, color, nature of material, pattern of weave, pattern of dyeing, thread count (both in warp and weft), direction of twist of the threads - whether the twist is to the right or to the left, sewing threads (if any), and faults in the structure of the fabric, patches and other repairs, damage, etc. The availability of projection microscopes, and comparators today, have made the comparison of fabrics and textiles much more convenient.

In an investigation of a burglary, a piece of torn cloth was found on the window through which entrance was gained. One of the suspected persons was seen wearing a *dhotee* having a tear. An examination of the cloth found at the scene of crime and the *dhotee* of the suspected person exhibited a very good correspondence between them. When confronted with this evidence, the man confessed and others could be eliminated. In another case, a dead body was recovered from a well. It could go as an accidental fall in the well, but for the suspicious piece of cloth tightly clinched in the fist of the dead. A close examination of the cloth piece divulged that it could be a portion of the sleeve of a shirt. In the course of investigation a shirt with torn left sleeve was recovered from one of the suspects. A detailed examination of the cloth piece found in the fist of the victim and the cloth of the seized shirt revealed their source correspondence suggesting the association of the suspect with the incident.

Impression of cloth may also be found on various objects in different conditions. If a cloth is pressed on an object capable of retaining impressions due to plasticity like mud, wet paint, dust, chewing gum, and similar materials, an impression of the cloth would be made on the object. When located, such impressions should always be photographed immediately. If the original impression can be preserved intact, it is done with all possible precautions against destruction or alteration. Control impression for comparison should be made from the suspected cloth in a manner, which is as nearly the same as possible to the manner in which the questioned impression was made. Thus, an impression in mud is best compared with that in mud, and a paint impression with a paint impression. Cloth impressions on hard surfaces such as fenders or bumpers of automobiles, bullets, etc. differ from those discussed above mainly in one important respect, viz. they are made with considerable force on a non-plastic surface. The force may have the effect of somewhat distorting the weave marks. Preparation of suitable control impressions for comparison is more difficult with this type of impression. Plasticine or clay may be used satisfactorily at times. If this does not give satisfactory impression for comparison, a suitable method is to procure a surface like the one struck, lay the cloth on it, and give it a hard blow with a sand bag or a wooden hammer. Impressions of fabrics have great associative value as evidence.

Footprint

The impressions/prints made by bare foot or footwear are, in general, termed as footprints. The value of footprint evidence is subject to the individual features or points of identity that may be found in the questioned impression. If ridge characteristics and unique features are present in the footprints, these can lead to positive identification. Similarly, impression of well-worn shoes may show flaws, irregularities, worn out design on the sole, nails, patchwork, worn out heel etc. and provide points for positive identification. On the other hand footprints/shoeprints, which show only dimensions and pattern or general shape, can be used only to eliminate a suspect or corroborate some other evidence.

Depending upon the surface on which the prints are made, footprints may be classified as surface footprints or sunken footprints. Surface prints are made on hard surface when the foot is coated with dust, oil, ink, blood etc. Footprints may also be produced on hard surfaces by lifting sticky material from the surface. Sunken prints are made in pliable surfaces like soft clay, mud, loose soil, snow etc. Slightly sunken prints are made in the soil (thick layer of dust) accumulated on hard surfaces for example in the *veranda* of a house.

The methods commonly used for recording/lifting footprints are photography, tracing, lifting, and casting. While photographing the footprint one should ensure that the lens of the camera is parallel to the footprint and the aperture is small (for better depth of field). An identification card/scale should be placed by the side of the footprint. For tracing the surface footprint, a glass (or a celluloid sheet) is held as close to the print as possible. The contour is drawn by sketch pen and the details of crease etc. are carefully traced. Surface prints (made of dust etc.) may be lifted on photobromide paper. The fixed bromide paper is moistened by soaking it in water for a few minutes and is kept with emulsion side down on the print. Uniform pressure is applied on the bromide paper so that the dust particles get attached to gelatin surface. Electrostatic technique is another useful method to lift dusty prints. A black vinyl sheet is placed on the area having the footprint. The vinyl sheet is covered with aluminum foil through which a high voltage is passed. The dust particles of the print get attached to the vinyl sheet. Sunken footprints are lifted by making their cast. The cast is generally made with plaster of Paris. A suitable frame is placed around the impression and a thick solution of plaster of Paris in water is poured slowly to a thickness of about half-inch. A wire gauze piece is placed to reinforce the cast, and the plaster of Paris solution is poured again till the thickness of the cast is about one inch. The cast is allowed to set for about 15 minutes and lifted carefully. It is gently washed in running water to clean the soil etc. adhering to it. Efforts have also been made to make hologram of footprint on rugs, carpets etc. This technique is not yet available for fieldwork however; it would be of immense help whenever it is available for routine work.

Footprints are compared for their dimension, general shape, ridge patterns (if any), toe-marks, crease, phalange, cut marks etc. Similarly shoeprints are compared for their size, pattern on the sole and heel, peculiarities of repair, nails, screws, patches of other material, cuts, holes, tears etc. In most of the cases footprints are supportive evidence. However, it is not very uncommon to have definitive footprint evidence.

In a case of burglary, a few surface (dry mud) shoeprints were found in the *veranda* of the house. These prints had characteristic sole pattern. Of the suspected thieves one was wearing a shoe with the particular sole pattern seen and photographed at the scene of crime. On further interrogation he confessed the crime.

If a series of footprints of the perpetrator are available, one can evaluate the direction line, gait line, foot line, foot angle, principle angle, step length (stride), and step width etc and study his gait (walking) pattern, which can be compared with that of the suspect. In a case of murder a series of footprints were left at the scene of crime. A closer look into the walking pattern revealed a deformity in the right foot, which led to the criminal in the course of investigation.

Building materials

The construction of buildings, bridges, dams, roads etc. is an essential component of development and is a continuous process since beginning of the civilization. Nowadays, cement mortar, and concrete are basic ingredients of building material. Adulterated cement and inferior quality of mortar and concrete are often sent for forensic examinations. Adulterants used in cement are such material, which do not change the color and fineness of the cement significantly. The most common adulterants are fly ash, coal ash, black clay, silt, stone dust etc. Sometimes expired cement is also used for adulteration. The cement used in the construction work may be good but fraudulent contractors may reduce the proportion of cement in the mortar/concrete, for illegitimate gains.

The methods generally employed for cement analyses are microscopic examination, ignition test, analysis of chemical constituents, initial and final setting time, and compression strength test. In the case of adulteration of cement with expired cement; it is difficult to detect adulteration on the basis of the analysis of chemical constituents only because there is no change in the chemical composition. The proportion of cement in the mortar or concrete is calculated from the percentage of silica and lime found in the samples. As is known, the properties of cement depend on phase compositions of clinker and the structure of individual crystal phases. Hence, the x-ray diffraction technique could be quite advantageous for the analysis of cement samples. It can also detect expired cement. The Differential Thermal techniques may also be used for comparison of cement samples.

Miscellaneous items

In addition to the materials described above, lead and wax seals, paper, camera and photo related material, ropes, strings, tyre marks and skid marks, electric meter, gas cylinders, locks and keys, electrical appliances and devices, suspicious parcels, metals and alloys, counterfeit coins, gems, idols, railway tracks, debris of explosion, spurious products, etc. are referred to the physics division for forensic examination. The forensic physicist employs different physical/chemical methods and instrumental techniques to answers relevant questions. At times, experiments are conducted in the laboratory to simulate and reconstruct the events. Knowledge, skill, and experience of the scientist play a great role in the examination of sundry items referred to the physics division.

In an alleged theft of goods from a railway wagon, security seals (control and questioned) were referred to for forensic examination. The shape, size and the seal impressions on both the sides of the questioned seal were examined and compared with those of the control seal. These general features could establish a close similarity. In addition to the general feature akin-ness some fine striations were also observed on the surface of all the seals, questioned as well as control. These striations on the questioned seals were compared with those on the control seal under a comparison microscope. The striations matched well. Then the questioned seals were cut open to examine the inner surfaces for any sign of manipulation such as scratch marks etc. No evidence of observed to suggest any tampering of the seals. Thus, the security seals on the wagon in question were found to be genuine and intact, and the allegation of theft was found to be incorrect.

The evidential and associative values of the opinion expressed in comparative studies depend upon the nature of exhibits (samples) and the associated circumstances in the case, and vary from case to case. In many cases, even the classical and conventional methods of examinations like mechanical fits of the pieces of a broken object, layer structure of paint samples, tool marks, etc. lead to definite identification and source correspondence. The use of modern sophisticated analytical instruments/techniques like Chromatographic techniques, Gas Chromatograph-Mass Spectrometry, Inductively Coupled Plasma-Mass Spectrometry, Neutron Activation Analysis, Fourier Transform-Infrared spectrophotometry, Scanning Electron Microscopy-Energy Dispersive X-ray analysis, X-ray Micro Fluorescence, X-ray Diffraction, Digital Image Processing, and Pattern Recognition techniques have enhanced the chances of positive identification and definite source correspondence between the crime and known exhibits. Recent trends in the use of statistical methods of interpreting analytical results and creation of reliable data bases for various attributes of different materials would lead to quantitative estimates of evidential values for the propositions which are difficult to interpret today.