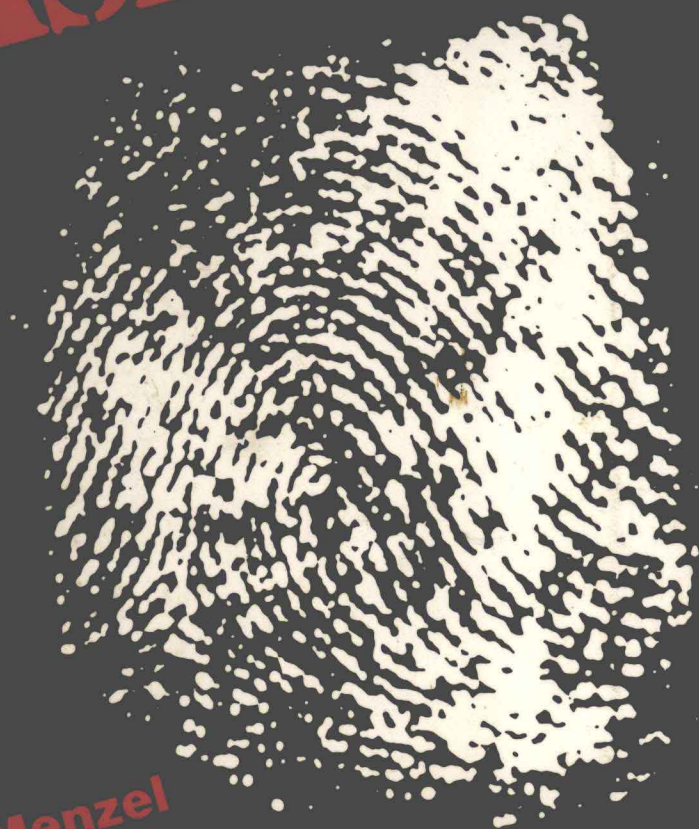# FINGERPRINT DETECTION WITH LASERS

E. Roland Menzel

Fingerprint Detection With LASERS

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PREFACE

The application of lasers to detection of latent fingerprints, initiated in 1976, has already become instrumental in a number of criminal investigations and can be anticipated to develop into a highly valuable forensic tool. Indeed, several law enforcement agencies now use lasers for latent fingerprint detection, and others are in the process of acquiring lasers for this purpose. Court cases involving laser-detected latent prints are presently pending. Two manufacturers in the United States now offer laser systems specifically designed for fingerprint detection.

This text aims to provide forensic researchers and investigators with a guide to both established and potential uses of lasers and optical spectroscopy in forensic identification. Forensic analysts will benefit from having the available information on the current state of laser detection of latent prints collected in one text, rather than having to search the scattered, and often terse, research literature. A text at this stage is timely, since lasers and spectroscopic instrumentation are expensive, so that some forensic laboratories may be reluctant to consider acquisition of this machinery unless cognizant in detail of its already demonstrated as well as potential utility.

Optical spectroscopic techniques are valuable in optimizing the sensitivity of laser detection of latent prints. In discussing optical spectra, the principles of operation of lasers, etc., it is necessary to deal with quantum mechanical aspects in order to gain fundamental insight. Chapter 1 approaches this in a highly simplified form. The chapter is designed to give the reader, who in the majority of cases will likely have little formal training in the physical sciences, some appreciation of the nature of atomic and molecular spectra. Luminescence is particularly emphasized, since it is the crux of laser detection of latent prints. A description of the principles of laser operation is also provided. For readers who want a more thorough treatment of the sub-

ject, supplementary references are given at the end of the chapter. A major aim of Chapter 1 is to acquaint latent print examiners with the basic physical principles underlying laser detection of latent prints, since questions about these principles can be anticipated to arise during court testimony.

While there are a number of ways in which lasers have already been used in forensic work, a great deal of research has yet to be undertaken if lasers are to be exploited to their full potential in forensic analysis. Such research will often require measurement of absorption, luminescence, and luminescence excitation spectra. Chapter 2 describes the general features of instrumentation for measurement of such spectra. Since an extensive treatment of a large variety of spectroscopic techniques is beyond the scope of the text, the description of instrumentation is restricted to a flexible and cost-effective modular spectroscopic system whose components can be rearranged for a variety of tasks. The system, while specifically geared for use in latent fingerprint luminescence studies, is useful for optical spectroscopy on a much wider scope. Readers who wish to approach the utilization of lasers in forensic work pragmatically and who do not engage in research should be able to ignore parts of Chapters 1 and 2. Some readers may find it helpful to glance at Chapters 3 and 4 prior to reading Chapters 1 and 2.

The specific application of lasers to the development of laser fingerprints is discussed in Chapter 3. Latent print detection by inherent fingerprint luminescence is discussed and a variety of latent print treatments which lead to laser-detected luminescence are then described. Case applications which provide a measure of the power of several classes of procedures are presented. Laser detection via inherent luminescence requires *no* physical or chemical treatment of the exhibit under scrutiny. Latent print treatments yielding luminescence use procedures analogous to or identical with conventional methods and, at the same time, take advantage of the great detection sensitivity lasers can provide.

The use of optical spectroscopy in latent fingerprint detection by laser is described in Chapter 4. Measurements discussed in this chapter serve two purposes: optimization of detection sensitivity and investigation of the nature of luminescers in fingerprint residue. Filters needed to optimize detectability are explicitly treated, since correct filter selection is often critical to laser detection of latent prints. Finally, Chapter 4 briefly considers a number of potential uses of lasers and optical spectroscopy in forensic work.

Any user should be familiar with the operation and maintenance of argon-ion lasers. This subject is briefly addressed in Chapter 5. It is intended to supplement instruction manuals for lasers, and only considers the most salient features of laser operation and maintenance.

The research which forms the basis for this text was undertaken at the Xerox Research Centre of Canada. I am greatly indebted to Michael L. Hair (XRCC) for a critical reading of the manuscript, a number of very helpful suggestions, and for interceding on my behalf with Marcel Dekker, Inc.

In return for royalties, Xerox Research Centre of Canada has underwritten the production of the color photographs of the text.

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CONTENTS

1 LIGHT, SPECTRA, AND LASERS

In 1976, development of a method for detection of latent finger-prints, using a continuous wave argon-ion laser, was initiated at the Xerox Research Centre of Canada. In the early stages of this development, the detection of latent prints proceeded primarily via their inherent luminescence [1]. In a nutshell, detection amounted to illumination of exhibits by Ar-laser light and observa-tion through suitable filters of luminescence from latent finger-prints. These prints, once observed via their luminescence, were photographed, again through appropriate filters. Even at this stage the method sparked sufficient interest by several law enforcement agencies to cause them to acquire Ar-lasers for fingerprint work. Since then, a number of procedures for laser detection of latent prints which are not amenable to detection by inherent lumin-escence have been developed [1–5]. These procedures entail treatments of exhibits which yield laser-detected luminescence. Often such treatments are analogous to conventional ones. At the same time, they take advantage of the greatly enhanced detection sensitivity lasers and luminescence photography can provide. For instance, luminescent dusting powders can be employed. If a dusted print is not observable in room light, then laser examina-tion may bring out the elusive ridge detail. Similarly, chemical reagents analogous to ninhydrin can be used.

   The luminescent materials in fingerprint residue or the treat-ment compounds which give rise to luminescence are organic molecules in most instances. We will, therefore, largely confine our attention in this chapter to organic molecules. The organic mole-

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cules of interest to us are usually comprised of at least tens of atoms, such as carbon, hydrogen, nitrogen, and oxygen, which are linked together by chemical bonds. The detection of latent finger-prints by laser amounts in essence to incidence of light on such molecules, absorption of this light by them, and subsequent emission of light different in color from the incident light by them. Molecules require illumination with light of well-defined colors if luminescence is to be obtained. The luminescence also is of a specific color. For luminescence to occur, light must first be absorbed by these molecules. The determination of the light colors which are best suited for absorption is done by absorption or luminescence excitation spectroscopy. The determination of the colors of luminescence is performed by measurement of lumin-escence spectra. Absorption, excitation, and luminescence spectra are necessary, at least in the research stage, if laser detection of latent prints is to be exploited to its maximum sensitivity. For example, the fingerprint luminescence color, as compared to the color of background luminescence, which often occurs, dictates the kind of filter(s) necessary for best photographic contrast. As will be seen in Chapter 4, spectroscopic techniques can also permit one to locate latent prints which are too weak to be seen by eye under the laser. Once located spectroscopically, such prints can be photographed. This chapter deals with the nature of light, fea-tures of light absorption and emission by molecules, and, finally, the principles of operation of lasers. The chapter is partly designed to provide background which will allow latent print examiners to field questions one might expect to arise during court testimony about the physical principles involved in laser detection of latent prints.

In a fundamental sense, insight into the nature of atomic and molecular spectra, into the principles of operation of lasers, indeed into the very nature of the light absorption and emission processes, requires a "quantum mechanical" approach. Unfortunately, quan-tum theory, by which the interpretation of atomic and molecular spectra is made, entails a great deal of mathematical complexity and conceptual difficulty. This text assumes that most readers will

not have much formal training in the physical sciences. Quantum mechanical aspects of spectra are therefore described in a highly simplified form. The purpose of this description is largely to provide a "flavor" of the nature of atomic and molecular spectra (since laser detection of latent prints is in essence luminescence spectroscopy) and to delineate some of the terminology which recurs in the text and, for that matter, throughout the spectroscopic literature. Readers who want an in-depth understanding of atomic and molecular spectra are referred to the supplementary references at the end of the chapter.

1.1 LIGHT

One usually thinks of light as wavelike in nature. The wavelike nature of light is demonstrated, for instance, by the phenomenon of diffraction (light bending, as in the passage of light from air into water). Waves can be of several types. Sound waves, for example, are characterized by back-and-forth vibration of molecules in the direction of propagation of the sound wave. Molecules can also vibrate in a direction perpendicular to the direction of propagation of waves, as in water waves. Finally, there are electromagnetic waves, such as radio waves. Let us briefly consider the nature of electromagnetic waves in some detail. Electric charges have an electric "field" around them by which opposite charges are attracted and like charges are repelled, just as magnets have a magnetic field by which opposite magnetic poles are attracted and like magnetic poles are repelled. Movement of electric charge causes a magnetic field to be set up (which is how electromagnets operate). Electric and magnetic fields have magnitude (strength) and direction. Suppose, for example, we have two opposite charges vibrating periodically against each other. This causes the electric field between them to oscillate in strength and direction. It also produces an oscillating magnetic field which has a direction perpendicular to the electric field at every point in space. The thus produced electromagnetic oscillation propagates as a wave through space with a constant velocity of 3×10^8 m/sec. We will use ex-

ponential notation in this text: $3 \times 10^8 = 300,000,000$ (eight zeros). Radio waves and microwaves are examples of electromagnetic waves. In addition to speed, waves are characterized by wavelength and frequency. If one were to measure the strength and direction of the electric field at a single time at various points along the direction of propagation of an electromagnetic wave, one would find a pattern of the electric field as shown in Figure 1.1, where field direction is denoted by arrow direction and field strength is denoted by arrow length. The distance between crests of this sinusoidal wave pattern is the wavelength. If, instead, one were to sample the electric field strength and direction at a single point in space, but at various times, one would again obtain a pattern as in Figure 1.1, but with distance scale replaced by time scale. The interval between crests would now denote the frequency with which crests occur, i.e., how many times per second the wave crests at a given point. The speed, c, the wavelength, λ, and the frequency, ν, are connected by the relation

$$c = \lambda\nu \qquad\qquad\qquad (1.1)$$

Since the speed of the wave is a known constant, it suffices to determine either the wavelength or the frequency to specify the main characteristics of a wave. Light waves are electromagnetic waves, identical in nature to radio waves or microwaves, differing from them only in wavelength and frequency. The speed of light propagation, c, is again 3×10^8 m/sec. The most important fea-
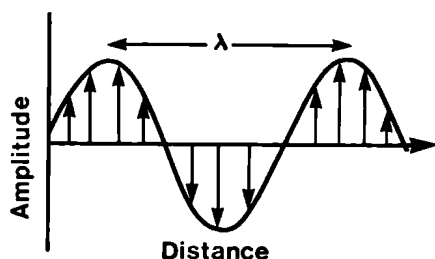

Figure 1.1 Schematic representation of an electromagnetic wave. Vertical arrows denote electric field strength by their length and electric field direction by their direction.

ture of a light wave, namely its color, is customarily specified in units of wavelength rather than frequency. The usual units of light wavelength are microns (or micrometers), μm, angstroms, Å, or nanometers, nm. Values of these units in terms of meters are

$$1 \ \mu m = 10^{-6} \ m$$
$$1 \ \mathring{A} \quad = 10^{-10} \ m$$
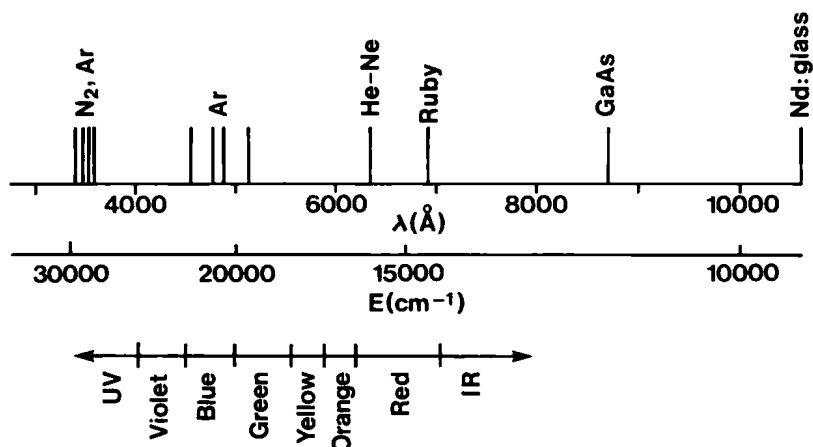$$1 \ nm = 10^{-9} \ m$$

For the description of a number of physical phenomena it is more appropriate to consider light to be particle-like rather than wavelike. This is not just a matter of conceptual convenience; it is a consequence of the quantum mechanical nature of light. Indeed, wave-particle duality is not confined to light. Electrons, for instance, which one is accustomed to think of as particles, display diffraction effects which are wave phenomena. For purposes of description of the nature of atomic and molecular spectra, as well as the operation of lasers, the particle-like nature of light is highly pertinent. Light particles, or photons (sometimes called quanta), have energy, E, given by

$$E = h\nu \tag{1.2}$$

where h is Planck's constant, of value 6.63×10^{-34} in units of joules $\times$ second, and where 1 joule/second = 1 watt. Negative exponents have the meaning given by the example $10^{-5} = 1/100,000$ (five zeros in the denominator). In units of watts, $h = 6.63 \times 10^{-34}$ watt $\times$ second². The quantity ν is none other than the light frequency of equation 1.1. In terms of wavelength we thus have

$$E = \frac{hc}{\lambda} \tag{1.3}$$

This means that the characteristic feature of light, namely its color, can be specified either by wavelength or by photon energy. Photon energies are usually given in units of electron volts (eV) or wave numbers (cm^{-1}). To obtain the energy in wave numbers, one

Figure 1.2 Wavelength and energy range of the visible spectrum and wavelengths of some lasers.

takes the light wavelength, λ, in units of centimeters (cm) and computes $1/\lambda$. One electron volt equals approximately 8000 cm^{-1}. In terms of photons, a monochromatic (single color) light beam of wavelength λ is now nothing more than a group of photons, all of which have the same energy, hc/λ, with beam intensity corresponding to number of photons. For example, a 10 W beam of the blue-green light from an Ar-ion laser illuminating a surface for 1 sec causes the surface to be struck by some 3×10^{19} photons, each of which has an energy of approximately 20,000 cm^{-1}. Unlike ordinary light sources, which radiate a broad range of colors and emit in all directions, lasers emit a well-collimated (parallel rays) light beam which is either monochromatic or consists of a few "lines," i.e., a beam consisting of a few very sharply defined colors. Figure 1.2 shows the wavelength range of the visible spectrum and light wavelengths of several lasers.

1.2 ATOMS, MOLECULES, AND SPECTRA

For our purposes, it suffices to consider an atom as comprised of a nucleus containing a number of elementary particles, most notably

protons (positively charged), about which electrons (negatively charged) orbit in a manner somewhat analogous to planets orbiting a sun. In the classical mechanics framework, i.e. a conceptual framework which deals with physical phenomena on a macroscopic scale, the energy (potential and kinetic) of an orbiting planet is specified by the mass of the planet (and, of course, the mass of the sun), its velocity, and the radius of its orbit (if circular). This energy can vary "continuously," i.e., arbitrarily small energy changes are possible. Atoms and molecules, however, are quantum mechanical systems. Orbits in which electrons can be found (atomic and molecular orbitals) can only take on "discontinuously" varying energy values, i.e., *discrete* energies. An electron can be promoted from a given orbital to a higher energy orbital by the *absorption* of *one* photon. The photon is gobbled up by the electron which thus acquires the necessary energy to jump to the higher orbital. Conversely, an electron can jump from a higher orbital to a lower one and release the excess energy in the form of *one emitted* photon. The photon energy, or light color, involved in the acts of absorption or emission corresponds to the difference in energies of the involved orbitals, E, and the absorbed or emitted photon has wavelength hc/E. The wavelengths of light which can be absorbed or emitted by an atomic or molecular system, i.e. the absorption or emission spectra, probe the "energy level" structure (or "states") of the system. These states are characteristic of the species under study, just as fingerprints are characteristic of individuals. In atomic spectroscopy, these wavelengths are very sharply defined and "line" spectra are measured. The measured line widths give the precision with which orbital energy differences are determined. Line widths in atomic spectroscopy are typically on the order of 10^{-1} to 1 Å. In molecules, electrons are not confined to orbit a single nucleus, but can spread out over several nuclei. Consequently, a greater number of orbitals are available. These are often closely spaced and include orbitals which differ only by discrete vibrational and rotational states of the molecule. Moreover, because of the greater spacial extent of molecular orbitals, compared to atomic orbitals, electrons in molecules are sus-

ceptible to a variety of perturbations which significantly affect orbital energies. As a result, molecular spectra are very often much broader than atomic spectra, with line widths of hundreds, sometimes even thousands, of angstroms.

In absence of external influences, electrons in molecules reside in orbitals of the lowest possible energy. This state of the molecule is called the *ground state*. Promotion of an electron to a higher energy orbital, by absorption of light, electric discharge, etc., results in an *excited state* of the atom or molecule. Atoms and molecules in excited states tend to quickly return to the ground state (principle of universal laziness) by emission of light or other means of releasing energy. Emission of light (luminescence) during this return to the ground state can take on the form of *fluorescence* or *phosphorescence*. For the moment it suffices to note that molecular fluorescence takes place very quickly, generally in a time less than 10^{-6} sec, after absorption of light has generated an excited state. Phosphorescence, on the other hand, occurs in molecules generally 1 to 10^{-5} sec after absorption, and phosphorescence occurs in a given molecule at a lower energy (longer wavelength) than fluorescence. Molecules seldom display both pronounced fluorescence and phosphorescence simultaneously, however. While molecules in solution, particularly at low temperatures, frequently show intense luminescence, molecular solids, such as powders, very rarely show observable phosphorescence at room temperature and usually fluoresce only weakly.

In contrast to atoms, molecules slightly rearrange their structure once absorption has promoted an electron to a higher orbital. This rearrangement is due to change in electrostatic forces between electrons and nuclei of the molecule arising from the change in electron distribution in the molecule caused by the absorption event. The rearrangement takes place before light emission occurs and causes a reduction in energy of the excited state. In terms of absorption and fluorescence, this means that absorption into a given state occurs at higher energy (shorter wavelength) than fluorescence from this state. This wavelength difference, called the Stokes shift, is schematically shown in Figure 1.3.
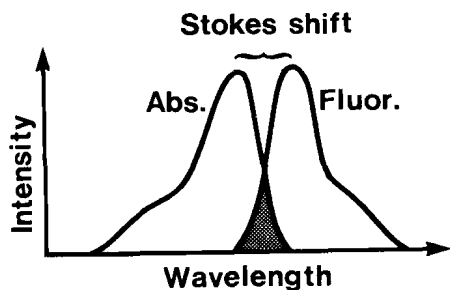
Figure 1.3   Schematic diagram of Stokes shift in molecular spectra.

1.3 MOLECULAR SPECTRA: A CLOSER LOOK

In this section, some features of optical spectra of organic mole-
cules are briefly outlined. Some of the terminology frequently
encountered in the spectroscopic literature is also defined.

Let us first consider the arrangements of electrons in mole-
cules in their ground state. Molecular orbitals are filled up by elec-
trons in pairs, with the lowest energy orbitals filled first. Electrons
occupy the lowest possible orbitals as long as the molecule is in
the ground state. Since the organic molecules of interest to us have
an even number of electrons, the highest occupied orbital of a
molecule in the ground state must contain two electrons. Optical
absorption promotes an electron from this orbital to an unoccu-
pied orbital. For many purposes, a molecule can thus be treated
as if it only had two electrons. In the ground state, these two elec-
trons are in the same orbital. In an excited state, one electron re-
mains in this orbital and the other is located in a higher orbital
which it occupies alone.

The motion of an electron in its orbital produces a magnetic
field. The electron itself has properties of an "elemental" magnet,
called the electron *spin*. The total energy of an electron in an or-
bital depends on the spin, since the magnetic field due to the elec-
tron's orbital motion interacts with the electron's spin, just as
electromagnets interact with magnetic materials. The total energy