Chapter 1

Introduction

1.1 Introduction

What do liquid crystals, laptops and life have in common, besides that they all begin with the letter "l"? At first glance, the answer might well be "not much." Rather surprisingly, they have a great deal in common. Liquid crystals are essential to life and are used in many practical devices that simplify and reduce the physical labor of our lives. Liquid crystals are also a medium that artists use to enrich our lives. The same technology that helped bolster the semiconductor industry has also helped advance the liquid crystal industry.

Liquid crystals are also an essential component of our bodies. Every cell membrane in every living organism is in a liquid crystalline state, the breakdown of this liquid crystalline structure can lead to many diseases. An understanding of the relationship between liquid crystals and diseases may help in finding new medicines and treatments for these diseases.

There is also a less critical, though more easily noticed connection between liquid crystals and our daily lives. In the course of a typical day, we encounter many different kinds of information displays. One of the more ubiquitous is the liquid crystal display that is common in such "low tech" applications as watches, clocks, radios, and household appliances, as well as "high tech" cell phones, automobiles, laptop computers,and electronic instruments. Liquid crystals also suffuse our lives in a less "techie" manner. They are common in simple "toys" such as mood rings and they are being incorporated into many works of art.

The relationship between liquid crystals and laptops is quite clear. In fact, laptop computers could not exist without a light weight, low power, low cost display. The microprocessor and the operating system get more ink, but the liquid crystal display is the lynchpin technology that makes the laptop possible. Does the hardware run a little slow? (Ok, we can wait.) Does the operating system hang from time to time? (<Ctrl><Alt><Del> . . . Ok, nothing's perfect.) Is the display hard to read unless you tilt it at just the right angle? Does it wash out in sunlight? We can tolerate quite a few shortcomings in a laptop, but if the display, the primary and most heavily used of all computer output devices, is difficult and irritating to use, we'll trash the whole unit.

This juxtaposition of display and computer masks a less apparent but more fundamental connection between the semiconductor and the liquid crystal industries. The growth of the electronics industry created much of the infrastructure that allowed larger and more complex displays to be made. Cleanroom manufacturing techniques developed in the electronics industry have been used and modified by the liquid crystal display industry. This synergistic relationship continues to grow and both industries are prospering.

Computers are becoming increasingly common in our lives. The speed and cost of computing is so low that computers are "buried" or embedded inside many appliances, automobiles and other tools of everyday life. The personal computer has become a common accessory in our lives. We use it as a typewriter, a calculator, a terminal for information exchange and a source of entertainment. Much of today's fast paced, high-density communication is based on computers.Unfortunately, in this author's opinion, there are many questions about computer technology that too few people ask: For example, what are the basic science and technologies behind a computer? How does a computer work? How does a computer display work?

Arthur C. Clarke, the famous science fiction writer, once observed that "Any sufficiently advanced technology is indistinguishable from magic."[1] (at least to the ignorant person seeing it for the first time.) Are computers magic? Are the liquid crystals found in displays studied in the biophysics of life magic? Should the average person treat them as magic? Put another way, can the average person understand the basic and applied science and technology behind these three converging topics? Should they try to understand this convergence, and if so, why?

[1]From *Profiles of the Future: An Inquiry into the Limits of the Possible*

1.2 A few preliminary answers

At this point you may be thinking "That's interesting; now let me move on with my life." Why are the connections between liquid crystals, laptops, and life important and worthy of further study? The answer to this question lies in the whole of this book, but we'll begin with a few general, preliminary answers.

1.2.1 *The relationship between technology and life*

Let's start by addressing the importance of a basic understanding the computer and how it functions. You might begin by asking, "Isn't a computer a tool just like a car, a bicycle or a pencil? Can't I just use it and let others worry about the details?" You could if you want to rely on "the others" to always have your best interests at heart. An educated person should want to understand science and technology at a basic level. If educated people do not understand technology, how can they control its use? How can they ensure that appropriate technologies are developed and inappropriate ones left to wither or even be banned? Should the direction of science and technology be determined by the specious arguments of charismatic speakers or by an educated populace? In the time of Galileo,[2] an authoritative body decided what was good science and what was bad science. Four centuries later the authorities have changed, but an uninformed populace, by default, will still let the authorities decide science policy.

History provides examples of people who understand technology controlling people who don't. Author Anthony Walton, in the January 1999 Atlantic Monthly, argues persuasively that technological innovations have traditionally made life worse for African-Americans. He asserts that since the discovery of the New World, African-American encounters with technology have devastated "their hopes, dreams and possibilities." He presents several examples of this devastation. The first was the development, by the Portugese, of the Caravel ships used in the slave trade. Later, the cotton gin hurt these people, because, in his view, it made slavery economically viable. Still later, the mechanical cotton picker threw workers off the land and led to the northward urban migrations after World War II. The increase in au-

[2]Galileo Galilei 1564-1642, invented the microscope and other devices, and built a telescope that he used to discover the moons of Jupiter. He was an early proponent of the theory that the earth revolved around the sun. He was compelled to abjure the theory that the earth was not the center of the universe.

tomation in factories that has occurred in the past 30 years put those who moved north out of work. Walton asserts that these developments all led to "Black folkways," a "consciousness of the race" that he believes is, at best, ambivalent towards interactions with technology. This ambivalence, coupled with the traditional poor education of too many African-Americans, has essentially shut this group out of the benefits of technology. Walton further states, "As a group, they have suffered from something that can loosely be called technological illiteracy."

Increasing technological developments will affect the destiny of all peoples. Therefore, all people must develop an understanding of technology so that they will benefit from it and not be left behind.

The "information age" is predicted to have profound effects upon our lives. James Burke of "Connections" fame has written that we are in the middle of a surge of information. This surge is a powerful agent for change that will change the whole world, including the way we think. He compares this new change to the fundamental changes brought about by the Greek invention of the alphabet[3] and the later development of the printing press by Gutenberg. He argues that the alphabet gave us the step-by-step reductionist manner of thought that has characterized western thinking for the past three millennia. The printing press greatly expanded the availability of information that allowed the nation-state to form.

The newly evolving information systems, which include the Internet and wireless phones, are already starting to break down the barriers of nation-states and may well lead to one world-state. If information is the ultimate commodity, then the ease with which information can be spread, used, and critically analyzed will lead to great economic growth and changes in governments, education, and society itself. Unfortunately, there is a dark side to this transformation. If we do not understand the technology we use, who then is in control? The ignorant end user or the knowledgeable supplier? Once more, only an educated populace that understands the basis

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[3]This was questioned by one reader. It appears that the Egyptians were the first to represent each consonant phoneme (a member of the set of the smallest distinct units of speech in a language or dialect. For example, the \p\ in *pat* and \f\ in *fat* in English) with a single sign. In this way, typically fewer than thirty 'letters' were needed to convey the consonantal phonemes of a language. A difficulty was some languages required equal representation of both vowels and consonants. The Greeks provided the simple and adaptable innovation of adding vowel phonemes. The Greeks thus invented the first 'complete' alphabet. This is discussed in **A history of writing**, Steven R. Fischer, 2001; **The alphabet**, David Diringer, 1968, and **Alpha to omega**, Alexander and Nicolas Humez, 1981.

and basics of science and technology will be able to control it.

1.2.2 *The relationship between life and the arts*

Paintings, sculptures, woodcuts, silk screens, photographs, movies, videos, and computer images are all visual works of art. We are able to see and appreciate these works because in some way, the artwork interacts with light and we then see the light. How does a typical paint produce the colors we associate with it? How can paints be changed and why might we want to change them? How are liquid crystals and computers changing the traditional manner in which we see art? These are a few of the questions that will now be discussed.

Many types of visual artwork are static. By this it is meant that the composition (the paint, lighting (including shadows and shades of colors), position and relationships of objects) and other details of the artwork is expressed using the materials selected by the artist when the work is formulated and are, to a large extent, never changed except by aging and other similar phenomena. To follow an example from Lovejoy[4], consider the Mona Lisa, painted by Leonardo da Vinci. It is housed in a climate controlled glass case at the Louvre in Paris. It is viewed in artificial light, and is far removed from the Medici palace where it was first displayed. Physically, it is not the same painting it was originally and, it appears different than it would if it were still in the Medici palace under the original lighting conditions. This particular painting has also acquired a great deal of social meaning (or baggage depending on your point of view). In this interpretive sense, it is not and never has been a static work. Nevertheless, except for possible restorations, this work has not been creatively altered since da Vinci completed it.

This "static" work of art should be contrasted with other works, such as mobiles, that, by their very nature, are temporally changing. Similarly, a statue in an outdoor setting may appear very different in winter covered by snow than in summer surrounded with a skirt of flowers. Some contemporary artists have produced works that are ever changing such as Moholy-Nagy's Light Space Modulator.

In recent years, artists have begun to address how to make a traditionally static work of art dynamic by the use of new media. Liquid crystals, molecules that form oriented liquids, and some types of polymers have the

[4] *Postmodern currents: art and artists in the age of electronic media, Prentice Hall 1977.*

potential to achieve this goal. These materials introduce dynamic aspects into the work that cause it to interact with both the environment and the observer. These materials produce colors by selective reflection and differ in both saturation and quality from colors produced by more traditional pigments that depend on absorption of certain wavelengths of light.

David Makow, an artist and physicist, has explored liquid crystals as a medium for painting. He observes that by using liquid crystals, the colors and mood of a composition can change as a viewer approaches, pauses in front of, and backs away from a work. These colors may also be made temperature sensitive.

Traditionally, the artist has had an intimate knowledge of his materials. The sculptor knew the mechanical properties of marble. The painter mixed his own paints, knew good pigments from bad, and knew the effects of grinding the pigments more coarsely or finely. In general, they knew the thousands of little details that were part of the artist's craft. It is no accident that art and science were so closely connected during the Middle Ages and the Renaissance. In more modern times, it more difficult for an artist to develop an intimate knowledge of his materials. Nevertheless, it is possible to develop this understanding. Later in this book, after studying some of the science of light and liquid crystals, we will return to this topic and discuss the differences between liquid crystals and traditional pigments, as well as other aspects of this new art.

The computer has significantly changed the nature of the image. Before computers, even a simple picture was the product of human hands or arts, such as photography, that produced an image through chemical means. The data in a computer is stored as tiny charges of electricity, pits on plastic or tiny magnetic domains. A picture no longer needs to be a physical object – it can be nothing more than a series of ones and zeros recorded on any one of a large number of different storage media. A computer can create images by dutifully following an algorithm, a recipe, that states "Go here and plot color one" and then "Go there and plot color two" and so forth. Using a single keystroke a person can change all the colors to their complementary colors or make a color picture black and white, or vice versa.

The computer has changed the very nature of art. Formerly simple questions such as "What is an original?" have now come to the forefront. Other issues, including ownership of a piece of art, are now opened anew. The computer and digital art may represent the greatest challenge to art since the photograph. We may anticipate that the art forms that this medium spans and those that grow in response to it will be as invigorating and exciting as those spawned by the Daguerreotype. While one does not need to know ones media to be an artist, such an understanding is important, and allows one to fully utilize the potential of the medium. A computer is little more than plastic, metal, and sand, yet it has profoundly affected all of us. Yet another goal of this book is to understand how this technology works so that we may use it to its fullest.

1.2.3 *Liquid crystals and life*

The fundamental importance of liquid crystals to the cells of all organisms might be reason enough for a physical scientist to want to study them. On the other hand, a layperson might feel that the biophysics of cell membranes is excessively complex and difficult to understand, and question the importance of such studies to the non-technophile. Satisfactory answers to this question can be hard to come by. Nevertheless, a few answers will be provided.

Certainly, one of the big questions that we all ask is, Where and how did life originate? Can life be created in a test tube? Should such an experiment be performed? Another fundamental question is, "Did bilayer membranes, a liquid crystalline structure, form in the 'primordial soup'?" Similarly, why are liquid crystalline structures so common in biological structures? Why does a breakdown of this structure lead to disease? These questions require an understanding of how cellular life functions. This is the realm of biochemistry and biophysics, highly technical areas filled with specialized terminology. Nevertheless, ethical issues raised by recently publicized work in the areas of cloning and the study of DNA strongly suggest the importance of learning the terminology and relationships of these areas. (The educated populace argument once more rears its beautiful and bountiful head.)

While it is true that yesterday's lecture may well be out of date by next year, the ability to make the connections between disciplines and a primary knowledge of the relevant terminology, combined with the ability to teach oneself, will always allow a citizen to make educated choices.

A further motivation for studying the biophysics of liquid crystals is that the relationship between liquid crystals and life is at the very frontier of science where ideas and approaches from many disciplines are important and help to move the field forward. All of the "prefixed" sciences (bio-x, physical-x, structural-x, etc.) grew from the frontiers of the past. This makes studying such areas an exciting intellectual experience.

Too often, science is misrepresented as a well-known set of facts (most likely needing to be memorized) that have been known for ages. Usually, these "laws" were discovered by a bunch of dead white people who are completely unlike you. This author believes non-technical people should at least catch a glimpse of a frontier area of science so that they can understand why science is so fascinating and a discipline worthy of study and support. They should also learn about scientists who work at the frontier and see that scientists and non-scientists are much more alike than different.

The biophysics of membranes and the relationship between liquid crystals and life and disease is certainly not the only frontier in liquid crystal science. However, it is an ever more important one that naturally ties into our study of molecules and their interactions.

1.3 Overview - the road ahead

This book is a tool to help you start to understand the relationship between basic science, technology, everyday high tech devices, and life. There are no easy shortcuts that allow one to go from start to finish without climbing each hill and stopping at each summit to observe and understand the surroundings. Modern high tech devices rely heavily on many basic and applied technologies, each of which depends on basic science. There is no single basic science that dominates these areas. A healthy dose of chemistry, physics and biology will be needed to understand this material.

One of the amazing features of contemporary science is its reliance on scientific models. Often, the results of an experiment are explained in terms of a scientific model. The use of models to guide science and suggest experiments has been critical to the growth of science and technology. The explanations in this book are almost exclusively based on models. Thus, the first topic will be a discussion of scientific models.

One of the tools that scientists and engineers use to simplify problems, and to unify different aspects of problems is symmetry. Symmetry deals with similarities in patterns, and an understanding and knowledge of the use of symmetry is one of the techniques used by many scientists. We will have occasion to use symmetry to simplify discussions; for this reason a chapter on symmetry comes next.

With this as background, we will study the basic science that is the foundation of the technologies that we will investigate. One of the fundamental forces of nature is the force between two charged bodies. This force is called the electric or electrostatic force. We will study it and learn how more complicated charged objects interact with an electric field. This is important in biophysics, liquid crystal displays and all of electronics. The nature of light, how to control it, and its behavior at interfaces and in matter is crucial to understanding displays, sight, and colors. This will form the next chapter of this book. We will then turn our attention to the chemical nature of materials and discuss atoms and molecules. The systems that we observe and study consist of large numbers of molecules acting in concert. Thus we must start to understand how large numbers of molecules behave in order to discuss solids, liquids and gases. This study will form a backdrop for us to explore and understand semiconductors, polymers, liquid crystals and related phenomena.

The next four chapters will explore several types of molecules and materials. The first will discuss polymers, long chain or branched molecules. These molecules are important to life in the form of proteins and DNA and important to technology as a class of materials that can be made with a wide variety of properties. The second chapter in this group will discuss liquid crystals. Liquid crystal molecules act in concert to form structures that are not only useful in technological applications but fundamentally important to life itself. Semiconductors, the electronic building blocks of computers and microelectronics, will then be studied. You will learn about the unique properties of these materials that make them so technologically useful. only useful in technological applications but fundamentally important to life itself. The last chapter in this group will discuss the molecules that are important to life. These molecules are often polymers and amphiphiles and particular and important examples of the types of molecules in the previous chapters.

We will then discuss how these materials are put to use in technologically useful configurations. We will next investigate digital devices and microcomputers. This chapter will present and demonstrate new ideas that are needed to understand and explain these devices. It will end by discussing a fully functional, bare bones computer. We will then discuss liquid crystal displays, and bring together almost every topic that we've considered and introduce a few new twists that are exciting all by themselves. Finally, the combination of these devices into a laptop computer will be summarized.

The last part of this book contains two topics of contemporary interest. These chapters can be taken in any order and will explain how the basic science and technologies discussed earlier in the book relate to these topics. The next chapter explores some of the relationships between art and science mentioned earlier. In particular, we will look at some of the scientific aspects of pigments and the use of liquid crystals as an artistic medium. The last chapter is a rather detailed discussion of liquid crystals and life.

The language of quantitative physical science is mathematics. This does not mean that one must love math or be highly proficient at mathematics to understand how these technologies work. What it does mean is that we must go beyond a simple word description of the sort, "I do A, and B results." One must in some way associate numbers with A and B so we can discover how much a change in A causes a certain amount of change in B. For this reason there is an appendix with a very brief review of math you already know.

The more technical reader will already know some of the material presented in this book. It is hoped that there is sufficient new material and that the material is presented in such a way as to satisfy their curiosity.