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Identification and Characterization of Rayon in Women's Dresses of the 1920s and 1930s

by

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ABSTRACT

The use of rayon in 1920s and 1930s garments confronts conservators with new challenges: definitive fibre identification involves more than basic microscopy and treatment can be difficult with little available research on early rayon and its conservation. Rayon is expected to degrade similarly to other cellulosic fibres; however, since it is a regenerated fibre, rayon is at risk of doing so at a faster rate. The purpose of this research was to develop and test a protocol for the identification of viscose and cuprammonium rayon and to determine whether early rayon dresses have condition issues at this time. Polarizing microscopy, hot-stage microscopy, acetone solubility and relative fibre refractive index were explored as fibre identification techniques, resulting in the development of a rayon identification scheme. 1920s and 1930s rayon dresses were surveyed for condition and it was determined that dresses in this sample have limited condition issues at this time.

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CHAPTER ONE: INTRODUCTION

The modern era of chemistry, which began in the nineteenth century, has had wide implications for society, not least of which has been the innovation of modern materials. In pursuit of the goal to discover and develop new products, chemists have invented entirely new substances by developing the means for processing naturally occurring matter to form, for example, fibres, films, coatings, and adhesives. Similar to natural materials, modern materials make up an important part of the historic record and as such have made their way into museum collections. Textile collections reflect this trend. It is no longer the case that they are populated exclusively with artifacts made of natural fibres; increasingly, artifacts made from manufactured fibres are being accessioned. Research initiatives in the field of textile conservation, however, have long focused on the natural fibres cotton, wool and silk. Despite the presence of manufactured fibres in collections there has been little research on their conservation.

A perceived need for conservation research in the area of manufactured fibres has been clearly established by Ferreira (1999). As Ferreira states, "[because] cultural institutions began accessioning objects composed of manufactured fibres into their collections, their historical significance has been legitimized" (p. 9). Ferreira found, through analysis of questionnaires distributed to conservators across the United States, that conservators wanted more information about the degradation and conservation of manufactured fibres, with rayon being of greatest interest. Among manufactured fibres, rayon is unique in that it was the first manufactured fibre to achieve widespread, commercial success; consequently, some of the oldest artifacts made of manufactured fibres are made of rayon. Yet, in the nearly ten years since Ferreira's survey was published there has been almost no research on the conservation of any manufactured fibres including rayon. Rayon is also an interesting type of manufactured fibre in that it is cellulosic and is therefore expected to degrade in a manner similar to cotton; however, there is no explicit evidence to suggest that conservation practices developed for use with natural cellulose fibres can be directly applied to regenerated cellulose fibres. For these reasons, rayon will be the focus of this research project.

In addition to a lack of research into the nature and degradation of rayon, there has been little historical study of the fibres and their relationship to material culture. This has implication for textile conservators in several ways. First, historical research can enlighten conservators as to where in collections rayon is most likely found. Literature on the development of rayon industrial processes indicates that rayon was used for many different purposes, suggesting that rayon and blended rayon fabrics may take on a variety of different appearances (Hottenroth, 1928). Knowledge of the different ways that rayon is manifested in garments and in collections means

that rayon is less likely to be missed during identification and thus that conservators will have more information available to them when deciding upon treatment. A second way historical research can benefit textile conservators is by revealing how manufacturing processes developed and changed. Often changes in production have a significant impact on fibre properties. In the case of rayon this is particularly important, as rayon production encompasses some of the earliest industrial manufacturing processes for textiles. A considerable amount of trial and error was involved in developing effective methods of production, which resulted in rayon having a range of different properties through the first few decades of the twentieth century and indeed improvements continue to be made. Finally, research into how early rayons were consumed and used can contribute information about the conditions that rayon fabrics were exposed to during use-life and what the fabrics were expected to withstand in terms of durability and washability. This information can be helpful to conservators by establishing a baseline of durability, and by revealing use-life conditions that may accelerate degradation.

Though rayon, in many ways, is quite different from both natural fibres and fully synthetic fibres, identification is not as straightforward as might be expected. While it is fairly simple to differentiate between natural and manufactured fibres using bright-field microscopy, narrowing down the identification within the manufactured fibre category is more challenging. Since morphological features that allow for the identification of individual natural fibres are not specific to fibre type in extruded fibres, simple microscopy cannot differentiate rayon from other manufactured fibres. For example, though cuprammonium and viscose rayons have different longitudinal sections viscose could easily be confused with acetate as they are both striated cellulosic fibres, or the smooth regular cuprammonium fibre could be mistaken for synthetic fibres with round cross-sections. As a result, museums often rarely know definitively whether textile artifacts are made from rayon or from another manufactured fibre.

Fibre identification techniques that do allow for the identification of specific man-made fibres require more sophisticated techniques and equipment. Conservators may use a series of chemical solubility tests; however, there are a number of drawbacks to this method of identification. Many of the chemicals used are hazardous to humans and the environment. Proper handling can mitigate these risks; however, as the conservation profession pushes toward more sustainable practices, the use of chemicals should be reduced where other techniques are available. In addition, chemical solubility testing is destructive; therefore, results cannot be confirmed at a future date without the removal of further samples. Moreover, chemical solubility testing cannot differentiate definitively between cuprammonium rayon and viscose rayon as they are both made up of cellulose and thus dissolve in the same reagents. Determining melting point by means of hot-stage microscopy is another technique for identifying synthetic manufactured fibres, and the

fact that many synthetic manufactured fibres are thermoplastic make them readily distinguishable from rayon fibres, which are unchanged or char upon the application of heat. However, melting fibre samples is also a destructive technique.

Identifying fibres based on their optical properties is a method that is frequently used in the field of forensics. Fibres refract light in different ways depending on the shape of the molecules they consist of and their degree of orientation. Based on these different properties fibres can be differentiated from one another. Using optical properties for fibre identification has the potential to be helpful for conservators because, as Gaudette (1988) states, "optical properties are particularly valuable when only small amounts of questioned fibers are available" (p. 223) and conservators are concerned with removing the smallest sample possible to respect the integrity of the artifact. Moreover, the optical properties of cuprammonium rayon and viscose rayon are sufficiently different to be differentiated using this technique.

In addition to adhering to the conservation principle of identifying materials with as much detail and precision as possible, distinguishing between curprammonium rayon and viscose rayon can be of further interest and importance. For example, information about the history of the production of these two fibres and about how the fibres were used in the production of fabrics and garments can be collected based on fibre type – information curators often look to conservators to provide. Moreover, cuprammonium and viscose rayon have slightly different properties, especially in the early years when cuprammonium was made in much finer deniers than viscose and was stretched to a greater degree, making it somewhat stronger. For conservators, however, of greater importance is distinguishing between cuprammonium rayon fibres and other synthetic fibres and between viscose rayon and other striated manufactured and synthetic fibres as these fibres can have significantly different properties. A case in point of where this can become problematic is the misidentification of fibres that are sensitive to chemicals sometimes used in conservation laboratories. If acetate were misidentified as viscose rayon, treatment with acetone, such as in the removal of residues, would not be immediately ruled out, and the artifact could be at risk.

A protocol for definitively distinguishing different types of early rayon fibres from each other and other manufactured fibres is therefore necessary. Such a protocol can assist conservators in deciding the most effective, safe and practical manner of identifying rayon fibre content. In the context of this research project, applying different fibre identification techniques was used not only to help develop the protocol but also to help determine the extent to which early rayon is present in 1920s and 1930s dresses from the Clothing and Textiles Collection housed in the Department of Human Ecology at the University of Alberta in Edmonton, Alberta.

Since rayon is made up of cellulose it is expected to degrade in a manner that is similar to natural cellulose fibres such as cotton and linen. However, since the chains of cellulose are shorter and less organized, rayon is expected to exhibit accelerated degradation as compared to cotton and linen. Moreover, since early rayon is between 80 and 90 years old, this may be old enough for a difference in degradation to have become apparent. This project investigated the current condition of rayon from the 1920s and 1930s where the 'condition' of an artifact was defined as an "assessment of its general state of preservation, or its physical stability" (Lemiski, 1996, p. 54). In order to do this rayon dresses from the 1920s and 1930s were examined for evidence of damage or degradation.

Statement of the Problem

The purpose of this study was to investigate methods for the identification of cuprammonium rayon and viscose rayon, to confirm the varied location/nature of rayon in dresses from the 1920s and 1930s in the Clothing and Textiles Collection, and to determine whether early rayons have specific conservation issues at this time. Identification by means of bright-field microscopy cannot definitively identify cuprammonium and viscose rayons, nor can chemical solubility testing alone. Identification based on optical properties and melting points show promise, but are not in widespread use by conservators. A clear protocol for the identification of rayon, which makes use of one or more of these techniques for use by textile conservators is lacking. Furthermore, since there has been limited historical research on rayon as material culture, it is unclear how rayon from the 1920s and 1930s is represented in collections. A review of the literature indicates that rayon was commonly used in blends with cotton, wool and silk, for embroidery, and in knitwear among other applications that are not woven broad fabrics made wholly of rayon. Finally, although rayon and natural cellulosic fibres are expected to degrade in a similar fashion since they are all made of cellulose, the less organized, shorter, more poorly oriented polymers of rayon would seem to be at risk of doing so at a faster rate. It is unknown whether there is any visible evidence at this time of rayon exhibiting characteristic damage or accelerated degradation.

Research Questions

What is the best protocol for identifying cuprammonium and viscose rayons with a limited sample size, in a conservation context?

Since fibre identification of man-made fibres is often a process of elimination it was expected that a combination of several techniques would be the best scheme for identifying rayon. More specifically, it was hypothesized that the combination of hot-stage microscopy, which can differentiate acetate and synthetic fibres and polarizing microscopy, which is non-destructive and

can identify a wide range of fibres would be most effective. It was thought that hot-stage microscopy would separate fibres into synthetic and cellulosic manufactured fibre groups and then the fibres' optical properties, observed under crossed polars, would lead to a more precise identification.

What does rayon look like in rayon dresses from the 1920s and1930s?

- What relative proportion of the rayon dresses are viscose rayon and cuprammonium rayon?
- What relative proportion of the rayon dresses is: Single fibre fabrics? Combination fabrics? Blended fabrics?
- What fabric and yarn structures are represented in the rayon dresses?
- What proportion of the yarns and fabrics is made from staple fibres versus filament fibres?
- Can increase in the prevalence of staple fibre fabrics be seen in the thirties that parallels the documented increase in production?

Since the viscose method of rayon production was much more widespread than the cuprammonium process it was expected that more viscose rayon fabrics would be identified. Based on reviewed literature that indicates rayon was often blended and/or combined with natural fibres to improve properties of durability and hand, it was expected that there would be significant representation of combination and blended rayon fabrics found in the sample. Moreover, it was expected that some increase in the instances of staple fibre fabrics would be visible in rayon dresses dating from the 1930s as compared to dresses dating from the 1920s as there is a documented increase in production through the 1930s.

Is there visible evidence that rayon fabrics and garments from the 1920s and 1930s have been damaged in a characteristic way or are degrading at an accelerated rate?

- Is there any relationship between yarn structure, fabric structure, fabric fineness or the presence of delustrants and the presence or severity of damage?
- Do combination or blended rayon dresses appear to be less damaged or degraded than single fibre rayon dresses?

Since rayon has a lower degree of polymerization and is more highly amorphous than natural cellulosic fibres it was expected that rayon would show signs of degradation such as embrittlement, splitting and yellowing. Moreover, certain yarn and fabric structures may

exacerbate damage of the weakened fibres. It was expected that those fabrics combining rayon with natural fibres would be in better condition since the weaker properties of the rayon fibres will be supported and mitigated by the stronger natural fibres.

Definition of Key Terms

Cellulose A carbohydrate and a key constituent of all plant life. Cellulose also makes up the major part of all vegetable fibres and some manufactured fibres, including cotton, linen, jute, hemp and all bast fibres, leaf fibres, stem fibres and cuprammonium and viscose rayon. It is a polymer of the sugar glucose with each glucose residue having three hydroxyl groups (Tortora & Merkel, 2007, p. 102).

Regenerated Cellulose Material which begins as cellulose, is converted to some other form during some stage in the chemical processing, and, finally, reforms as pure cellulose during the final stages of manufacturing (Joseph, 1986, p. 388).

Man-made Fibre or Manufactured Fibre " Any fiber derived by a process of manufacure from any substance which, at any point in the manufacturing process, is not a fiber" (Textile Fiber and Products Identification Act as cited in Tortora & Merkel, 2007, p. 345).

Artificial Silk The name first given to all early manufactured fibres made from cellulose polymers. The term encompassed fibres made by the viscose rayon, cuprammonium rayon, cellulose acetate and cellulose nitrate processes. The term was used between approximately 1885 and 1924 when it was replaced by the term 'rayon'; however, some countries were slower than others to adopt the new term, thus 'artificial silk' continued to be used to varying degrees through the 1930s. (Coleman, 1969; Cooke, 1984).

Rayon The generic term rayon was adopted by the U.S. Federal Trade Commission in 1924 for manufactured natural polymer fibres of all types. However, today the term refers to manufactured fibres composed of regenerated cellulose in which substituents have replaced not more than 15% of the hydrogens of the hydroxyl groups (Cooke, 1984, pp. 8-9; Joseph, 1986, p. 73). This current meaning of the term rayon will be used in the context of this study even when discussing rayon fibres at dates prior to the adoption of the term.

Viscose Rayon A type of rayon produced by xanthanating cellulose and dissolving it in sodium hydroxide. The solution is extruded into an acid bath where the pure cellulose is regenerated and coagulated into filament form (Joseph, 1986, p. 392).

Cuprammonium Rayon A type of rayon formed by precipitating cellulose dissolved in a solution of copper oxide and ammonia (Joseph, 1986, p. 382).

Acetate A manufactured fibre in which the fibre-forming substance is cellulose acetate and where not less than 92% of the hydroxyl groups are acetylated (Joseph, 1986, p. 379).

Cotton A natural fibre obtained from the cotton plant (Joseph, 1986, p. 382).

Synthetic Fibre A fibre made from chemicals that were never fibrous in form (Joseph, 1986, p. 390).

Dress A one piece, outer garment worn by women and girls consisting of bodice and skirt attached, with or without sleeves. This is the meaning of the term 'dress' that will be used with respect to sampling from collections.

Condition An assessment of the general state of preservation of an artifact, its physical stability or its closeness to its state upon production (Lemiski, 1996, p. 54).

CHAPTER TWO: LITERATURE REVIEW

A review of the literature concerned with rayon fibre, and other concepts that help inform the history, true nature, and preservation of regenerated cellulose, provides the necessary theoretical and contextual background for the study. First, the development of regenerated cellulose fibres, their manufacture, structure, properties and the nature of their degradation are examined. Then, the use of rayon fibres in textiles, and their care will be studied. Finally, conservation literature dealing with rayon will be considered.

History of the Manufacture of Rayon

Rayon, or 'artificial silk' as it was initially called, was the first manufactured fibre and marked the first step in what has become a vast and important man-made fibre industry. Rayon consists of cellulose which is dissolved by chemical processes and is then reformed or regenerated into pure cellulose by further chemical means. The manufacturing process has changed and developed over time, from early experimental techniques, to the technologically advanced continuous spinning techniques of today. An understanding of the manufacturing process and its evolution reveals aspects of processing that may affect the structure of rayon and in turn its properties.

Early Experiments

There has been considerable attention given to the origin of the idea of a man-made fibre. Often quoted are both Robert Hooke (1635-1703) who reflects in his book *Micrographia* (1664) upon the possibility of creating artificial silk, and French naturalist and physicist Rene-Antoine de Réaumur (1683-1747) who ponders, “Silk is only liquid gum which has been dried; could we not make silk ourselves with gums and resins?” (Schwarz & Mauersberger, 1936, p. 1). De Réaumur actually went so far as to form fibres, albeit unusable ones, by forcing different types of varnish through perforated tin cans (Woodings, 2001b). It has been assumed that some quest to replicate silk or to make a cheaper version of silk was the impetus to initiating the development of man-made fibres. However, in his economic and social history of the Courtaulds company, Coleman (1969) makes the point that the musings of 18th century naturalists are not really germane to the commercial development of ‘artificial silk’ or man-made fibres in general. Coleman suggests that there is little evidence to support the idea that the textile industry even recognized such a problem as ‘finding a substitute for silk’ in the mid to late 19th century. Prices of textiles, including silk, had followed a downward trend from the 1860s almost to the end of the century. While silk had always been more expensive than other fibres – that fact was exploited in the eventual marketing of artificial silk – rising silk prices do not seem to have been a significant reason for developing regenerated cellulose fibres (Coleman, 1969). However, Woodings (2001b) points out that silk was *the* luxury fibre and there are accounts of many inventors trying to extrude silkworm gum

artificially. Though none of these attempts were successful, there seems to have been an awareness, if not within the industry, certainly among entrepreneurs, that a cheaper and more controlled form of silk could be extremely lucrative.

An important stimulus for the development of man-made fibres was generated, in fact, by advances in science and the interests of industries beyond the textile field. During the 1830s through the 1850s organic chemistry advanced, identifying cellulose and initiating research into its chemistry. The papermaking industry played a significant role in this advancement, especially in the development of viscose rayon as it perfected the process of producing wood pulp. The explosives industry contributed through its discovery of cellulose nitrate, an extremely volatile substance. In fact, cellulose nitrate was spun into fibres and then de-nitrated to form cellulose hydrate; however the manufacturing of this fibre was hazardous because of the risk of explosion posed by the intermediate product, cellulose nitrate. Perhaps most importantly, however, were contributions from the electric lamp industry. For example, the English physicist, J. W. Swan's primary interest in manufactured fibres was within the context of improving carbon lamp filaments. He exhibited some of the first artificial silk fibres, which he had created by denitrating cellulose nitrate, to the Society of Chemical Industry in 1884 and a year later showed the fibres crocheted into fabric at the Exhibition of Inventions, both in London (Coleman, 1969; Woodings, 2001b). Much money and research were expended on the development of different sorts of filaments that could be utilized in electric lamps; however, many of the resultant fibres were better suited to textile applications than lamp filament (Coleman, 1969). Finally, Louis Schwabe, an English silk weaver, played a role in the eventual viable production of any manufactured filament fibre with his invention of a precursor to today's spinnerets, needed to extrude filaments on any sort of large scale (Woodings, 2001b).

Early experiments producing cellulose based manufactured fibres, in the latter years of the 19th century were fragmented, and it is not within the scope of this review to outline all of them. Coleman (1969) describes comprehensively the contents of various early patents and Woodings (2001b) provides a more succinct summary of early experimentation with regenerated cellulose. This review will be limited to processes that were followed through to production and for which there is the potential of extant examples in museums or elsewhere. That said, there are two manufactured fibre process that must be mentioned here. First, one process that enjoyed some commercial success, and for which there may indeed be extant material evidence, is cellulose hydrate (denitrated cellulose nitrate). This fibre, called 'Chardonnet silk' or later nitro rayon was important in that it paved the way for other manufactured fibres. Cellulose hydrate is the chemical name for the manufactured cellulosic fibre made using the cellulose nitrate process, whereby; cellulose nitrate is spun into fibres and then denitrated rendering it no longer explosive. For this

reason, the fibre is sometimes falsely referred to as 'cellulose nitrate'. The fibre is also sometimes called nitro-rayon, nitro-cellulose rayon, or Chardonnet silk after Count Hillaire de Chardonnet who developed the process for textile application and brought it into commercial production. The production of Chardonnet silk peaked during the second decade of the 20th century and its market share was limited in the 1920s and 1930s, though the process was operated commercially to some extent until 1949 when the last factory burned down (Coleman, 1969).

The second process not within the scope of this research project, but extremely important nonetheless, is cellulose acetate. During the first half of the 20th century acetate was considered a rayon fibre. At that time the definition of 'rayon' was any man-made cellulosic fibre (Scroggie, 1950). As such, the reader should be aware that the term rayon when used in historical documents and statistics from that period include acetate fibre unless the manufacturing process name is specified. Moreover, in the following sections that deal with the history of rayon the term will be used in its historical sense (including acetate) and not by the contemporary definition provided above. It is difficult to easily distinguish some aspects of the early history of rayon and acetate due to this terminology issue.

Cuprammonium Rayon

The cuprammonium process was the second to reach commercial production, and is a process still used today, most notably by Asahi of Japan (Coleman, 1969; Woodings, 2001b). In 1857, Swiss chemist M. E. Schweizer discovered that cellulose could be dissolved in a solution of copper salts in ammonia, named Schweizer's reagent, and then regenerated in a coagulating bath (Woodings, 2001b). In the 1890s Louis-Henri Despeissis invented the fibre-making procedure using this solution. He extruded the cuprammonium solution into water with dilute sulphuric acid, which neutralized the ammonia allowing the cellulose to precipitate (Woodings, 2001b). A French patent was filed, but Despeissis died two years later and his patent was allowed to lapse.

Max Fremery (1859-1932) and Johan Urban (1863-1940), a chemist and engineer respectively, were already using Schweizer's reagent to make lamp filament and decided to expand their business into textile fibres. They patented their approach[1], which was nearly identical to that of Despeissis but with some improvement to the spinning method (Kamide & Kazunari, 2001; Woodings, 2001b), and began large-scale production of '*Glanztoff*' or artificial silk as the *Vereinigte Glanztoff Fabriken* (VGF) (Coleman, 1969; Kamide & Kazunari, 2001; Woodings, 2001b). Figure 1 shows the cuprammonium process as outlined in the patent filed by Fremery and Urban. The quality of the cuprammonium textile fibre, however, was problematic; it had an

[1] Fremery and Urban actually filed the patent for the 'improved' Despeissis cuprammonium process under the name Hermann Pauly, a director of the Textilschule in Müchengladbach, and a professor of chemistry at Wurzburg in an attempt to avoid the notice of their competitors.

extremely low tensile strength, particularly when wet. VGF subsequently switched to the viscose method of production as it was developed (Coleman, 1969).

In 1901 Dr. Edmund Thiele working at J.P. Bemberg invented a stretch-spinning system for cuprammonium rayon. The apparatus consisted of a funnel and a guide, which spun at a slightly faster rate than the filaments were extruded, thus stretching the fibres; the system is illustrated in Figure 2. Stretching the fibres resulted in vastly improved filament fineness and strength; it was coined Bemberg® silk and went into production in 1908. Until 1924 Germany

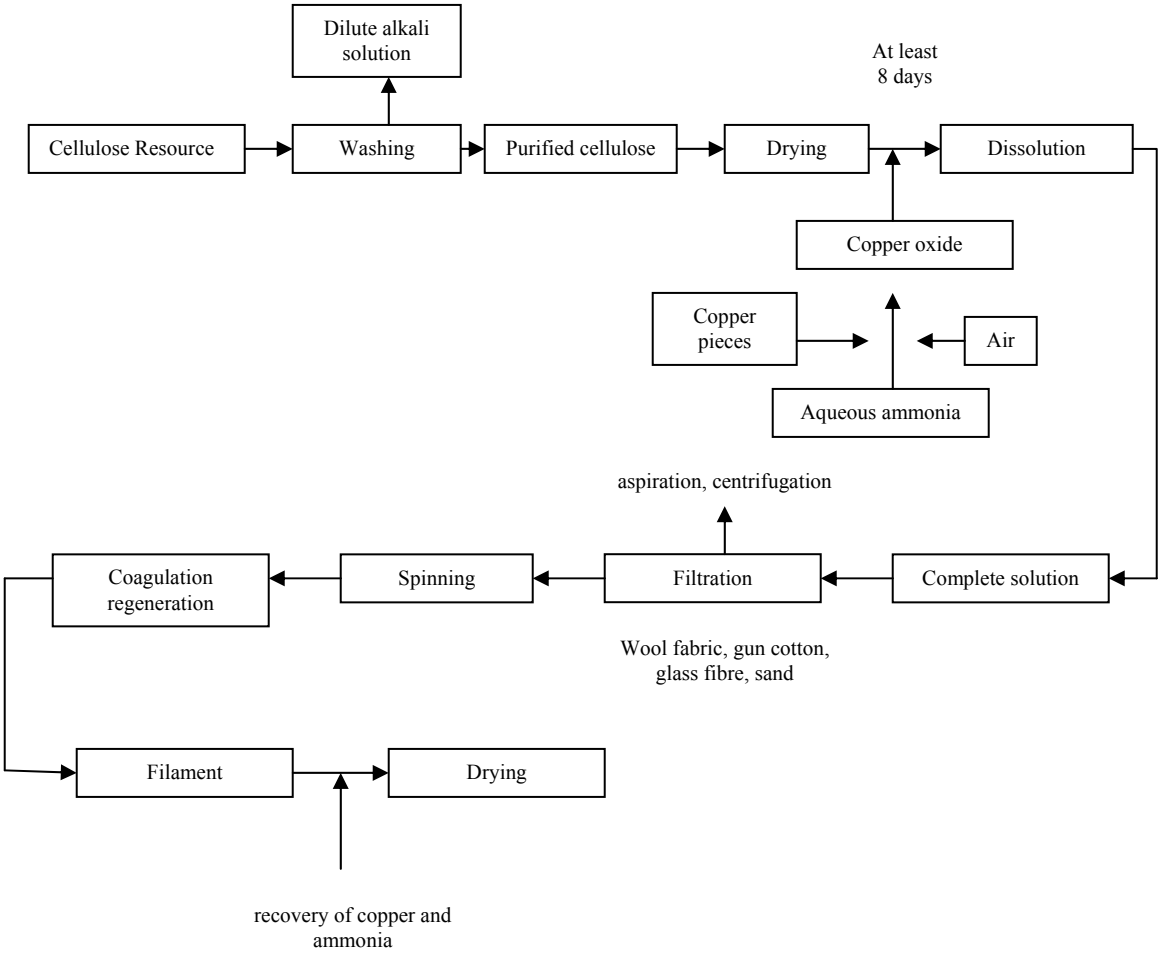

Figure 1. Procedure for producing cuprammonium rayon as used by Fremery and Urban adapted from (Kamide & Kazunari, 2001).

was the only country producing Bemberg®; however, through the second half of the 1920s Bemberg set up companies for the manufacture of Bemberg® silk cuprammonium rayon in the USA (American Bemberg Corp., Elizabethton, Tennessee, 1925), Italy (Bemberg S A; Gozzano, 1924) France (Le Cupro textile; Rennes), Japan (Asahi Bemberg; Nobeoka. 1928) and the UK (British Bemberg; Doncaster, 1928) (Kamide & Kazunari, 2001). Before Bemberg® spread out of Germany, other countries were producing cuprammonium but in coarser, weaker deniers, without the use of stretch spinning (Kamide & Kazunari, 2001).

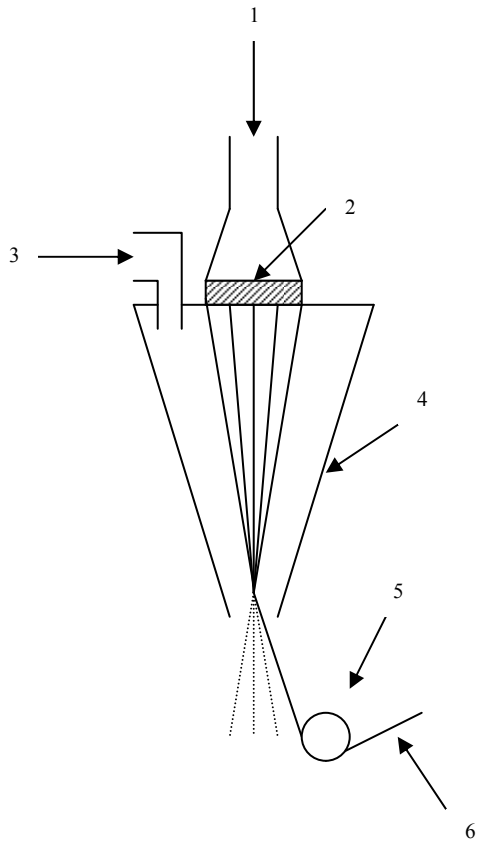

Figure 2. Stretch spinning apparatus showing funnel. 1: spinning solution; 2: spinneret; 3:spinning water; 4: funnel; 5: guide; 6: blue yarn (Kamide & Kazunari, 2001).

The cuprammonium manufacturing method during the 1920s and 1930s ultimately made use of the Fremery and Urban process (Figure 1) with (Bemberg) or without (all other companies) the addition of Thiele's stretch spinning system (Figure 2). Cotton linters, the short fibres remaining on the surface of the cotton seed after ginning, were used as the source of cellulose. The cotton linters were purified in a dilute alkali solution of 3-5% sodium hydroxide, then bleached if needed, with an aqueous hypochlorite solution. The copper oxide ammonia solution or cuprammonium was then added to dissolve the cotton linters. The complete solution consisted of approximately $15gl^{-1}$ copper (Cu), $150gl^{-1}$ ammonia and more than $45gl^{-1}$ cellulose. The solution was filtered through wool fabric, gun cotton, glass fibre and sand to purify it (Kamide & Kazunari, 2001; Moncrieff, 1975).

Following dissolution, the solution was spun into fibres. At Bemberg, the Thiele stretch-spinning process was employed and the dope solution was extruded under pressure through a nickel spinneret. At all other rayon production companies the dope solution was simply extruded into a dilute acid bath then subsequently reeled and rinsed. The basis of the Thiele stretch-spinning concept, however, was that it was easier to extrude through larger holes in the spinneret and then stretch the filaments to finer deniers; moreover, this procedure had the added benefit of strengthening the fibres. Thus, holes in the spinneret were one quarter or one eighth of a millimeter in diameter and the solution was extruded into a precipitating medium, usually soft water that acts slowly upon the cellulose solution. During this initial coagulation hydrolysis occurs removing part of the copper and 70-80% of the ammonium. At this time the cellulose solution could be substantially drawn out into fine filaments giving the copper-cellulose complex compound called 'blue yarn'. The stretched filaments then proceeded into a dilute acid (acetic or sulphuric) bath to regenerate completely. This occurs when the acid converts all remaining copper and ammonia in the yarns into copper and ammonium sulphates, thus removing them from the yarns and leaving pure cellulose (Kamide & Kazunari, 2001; Moncrieff, 1975).

Viscose Rayon

In 1891, British chemists Charles Cross (1855-1935), Edward Bevan (1856-1921) and Clayton Beadle (1868-1917), working at Kew in England, discovered that cotton or wood cellulose could be dissolved as cellulose xanthanate following treatment with alkali and carbon disulphide. The resultant solution was initially called viscous cellulose solution, but the name was later contracted to 'viscose' (Woodings, 2001b).

The papermaking industry had recently undergone a major shift in raw materials, trading cotton and linen rags for less expensive wood pulp. In 1885 Bevan and Cross set up a consulting partnership that served the pulp and paper industry; as such, the chemists published one of the

standard papers on papermaking with wood pulp. Beadle was later added to the partnership, and, based on the three chemists' discovery of viscose, took out the patent entitled *Improvements in Dissolving Cellulose and Allied Compounds* (Coleman, 1969; Woodings, 2001b). In 1893 and 1896 respectively the group formed the Viscose Syndicate for non-fibre end uses and the British Viscoid Co. for molded materials. The two companies were later merged in 1902 to become the Viscose Development Company (Woodings, 2001b).

It was Charles Henry Stearn, however, who saw the potential for the Cross, Bevan and Beadle viscose patent in the artificial silk industry. Wood pulp was a much cheaper raw material for artificial silk, an industry that showed promise, especially in light of the successes of Chardonnet silk. In 1898 Stearn took out a British Patent for "Improvements in the Manufacture and Production of Filament Material and Fabrics Therefrom." (Coleman, 1969, p. 11) This patent outlined the extrusion of the Cross, Bevan and Beadle viscose formula; however, there was no outline of a feasible production method. Development and financial backing was needed; therefore, Stearn together with Cross set up the Viscose Spinning Ltd., incorporated in 1899. Shareholders included Bevan and Beadle in addition to Alfred Nobel (explosives manufacturer) and Andrew Pears (soap maker). Research was undertaken at a small Kew laboratory, to develop the process of spinning viscose filament and ultimately to make rights to the patent attractive for sale (Coleman, 1969; Woodings, 2001b). Coleman (1969) describes the syndicate as a "curious assemblage of talent and inexperience…that managed to be neither a research laboratory or a pilot production plant" (p. 14). For further details on the viscose process at this early stage please refer to Coleman's outline (1969, pp. 14-15).

The viscose process did evolve in the next few years, but recurring difficulties arose as the original process appeared to be inconsistent and largely uncontrollable (Woodings, 2001b). The Kew laboratory utilized an alkaline spinning bath that produced weak fibres; an acid bath would later be developed that vastly improved fibre strength. The weak fibres produced by alkaline spinning baths led to the invention of the Topham Box, a piece of machinery that collected fragile filaments by centripetal force instead of by bobbin systems that incur strain and may break the yarns. The Topham Box was an important advance for the rayon industry and it is still used today as a gentle way to collect high quality, low denier yarns (Coleman, 1969; Woodings, 2001b). Between 1899 and 1904 the Viscose Syndicate was able to dispose of all of its patent rights. Most notably, the Courtaulds Ltd. bought the English rights in 1904 and would become the biggest player in the viscose rayon industry (Coleman, 1969).

When Courtaulds took over viscose spinning rights, many technical difficulties needed to be overcome to make quality, profitable yarns. Challenges included both engineering and chemical

problems, but by far the most prohibitive issue was the spinning bath composition. In its final incarnation the Kew laboratory process had viscose dope coagulating in an alkaline spinning bath, then treated with iron sulphate and finally fixed in an acid bath. At Courtaulds this process produced an output of which only one quarter was first grade. After experimentation a sulphuric acid bath with added sodium salts was developed, it had the triple advantage of producing more consistent fibre, eliminating malodourous ammonia and reducing costs. The advance was complicated however by a patent in the name of a chemist at the Donnersmarck viscose company in Germany. Courtaulds challenged the ambiguously worded patent and it was overruled in Britain, though not in continental Europe. Thus, Courtaulds was free to pursue the acid spinning bath. In 1907 the bath was further improved with the addition of glucose and again in 1910 with the addition of zinc sulphate (Coleman, 1969). Other developments that led to higher quality viscose filament included improvements to the Topham box between 1904 and 1907, a new viscose pump that ensured a steady flow of viscose to the spinning nozzles and a reeling machine which reduced the breakage of filaments. Problems persisted, however, and although a higher more consistent tenacity was achieved after 1910, the product was still inappropriate for fabrics to be washed in water (Coleman, 1969).

The trial and error involved in developing effective spinning techniques meant that a lot of broken filament was produced. An obvious use for the mounting stores of short waste filament was to spin it as staple fibre. Waste fibre was cleaned, baled and sold as 'artificial cotton' or 'artificial schappe' and patents were taken out on the process. However, cotton and wool shortages during WWI were the real stimulus to the development of viscose staple fiber. Originally Germany thought that viscose filament could make up for shortages. However, due to its weakness, smoothness and lack of warmth, applications were limited. Staple fiber viscose, in contrast, though still weak, had a softer, fuller hand and could be blended with wool or cotton to extend supplies (Coleman, 1969). Staple viscose came later to Britain. Courtaulds, after much research and development was just starting to produce filaments that resisted breaking during processing, and the notion of chopping them up was a tough sell. In 1921, however, when Courtaulds became financially interested in Snia Viscosa (Italy), they bought the rights to an Italian staple cutting machine and staple fiber production began in the UK. The use of staple fibres in the US however, was extremely limited (Coleman, 1969).

Around 1920, the conclusion of wartime restrictions in Europe, and the expiry of many basic patents allowed the rayon industry to expand rapidly (Coleman, 1969). World output by weight was at 32 million pounds and by 1941 it had risen to 2817 million pounds (including cellulose acetate). The 1920s also saw the rapid geographic spread of artificial silk production beyond the pioneering countries—to Italy in the early 1920s and Japan in the later 1920s—and the

increase in output from factories in the United States (Coleman). Technical advances, including the large-scale launch of viscose staple fibres, helped increase production. Through the 1930s viscose staple fibre and viscose staple fibre blended with natural fibres began to appear as a significant substitute for 100% wool and cotton (Coleman). Also, a variety of improvements to the strength, quality and appearance of viscose filament yarns led to more widespread application (Coleman). Tenacity was improved by the application of heat to the yarn during stretching between godets spinning at differential speeds and the use of higher proportions of metal salts in the spinning bath. Furthermore, research into washing the 'cakes' of filament that came out of the Topham box was undertaken so as to eliminate the step whereby cakes were reeled onto hanks, and in so doing limit opportunities for filament breakage (Coleman).

Another important advance in rayon production was the introduction of delustrants to the yarns. Viscose in its natural state is shiny, its luster often described as harsh or metallic (Coleman, 1969). What had been a positive characteristic at the turn of the century when shiny, silk-like fringes and tassels were stylish and symbols of status, had become a liability by the 1920s. Rayon was now being used to weave and knit broad fabrics and it was crucial that it should have a finish more in keeping with current tastes and one that did not so readily reveal its artificiality (Coleman). The aesthetics of viscose were improved with the introduction of dulled yarns through the addition of an emulsified oil to the spinning solution or later, in 1930, the addition of titanium dioxide. New duller yarns not only appealed to changing fashions but also helped stimulate the use of rayon in hosiery (Coleman).

The successful manufacturing process of viscose rayon ultimately includes the following steps (Table 1) starting with wood pulp, which is steeped in a 17-19% aqueous solution of sodium hydroxide which causes the fibres to swell and converts the cellulose to sodium cellusate, more commonly called alkali cellulose or white crumb. The swollen mass is then pressed so as to achieve a particular ratio of alkali to cellulose. After pressing, the cellulose is shredded to create sufficient surface area for uniform reaction in the following steps. The alkali cellulose is aged under controlled conditions so that oxidation occurs causing depolymerisation of the alkali cellulose to a desired DP. Next the alkali cellulose reacts with carbon disulphide to form sodium cellulose xanthate, occurring by the following equation:

$$\text{cellulose-O}^{-}\text{Na}^{+} + \text{CS}_2\,(\text{g}) \rightarrow \text{cellulose-OCS}_2^{-}\text{Na}^{+}$$

The xanthate is then dissolved in dilute sodium hydroxide to produce the viscous orange coloured solution called viscose (Wilkes, 2001).

To ready the viscose solution for spinning it is filtered, deaerated and ripened to the correct coagulation point or salt-index. The solution is then extruded through a spinneret into a spin bath consisting of sulphuric acid, zinc sulphate and water, often with the addition of a small amount of surfactant. The cellulose xanthate coagulates immediately into filaments as it is neutralized and then acidified in the spin bath. Controlled stretching and decomposition of the cellulose xanthate to cellulose also occurs at this point. Finally, the acid is washed from the filaments, they are then desulphurised in a liquor stream of NaOH/NaSH at about 60° C and pH 11-12. Any remaining sulphur or polysulphides are thus dissolved, so that they can be washed away. Next, the fibres are bleached with hydrogen peroxide and a processing lubricant finish is applied (Wilkes, 2001).

Table 1
Steps in the Viscose Manufacturing Process (Moncrieff, 1975; Schwarz & Mauersberger, 1936; Wilkes, 2001)

Step	**Description**	**Function**
Steeping	In historic viscose rayon manufacture, sheets of cellulose were placed in a rack and then submerged in a tank of soda (steeping lye). Today slurry steeping with high agitation is performed. Temperature and soda concentration parameters optimize steeping; 45-55° and 17-19% is usual. Duration is 10-15 min.	To convert the cellulose to its alkoxide derivative. It is critical that both amorphous and crystalline regions are converted. To dissolve out short chain material
Pressing	Alkali cellulose is pumped between rollers with a between 5 and 15 mm gap.	Reduces ratio of alkali to cellulose
Shredding	Alkali cellulose shredded.	Alkali cellulose is relatively dense after pressing, shredding opens up the alkali cellulose and facilitates the penetration of oxygen and CS_2
Mercerizing or Pre-ageing	Oxidative depolymerisation using time and temperature to control required DP. Chain length is reduced by a combination of free radical and alkaline degradation.	Reduces the DP of alkali cellulose. As received, pulp has a DP of 750-850. Pre-aging reduces the DP to the 270-350 needed to go to xanthation
Xanthation	The mercerized alkali cellulose reacts with vapour to produce sodium cellulose xanthate. It is a heterogeneous reaction performed in a vacuum. Reaction: cellulose--$O^-Na^+ + CS_2 \rightarrow$ cellulose--$OCS_2^-Na^+$	The process yields a soluble derivative, sodium cellulose xanthate
Dissolving of Xanthate	Xanthate is dissolved in dilute sodium hydroxide solution of the required concentration to give the final target percentages of cellulose and soda. Usually the concentration of soda is 1-2%. Lower temperatures improve solubility.	Forms the viscose solution

Step	Description	Function
Ageing	The viscose dope is allowed to sit until such a time that tests reveal that the degree of xanthation and the evenness of xanthation are such that the cellulose is well solvated. The tests are described in more detail by Moncrieff (1975)	Dope must be aged before spinning so that the CS_2 can be distributed evenly along the cellulose chains. This step is critical to achieving good fibre properties
Filtration	Historically cloth filters were used in filter presses to remove particulates, usually there were three stages of filtration each with a number of parallel 'plate and frame' units. Modern viscose plants have automatic mechanical filters that utilize metal screens with holes in the 10-20μm range	Even if the cellulose is well solvated there is always particulate material in the viscose, this impurity needs to be removed prior to spinning so it does not block the spinneret
Deaeration	Cone, film or tank deaerators are employed where a vacuum is applied while the viscose is passed over a surface to maximize its surface:volume ratio.	Removes air bubbles or any other dispersed gas that would otherwise cause discontinuity at spinning
Additives	Diverse additives can be added via a barrel mixer around 10-15 min. prior to spinning	Titanium dioxide would have been added at this point to dull viscose yarns
Spinning	The viscose dope is extruded through a sulphuric acid bath by the following main reaction: 2 cellulose-O CS_2 Na + $H_2SO_4 \rightarrow$ 2 cellulose-OH + Na_2 SO_4 + 2 CS_2	Regenerates the cellulose
Modifiers	During the 1920s and 1930s the primary modifier used was zinc sulphate. When zinc sulphate is added the above regeneration reaction actually occurs via the more stable zinc cellulose xanthate in some regions of the fibres. Zinc sulphate is soluble up to around pH 8.5, so this material penetrates into the forming filaments ahead of neutralization by the sulphuric acid. However, at certain point the acid's penetration into the filaments overtakes that of the zinc sulphate and is thought to form other zinc species (Wilkes, 2001). The region in which zinc cellulose xanthate has formed is believed to be responsible for the skin effect that can be seen in rayon cross-sections.	The transient zinc complex is believed to aid the formation of greater crystallinity by delaying regeneration relative to sodium cellulose xanthate, and possibly by cross-linking neighbouring cellulose chains allowing greater orientation to occur Due to the effect of zinc on crystallinity and orientation it ultimately translates to increased tensile strength
Stretching	Fibre is stretched by running the filaments over a godet roller at a slower speed than the final traction units. Some stretch may also be applied in the spin bath where a significant speed differential exists between the extrusion speed and the faster take-up speed at the godet.	To achieve acceptable tensile properties. At the very early stages in regeneration the structure is not fixed within the filaments, and therefore the cellulose chains that will constitute the fibre can be aligned by stretching increasing crystallinity and orientation

Rayon Dyes and Dyeing

Cellulosic fibres in general, and cotton in particular have affinity for a large number of dye-classes; moreover, all dye-classes which can be used for dyeing cotton can also be applied on rayon, provided the alkalinity is low (Choudhury, 2006). Rayon is dyed with sulphur dyes, direct dyes, vat dyes, reactive dyes, azoic dyes, diazo colours, naphtol dyes and dope dyed using pigment. The above techniques have varying degrees of wash- and light-fastness, direct dyes generally having the least degree of fastness and pigments used for dope dyeing having the greatest. Today, direct dyes are used only for cheap rayon fabrics and articles that are not usually washed, such as blended curtain fabrics, furnishings and carpets (Choudhury, 2006). During the 1920s and 1930s, however, the majority of rayon was dyed using direct dyes as they were cheap, simple to apply and did not require strong alkaline conditions (Choudhury, 2006). Boulton (1951) writes that, "direct cotton dyes took pride of place in the coloration of the new fibre…[given] the early viscose rayons were physically weak and of variable characteristics, and thus, economics and end-uses apart, it was natural that a chemically inactive one-bath dyeing process should receive first attention to the exclusion of two-bath mordanting and coupling methods, or strongly alkaline vat and sulphur dyeing methods" (p. 67).

Hottenroth (1928) and Schwarz and Mauersberger (1936) both suggest that though virtually all classes of dyestuffs were used to dye rayon, direct cotton dyestuffs or 'substantive' dyes were the dyes in most widespread use. Hottenroth, however, also emphasizes the use of basic dyestuffs. On the one hand these statements seem to suggest that many fabrics must not have been particularly colourfast. As discussed above, even with modern dyeing techniques and knowledge of chemistry, direct dyes are not used where washfastness is a priority; moreover, basic dyestuffs even when used with a mordant were discontinued for use with cellulosics as several better dyes entered the market (Choudhury, 2006). Schwarz and Mauersberger write that the fastness properties of direct dyes on rayon are, "sufficient for most purposes". However, expectations of dye-fastness were likely lower in the early 20th century, as home-laundering guides from the period included sections on how to deal with bleeding dyes (Ahern, 1941; Jackman & Rogers, 1934; Johnson, 1927; Making smart clothes, 1930). On the other hand, Hottenroth writes that, "substantive dyes offer the advantage, apart from simple methods of dyeing, that they usually give results which are very fast to water and light and better than those obtained with basic dyestuffs (Hottenroth, 1928, p. 343)." Hottenroth also writes that the indanthrene or indigo-type of dyes were of, "particular importance in the case of artificial silk, as by their means both yarns and piece goods can be dyed to produce results extremely fast to washing, which are also very fast to light if the dyestuffs are rightly chosen" (p. 343). However, it is unclear to what extent this sort of dye was actually employed. Similarly, Schwarz and Mauersberger extol the virtues of vat dyes for

their high affinity for rayon and the bright shades they produce. But, special skill and experience was required to apply them and it was difficult to achieve level dyeing.

Based on these contrasting statements it can be assumed that for the most part rayon was dyed using inexpensive dyes with limited colourfastness, however select fabrics were dyed using other classes of dyestuffs to achieve more permanent colours. Boulton (1951) supports this. He states that though direct dyes were initially used almost exclusively, over time as the fibres became stronger viscose rayon was dyed according to the degree of fastness required.

Viscose rayon and cuprammonium rayon, in addition to cotton, have generally the same affinity for dyestuffs and show essentially the same reactions towards most chemicals used in the textile process. However, they are sufficiently different that a single dyestuff will not dye them a uniform shade (Schwarz & Mauersberger, 1936). Marshall and Peters' (1947) work on the affinity of direct dyes for cellulosic fibres suggested that the mode of attachment of direct dyes to cuprammonium rayon, viscose rayon and cotton is the same, and is highly dependent on the molecular structure of the dye; thus, differences in dyeing behaviour of the various cellulosic fibres arises solely from differences in their physical structure (Marshall & Peters, 1947). Prior to dyeing, rayon required little processing, only scouring to remove sizing, washing and/or bleaching with hydrogen peroxide or sodium perborate for knit goods if light colours were desired, and mordanting if the dyestuff necessitated it (Hottenroth, 1928; Schwarz & Mauersberger, 1936). Rayon is said to have been dyed in much the same way as other textile materials at the time, though with greater care in handling owing to the 'sensitivity' or low wet strength of the fibre. Hottenroth (1928) describes that the greater portion of artificial silk was dyed in hank form in ordinary troughs or vats, heated by leaden tubes, in which the hanks are dipped on glass or smooth wooden rods. Due to the sensitivity of the yarns, the dyeing process was carried out as quickly as possible, lasting from 30 to 45 minutes. Piece dyeing was also employed: goods were dyed on the jigger or winch dye beck, whereby fabric is continually carried through the dye-bath by rotating rollers or reels (Hottenroth, 1928).

Direct dyes, also termed substantive dyes—since dye molecules attach directly to the fibres without the aid of mordants—are chemically sodium salt of sulphonic acid derivatives of organic aromatic compounds containing one or more azo group (Choudhury, 2006). This group of dyes is applied in aqueous solution usually with the addition of common salt or Glauber's salt and caustic soda or soda ash. Other additives were sometimes added including bast soap, gelatin, glucose, starch or similar protective colloids, also Turkey-red oil or Monopol soap to exert a leveling effect, that is a uniform deposition of the dyestuff on the fibre (Hottenroth, 1928). The temperature is varied depending on the colour and shade desired (Choudhury, 2006; Hottenroth,

1928; Schwarz & Mauersberger, 1936). Hottenroth (1928) suggested that in the early 1920s when artificial silk was still more sensitive, too long an exposure of the fibre to the hot bath at too high temperatures was avoided as far as possible; however, he suggests that by the end of the decade, fibres were strong enough to enter dyebaths at near boiling temperatures. It is beyond the scope of this literature review to explore the theory of viscose direct dyeing. However, more information can be found in Boulton (1951) and Standing (1945). Dyeing with basic dyestuffs was carried out similarly to direct dyes but the yarn was mordanted in successive baths of tannic acid and tartar emetic, then rinsed and well washed prior to dyeing (Wheeler, 1931).

Schwarz and Mauersberger (1936) cite various different after-treatments applied following direct dyeing in particular. Formaldehyde could be applied to increase washfastness, and copper and chromium salts to increase light and washfastness, though they were known to dull the shades. Other after-treatments included copper sulfate, copper sulfate in combination with potassium bichromate and chromium fluoride. Schwarz and Mauersberger did not explicitly describe what these latter treatments achieved, but did warn that rayon yarns can become harsh after treatment with metal salts.

Structure of Rayon Fibres

Similar to plant fibres such as cotton and linen, rayon is made up of cellulose. However, during the rayon manufacturing process, as outlined above, native cellulose is altered. Dissolution and regeneration changes the structure and properties of rayon as compared with natural cellulose fibres, not only in terms of morphology, but also in terms of rayon's molecular arrangement.

Molecular Structure of Rayon Fibres

The cellulose molecule is the basic molecular unit that makes up rayon. Cellulose molecules consist of a series of glucose rings joined together (Figure 3). The cellulose molecule is a long-chain molecule with a ribbon-like structure, and can be bent and twisted to some extent, particularly at the glycosidic ether bonds. Protruding from the chain are hydroxyl groups (-OH), which can form linkages with other hydroxyl groups or water molecules by means of hydrogen bonding. This results in neighbouring chains linking together and/or water molecules being incorporated into the molecule (Morton & Hearle, 1993).

When neighbouring cellulose chains link together, forming hydrogen bonds, the chains position themselves closely, packed tightly together. Such compact, ordered arrangements of molecules form what are called crystalline regions in the fibre. However, the type of crystal lattice formed in crystalline areas differs in regenerated cellulose and natural cellulose fibres (Morton & Hearle, 1975). Cellulose can crystallize in a variety of allotropes designated cellulose I through

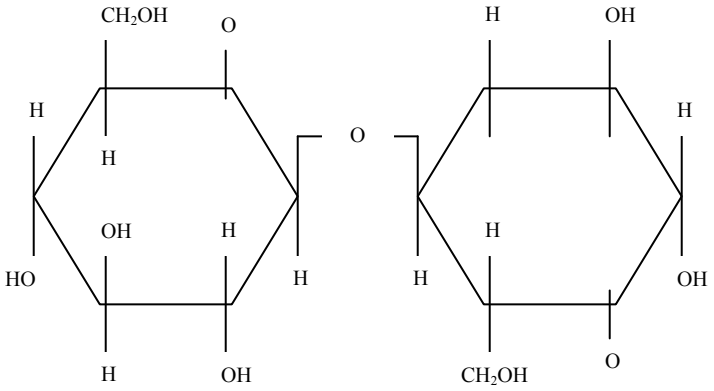

Figure 3. Basic unit of cellulose, two anhydroglucose units with a 1-4 β-glucosidic linkage.

IV. Due to the asymmetry of atoms in the glucose rings, cellulose chains are directional, and as such can be arranged with either parallel or anti-parallel packing. The crystal lattice in regenerated cellulose consists for the most part of cellulose II, thought to have anti-parallel packing. Native cellulose on the other hand is made up of cellulose I in which long-chain molecules are packed parallel to one another (Hearle, 2001). The result of parallel vs. anti-parallel chains in the crystal lattice affects how square molecules are to the chain axis. The unit cells of cellulose II are offset, such that the angle of interaction between two units of the crystal lattice is 62° as opposed to 84° as in cellulose I (Figure 4). The reason for this allotropic modification is that regenerated cellulose structure is formed rapidly and organization of the macromolecules is limited by the amount of tangling present in the solution; in contrast, native cellulose structure develops slowly under conditions of thermodynamic equilibrium (Lewin, 2006). In addition to having a different crystal lattice structure, the length of the cellulose chain molecules is also different. In native cellulose

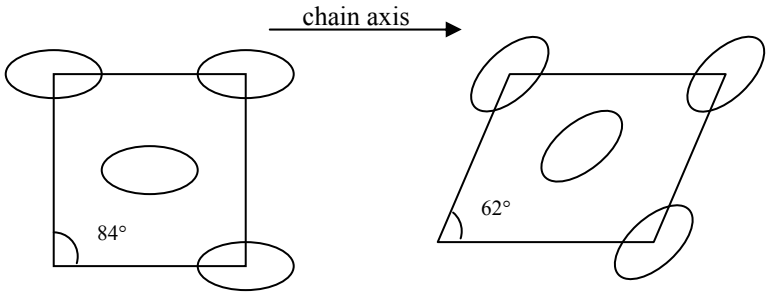

Figure 4. Cellulose I and cellulose II crystal structure (adapted from Timár-Balázsy & Eastop, 1998, p. 31).

fibres, chains are composed of approximately 10^4 glucose rings. The chains are thus about 5 μm long by 8 x 10^4 μm wide. In the case of rayon, chain length is reduced considerably in the viscose spinning solution; molecules must be short enough such that the solution's viscosity is sufficiently low to make extrusion possible. During the pre-ageing stage of production the degree of polymerization (DP) or number of glucose rings in the chain is reduced to between 270-350. When the cellulose is regenerated the chain length has just enough time to regenerate to a DP of about 500. In comparison, cotton fibres have a DP of approximately 10,000 (Morton & Hearle, 1993).

Fine Structure of Rayon Fibres

The fine structure or supra-molecular structure of rayon differs from that of natural cellulose fibres including cotton. The arrangement of cellulose molecules is less ordered in rayon than in cotton. Both x-ray diffraction photographs, showing regular patterns and a diffuse halo, and chemical evidence, whereby only part of the fibre is accessible to chemical reactions, confirm that cellulosic fibres are divided into two regions: crystalline regions, in which molecules are arranged in a regular order and amorphous regions in which there is relative disorder to molecular arrangement (Morton & Hearle, 1975). X-ray diffraction has also shown that the crystallites are small – many times shorter than the molecules themselves so it is believed that single molecules pass through both crystalline regions and amorphous regions (Morton & Hearle). In regenerated fibres such as viscose and cuprammonium rayon, crystallinity is limited to one-third of the fibre area, with the remaining two-thirds made up of amorphous regions. In contrast, estimates of crystallinity for cotton fibres are generally accepted to be in the range of two-thirds crystalline and one-third amorphous. (Morton & Hearle). The amorphous nature of rayon is further confirmed by calorimetric work performed by Suñol et. al. (2007) whereby upon heating at high temperatures the exothermic peak for viscose rayon occurs at a lower temperature than other cellulosic fibres. A lower exothermic peak indicates that the bonds within the fibre were more easily rotated and broken with the application of heat. Molecules in crystalline regions are more strongly bonded and thus resist rotation breakage and higher temperatures.

Factors that affect molecular orientation in regenerated cellulose fibres are different from those at work in natural cellulose fibres. Regenerated cellulose fibres' degree of orientation depends both on the orienting forces in the spinning process and the extent to which filaments have been stretched during manufacture. In natural cellulose fibres, molecules are highly oriented to one another but spiral around the fibre axis reducing the orientation relative to the fibre axis. The orientation of natural cellulosic fibres is fairly consistent across a plant species and depends on how the cellulose grows; for example, in cotton the spiral angle lies between 20° and 30°, and thus the fibres can extend by stretching the spiral (Hearle, 2001; Lewin, 2006). In 'low-stretch'

viscose rayon the orientation factor (ratio of the birefringence of the fibre in question to the birefringence of a hypothetical fibre with perfect axial orientation) is 0.54 as compared to 0.88 in 'high-stretch' viscose rayon, and between 0.62 and 0.72 in cotton (Morton & Hearle, 1975). The stretching process was added to rayon production during the early 1920s resulting in increases in the strength of rayon fibre. However, advances in the stretching process proceeded incrementally, so for the purposes of this paper an orientation closer to 0.54 can be assumed for most rayons from the 1920s and 1930s.

Since the cellulose molecules aggregate faster though regeneration than growth, regenerated cellulose fibres differ in structure from natural cellulose fibres. Where rayon fibres form almost simultaneously across their cross-section, natural fibers are essentially built up in layers, with certain parts identifiable and distinct from other parts formed previously and subsequently. As a result, rayon fibres have one less level of division within the fibers. Unlike natural cellulosic fibres, whereby cellulose aggregates into fine microfibrils that can be observed under optical microscopes or more clearly using scanning electron microscopy, rayon does not show a level of division between the molecular level and the fibre level (Morton & Hearle, 1975).

Morphology of Rayon Fibres

The morphology of rayon is a function of the process utilized to produce it (Table 2). The regeneration of rayon fibres from a viscose solution results in filaments with an irregular cross-section and the presence of a skin and core (Figure 5)**.** The serrated nature of the cross-section is created when immediately after extrusion the skin is formed and then collapses as solvent is removed from the core. The reason the skin/core formation occurs is that regeneration of the cellulose in the skin occurs via an intermediate product, zinc cellulose xanthate (Morton & Hearle, 1975). The rates of alternative reaction favour this route over direct regeneration; however, the

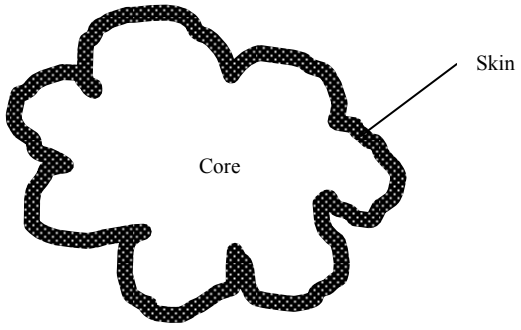

Figure 5. Cross-section of a viscose rayon fibre, showing the skin and core structures (adapted from Hearle, 2001, p. 202).

Table 2
Aspects of manufacturing processes that affect the structure of rayons (Hearle, 2001)

Rayon Type	**Structural Effect**	**Process**
Cuprammonium Rayon	Round cross-section, thin skin, compact core	Solution in cuprammonium hydroxide, formation of copper complex of cellulose, coagulation in water.
First Viscose Rayon	Consistent structure throughout, no striations, round cross-section, low crystallinity and orientation.	Sodium cellulose xanthanate dissolved in caustic soda, coagulated and regenerated in acid bath.
Viscose Rayon	Zinc ions help order cellulose molecules prior to regeneration; zinc cannot penetrate core so results in skin-core structure, striations, better crystallinity and orientation in the skin; stretching improves orientation.	Sodium cellulose xanthanate dissolved in caustic soda, coagulated and regenerated in acid bath, zinc atoms added to acid bath, followed by stretching.

low mobility of zinc ions prevent them from penetrating the core fast enough (Morton & Hearle). Bivalent zinc ions attract the cellulose molecules into a network prior to regeneration and as such, the structure of skin and core differ (Morton & Hearle). The skin contains more numerous, smaller crystalline regions whereas the core sustains fewer larger crystallites. Since molecules in the skinpass through many more ordered regions than the core, the skin is stronger than the core (Hearle, 2001; Lewin, 2006). Various modifications to the viscose process led to an increase in skin thickness and ultimately in 'all skin' fibers with bean-shaped cross-sections. All skin fibres are high-tenacity rayons, which were originally developed for tire cords and then later used for other textile purposes though not during the 1920s and 1930s (Hearle, 2001). Cuprammonium rayon has a circular cross-section and no visible skin; however under magnification a thin skin that is more porous than the compact inner core can be identified (Kamide & Kazunari, 2001).

Fibre Properties of Rayon

Rayon has many unique fibre properties, however, the properties having to do with moisture sorption and strength (Table 3) will be discussed here as these properties affect how rayon degrades and is damaged.

Table 3
Some Fibre Properties of Viscose Rayon, Cuprammonium Rayon and Cotton
(Kamide & Kazunari, 2001; Morton & Hearle, 1975)

Property	Viscose Rayon	Cuprammonium Rayon	Cotton
Absorption regain (%) (65% RH, 20°C)	12-14	-	7-8
Swelling in liquid water (Area %)	50-114	-	21-40
Tenacity (N/tex)	0.18 (filament)-0.21(staple)	0.22	0.45
Initial Modulus (N/tex)	4.8 (filament)-6.5 (staple)	-	7.3
Elastic Recovery (%) from 5% extension (60% RH; 90% RH)	32; 28	-	52; 59

Moisture Sorption

Early rayons did not hold up well to wet cleaning. Rayon garments were notorious for shrinking and owing to extremely low wet strengths, garments often were damaged during washing (Johnson, 1927). The property that accounts for this behaviour is moisture sorption. The moisture regain of rayon (12-14% at 65% RH) is nearly double that of cotton (7%-8%) (Morton & Hearle, 1975). In liquid water, rayon shows swelling in cross-sectional area of 50%-114% as compared to 21%-40% in cotton. This swelling alters the dimensions of the fibre, which in turn will cause changes in the size, shape, stiffness and permeability of yarns and fabrics (Morton & Hearle, 1975). Moreover, the mechanical properties and the frictional properties are altered, thereby affecting the behaviour of the fibres in processing and in use (Morton & Hearle, 1975).

The difference in moisture sorption between rayon and cotton is due to differences in both crystal structure and fine structure. The cellulose I crystal structure found in native cellulose shows an unchanged X-ray-diffraction pattern upon the absorption of water, indicating that no moisture is absorbed into the crystalline regions (Morton & Hearle, 1975). The cellulose II crystal structure that makes up rayon, however, is slightly less compact than cellulose I and changes in structure upon absorption of water due to the formation of a hydrate containing one water molecule to every three glucose residues (Morton & Hearle). Once the rayon is wet there is further modification of the crystal structure owing to the formation of a hydrate with three water molecules to every two glucose residues (Morton & Hearle). This sort of absorption corresponds to about 1% of the moisture regain in the whole fibre.

Even more than crystal structure, fine structure is a factor in the amount of water that can be absorbed into a fibre and accounts for the remaining 99% of moisture regain in rayon. Amorphous regions are accessible to moisture. Unlike crystalline regions, where the fibre molecules are closely packed and held together by hydrogen bonding, water molecules can easily penetrate into the amorphous region. In contrast, in crystalline regions the active hydroxyl groups would need to be freed from intermolecular hydrogen bonding to form bonds with water molecules (Morton & Hearle, 1975). Thus, the fact that rayon has one third more amorphous regions than cotton, for the most part, accounts for rayon's greater moisture regain.

Tensile Properties

The tensile properties of rayon, as reflected in stress-strain curves vary considerably depending on the type of rayon and how it was manufactured. The biggest difference exists between stretched (high wet modulus rayon) and unstretched rayon fibres. Stretched fibres have better molecular orientation, thus showing higher strength and little extensibility, similar to bast fibres. Unstretched fibres, in contrast, are weaker but are more extensible (Morton & Hearle, 1993). The rayon from the 1920s and 1930s resembled unstretched rayon, although some stretching was undertaken during manufacture. Stress-strain curves for rayon that resembled those of bast fibres were not achieved until the 1950s when the extent to which fibres were stretched was much greater. The stress-strain curves from 1945 for a number of fibres including cotton, staple viscose (Fibro), viscose rayon filament (Viscose rayon) and an early high wet modulus viscose fibre, Lilienfeld rayon (Durafil) is depicted in Morton and Hearle (Figure 13.15, p. 282).

The stress-strain curves for viscose rayon and cotton are distinct, demonstrating the disparate tensile properties of the two cellulose fibres. The stress-strain curve for cotton is slightly concave and there is no clear yield point. This stress strain curve indicates that cotton has low extensibility and relatively high strength (Morton & Hearle, 1993). In contrast the stress-strain curves for rayon show a rapid initial rise with a marked yield point, followed by a nearly flat portion and rise more rapidly again as break approaches. This curve indicates that a small applied force leads much greater extension in rayon than cotton and that rayon fibers are considerably weaker than cotton; rayon having a tensile strength of approximately 0.18 N/tex and cotton having one between 0.32 and 0.45 N/tex (Morton & Hearle). Difference in fine structure is the main factor that affects the incongruent tensile properties of rayon and cotton. Rayon fibres are weaker since their shorter molecular chains are incorporated into fewer crystalline regions where intermolecular bonding imparts strength. Finally, a lower degree of orientation means that fewer polymer chains share the load of forces applied along the fibre axis.

It is important, however, to acknowledge the limitations of fibre tensile properties as a measure of textile artifact strength. Morton and Hearle (1993) point out that the properties of

textile structures such as yarns or fabrics depend on a, "complex interrelation between fibre arrangement and fibre properties" (p. 265). Moreover, when damage to artifacts is considered, a further level of interaction is introduced. Thus, while knowledge of fibre properties is critical to understanding the properties of yarns, fabrics and even garments, it is not in itself sufficient. Fibre properties do, however, give a limit to what is possible in a yarn or fabric, as the strength of a yarn will not exceed the sum of the maximum strengths of its component fibers (Morton & Hearle).

Effect of Moisture on Tensile Properties

Rayon is weaker than cotton when dry; if moisture is added, the effect is magnified. All fibres become more extensible with the uptake of moisture, the modulus becomes lower and the breaking extension greater. However, whereas cotton and other natural fibres become stronger through the addition of water molecules, regenerated cellulose fibres become weaker. Morton and Hearle (1993) report that wet cotton increases strength to 111% of its tensile strength measured at 65% RH, whereas normal viscose rayon, when wet, retains only 50% of its tensile strength measured at 65%. Therefore, the tensile strength of rayon changes from about half the strength of cotton when dry to only one fifth the strength of cotton when wet (Table 3).

Rayon Degradation and Damage

Physical Damage

Shrinkage

Potential shrinkage of rayon garments during laundering or conservation wet cleaning is a source of concern. It is by far the type of damage reported most often in historic fabric care sources (Ahern, 1941; Jackman, 1934; Johnson, 1927) as well as contemporary textile science texts (Hatch, 1993). In rayon fabrics shrinkage occurs as a result of two factors: a release of tension introduced during manufacture, called relaxation shrinkage, and fibre swelling, or an increase in fibre diameter. During weaving, the warps and sometimes the wefts are held taut; moreover, during dyeing and finishing the fibres are hot and wet and are therefore easily molded into the new taut shape. Since fabrics are often dried under tension frictional forces between the yarns and fibres hold the taut configuration (Hatch). A more stable configuration for the yarns occurs when there is a slight yarn crimp in both the lengthwise and the crosswise yarns. Wetting, in combination with a surfactant and agitation, decreases the frictional forces between yarns and fibres and allows the fabric to assume a more stable state (Hatch). Once the yarns are in the more stable, crimped position the length of the fabric is diminished and shrinkage occurs (Hatch).

The second reason for rayon shrinkage is fibre swelling, which can lead to both fibre shrinkage and fabric shrinkage. Upon swelling, molecules of the fibre separate because of increased molecular mobility caused by the presence of the increased number of water molecules.

Since there is strain introduced into most fibres, including rayon, during processing the swelling action of water allows for the release of that strain and the molecules can slide along one another and reorganize into a relaxed or 'energetically favourable' configuration (Timár-Balázsy & Eastop, 1998). The small water molecules penetrate the amorphous regions of the polymers preventing close contact between the polymer chains and thereby increase the free volume in these regions leading to a decrease in fibre length. (Timár-Balázsy & Eastop) In addition, fibre swelling leads to swelling of the yarns in which fibres are incorporated through yarn twist. Swelling does not just fill the spaces between the fibres in the yarn, rather, the yarn diameter increases, which in turn means that yarn crimp increases at the expense of fabric length. When the fabric dries it remains in its shrunken state due to frictional forces between the fibres and yarns (Hatch, 1993)

There are two reasons that rayon exhibits particularly great shrinkage compared to other cellulosic fibres: first, rayon has a large proportion of amorphous regions where water can access the fibre and cause relaxation; second, rayon exhibits high extensibility thus a small amount of strain during processing will cause a great amount of stretch which is in turn eliminated upon wetting, so long as the yield point has not been surpassed[2] (Timár-Balázsy & Eastop, 1998). However, since rayon has a low yield point (Morton & Hearle, 1993, fig. 13.15) it is likely that during wet processing, such as dyeing and finishing the yield point is exceeded and that stretch will not be recovered.

Water and the character of yarns and fabrics affect the extent of shrinkage in rayon fabric. The effect of water on regenerated cellulose, under completely free conditions causes swelling of the fibres resulting in a decrease in fibre length and a decrease in fabric length due to increased crimp (Hatch, 1993; Timár-Balázsy & Eastop, 1998). The extent of yarn swelling depends greatly on the fibre density of the yarn. If the fibres are loosely packed in the yarn, the effects of lateral fibre swelling are reduced, as there is space for the fibre to expand into. The twist of the yarns and the construction of the fabric also play an important role in the swelling and subsequent shrinkage of the fabric. For example the close spacing of warp and weft yarns results in greater swelling-shrinkage effects because there is no room within the existing dimensions of the fabric for expansion; conversely, more open structures such as twill weaves display these effects to a lesser degree because swollen yarns expand into free spaces leaving dimensions unchanged (Timár-Balázsy & Eastop, 1998). Knowing how shrinkage occurs can be used to avoid it through restraint. Timár-Balázsy and Eastop (1998) suggest that water sensitive historical textiles are sometimes dried under tension in order to prevent or reduce molecular retraction and retain the strained state of the fibre. This would only be possible, however, if the fibres are strong enough to withstand the restraint during drying.

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[2] See discussion of swelling, p. 25.

Mechanical Damage

Mechanical damage typically happens during a garment's use life (when the garment is being worn or used in another capacity, as opposed to when it is being stored in as part of a collection) or due to improper handling in collections. First of all, the low wet strength of rayon means that during wet cleaning garments are weaker and may be damaged easily. Second, the extensibility of rayon suggests that rayon would be prone to stretching and bagging, particularly in areas such as the knees and elbows of garments, or at the shoulders of garments stored on hangers. A further disadvantage of rayon garments cited in the 1920s is that smooth rayon fibres 'slipped' and 'separated' from neighbouring fibres, particularly at the seams where there was strain. Also, rayon was reported to run easily in knitted fabrics (Woman's Institute of Domestic Arts & Sciences, 1923). Fibres had a tendency to slip at seams which led to holes and fraying (Johnson, 1927, p. 95). Finally, rayon is susceptible to mildew and some other microorganisms. Depending on the microorganism susceptibility can range from slightly susceptible to very susceptible. Rayon has resistance to moths and silverfish but not to termites or roaches (Zeronian, 1977).

Chemical Deterioration

In addition to physical deterioration, chemical deterioration is a significant factor in the overall integrity of rayon objects. Like other cellulosic fibres, rayon degradation involves two main chemical reactions: oxidation and hydrolysis. The severity and the rate of reactions depend on the concentration and strength of chemical compounds involved, the temperature, and the presence of catalysts. The deterioration, as exemplified by yellowing, loss of mechanical properties and embrittlement, also depend on the chemical properties of the given cellulosic material, characterized in turn by the functional groups and by the degree of polymerization (Lewin, 1997).

Oxidation

In the context of degradation, oxidation can be defined as, "the reaction of an organic compound with oxygen in such a way that oxygen is consumed and new chemical species are formed" (Grattan, 1980, p. 18). Two different types of oxidation occur on rayon. Thermal oxidation proceeds in the absence of light and accelerates with increase of temperature. Photo-oxidation is initiated and propagated by light energy absorbed by the material or by dyes or impurities associated with it.

Thermal Degradation.

Cellulose, and in turn rayon shows little tendency to degrade in the absence of light unless previously irradiated (Grattan, 1980). However, some oxidative degradation is always occurring, even at room temperature though cellulose is much more susceptible to thermal

oxidation at high temperatures. As more heat energy is added the temperature rises and an ever increasing number of molecules have sufficient energy to decompose (Grattan). Though high temperature thermal degradation is not often an issue within the museum context, it should be noted that rayon is more susceptible to thermal degradation than cotton. Ciolacu & Popa (2006) demonstrate that the cellulose II crystal structure of rayon, shifts the maximal temperature of thermo-oxidative destruction toward lower values, as compared with the cellulose I crystal structure of native cellulose.

Testing by Houston & Fletcher (1940) confirmed that heat does indeed cause degradation of both viscose and cuprammonium rayons. Exposure to heat at 270°-280° for between 10 – 60 hours lowered the breaking strength of all samples considerably and increased the copper numbers of both the cuprammonium and viscose rayons from approximately 1 to 5. The copper number is essentially an index of those end groups in the polymer chain that result from degradation indicating reduction in degree of polymerization.

Heat is present in small amounts at normal temperatures and leads to very slow oxidation of rayon garments. At higher temperatures arising during production or when garments are ironed thermal degradation is accelerated causing a more rapid oxidation of fibres. This sort of oxidation can result in embrittlement of fibres, a lowering of their pH and yellowing.

Photo-chemical Oxidation.

Light is an agent of oxidation and photo-oxidation poses a risk to rayon. When electromagnetic radiation is absorbed free radicals are formed which have the strength to alter or break bonds. (Timár-Balázsy & Eastop, 1998). Oxidation occurs in two general areas of the cellulose molecule: at the side groups causing changes in colour, polarity and sorption properties and at the glycosidic linkages on the main-chain of the polymer, which leads to a decrease in DP affecting in turn fibre mechanical properties.

Photo-oxidation of cellulose is a heterogeneous reaction. The reaction begins in the more accessible amorphous regions of the fiber, but in time attacks the more stable crystalline regions of the fibre (Timár-Balázsy & Eastop, 1998). The rate of reaction depends on a variety of factors including the condition of the cellulose, the wavelength and intensity of radiation, the amount of available oxygen, temperature, moisture content and presence of catalysts (Timár-Balázsy & Eastop). The oxidation of side groups, converts hydroxyls to aldehydes and with further oxidation to carboxyls, or changes hydroxyls first to ketones before they become aldehyde groups and finally carboxyl groups (Kronkright, 1992; Timár-Balázsy & Eastop, 1998). Oxidation at the glycosidic linkages between units of cellobiose occurs when UV radiation creates free radicals. This sort of photo-oxidation is usually catalyzed by moisture and sensitizing agents such as heavy

and transition metals (Timár-Balázsy & Eastop). The resulting chain-scission occurs mainly in amorphous regions of the fibre. The proportion of crystalline regions in the fibre therefore increases and fibres become rigid and brittle (Timár-Balázsy & Eastop). Carbonyl groups that appear in early stages of photo-oxidation function as chromophores and cause yellowing in objects (Kronkright, 1992; Timár-Balázsy & Eastop, 1998). The carboxyl groups that appear with continued photo-oxidation are acidic and colourless and cause subsequent fading of yellowing in the final stages of light degradation (Timár-Balázsy & Eastop).

Two studies have explored directly the affect of light on rayon. On subjecting rayon and cotton fabric samples to accelerated aging, Block (1982) found that the initial rate of discoloration of rayon is greater than that of cotton; however, cotton discoloration catches up over time. Block suggests that this could be the result of higher surface area of finer rayon filaments, the protective dense cuticle in cotton or a combination of the two. In another study, Houston & Fletcher (1940) found that after irradiating samples of viscose crepe, taffeta and satin and cuprammonium sheer and twill fabrics for 120 hours at 4,000 foot-candles (43055.6 lux) produced a 15-25% strength loss. No one fibre or fabric structure exhibited significantly different results. In addition, the samples showed little to no change in colour upon exposure (Houston & Fletcher). The lack of yellowing may suggest that the samples were not irradiated for long enough or at high enough intensities to result in visible light degradation and yellowing.

Sensitizing of Rayon.

The addition of certain dyes and pigments to rayon fibres results in accelerated photo-chemical degradation or photosensitizing. Titanium dioxide (TiO_2), added to rayon as a delustrant, is a particularly strong accelerant of photodecomposition. Titanium dioxide was originally applied to rayon fibre as a dulling finishing agent. Later, a wash-fast titanium dioxide treatment was achieved by adding the deslustering agent to the spinning solution. Unfortunately the titanium dioxide acts as a catalyst of photochemical changes for both the fibre and dyes (Timár-Balázsy & Eastop, 1998). Photosensitized oxidation of polymers by TiO_2 pigments involves the formation of a hydroxyl radical, which is believed to be the reactive species (Allen & McKellar, 1980). Photosensitized oxidation is most damaging at wavelengths of light 300 nm and higher in the presence of oxygen and is accelerated in the presence of humidity. This oxidation generally manifests itself as 'chalking,' whereby the surface of the fibre is gradually eroded away (Allen & McKellar). In addition titanium dioxide can affect the resistance of rayon fabric to bending, as the small crystalline particles can exert a cutting force on the fibres (Timár-Balázsy & Eastop).

Certain vat dyes are also a problem when it comes to the photosensitization of cellulosic fibres. Egerton (1948) examined this effect on both rayon and cotton. He found that rayon fabrics

dyed with the sensitizing agents suffer accelerated photodegradation. In addition, he found that adjacent undyed samples suffered greater degradation when relative humidity was high and samples were adjacent to fabrics dyed with Cibanone Yellow R dye. Egerton suggests that this is due to the formation of a volatile oxidizing agent, namely hydrogen peroxide, liberated by the vat dyes in the presence of atmospheric moisture. A similar outcome was found in the cotton samples; however, the effect of the peroxides from adjacent fibres was greater on cotton with all dyes and not just Cibanone Yellow R dye. Egerton concluded that liberated hydrogen peroxide is not sufficient to cause appreciable degradation of undyed viscose rayon, except with the Cibanone Yellow R dye, apparently because rayon is more resistant than cotton to photochemical oxidation by small amounts of hydrogen peroxide (Egerton, 1948, p. 665).

The acceleration of aging in cotton by iron present in dyes is well known to conservators (Timár-Balázsy & Eastop, 1998). Rayon also appears to be susceptible to the degradation accelerating effects of iron salts. Shevchenko et. al. (1980) found that impregnation with bivalent and trivalent iron salts accelerated the thermo-oxidative degradation of the cellulose in rayon within the temperature range 175°C to 240°C. There is a lack of evidence of photosensitization in rayon artifacts by iron salts; however, the chemistry of the fibres suggests that it is likely.

Hydrolysis of Cellulose

Hydrolysis literally means a reaction with water. It is a chemical process whereby a molecule is cleaved into two parts by the addition of a water molecule. One fragment of the parent molecule gains a hydrogen ion (H^+) from the water molecule. The other group takes up the remaining hydroxyl group (OH^-). In the case of rayon and cotton, hydrolysis chemically degrades the cellulose molecules by chain scission, thus breaking apart the cellulose polymer backbone causing a decrease in degree of polymerization. Hydrolysis is most often catalyzed by either an acid or an alkali.

Acid Hydrolysis

Though cellulose is relatively stable to dilute aqueous acids, the glycosidic linkages in cellulose are susceptible to acid-catalyzed hydrolysis. The mechanism of reaction consists of three steps. First, the glycosidic oxygen atom undergoes rapid protonation. Second, the positive charge is slowly transferred to C-1 forming a carbonium ion and causing fission of the glycosidic bond. Finally, water rapidly attacks the carbonium ion causing it to release a free sugar residue and reform the hydroxonium ion (Nevell, 1985). The culmination of these three steps is chain scission of the cellulose molecule resulting in decreased in DP.

Acids affect different types of cellulose at different rates; in particular, rayon hydrolyses faster than cotton. Michie, Sharples and Walter (1961) exposed cellulose specimens to acids under

different conditions. After, hydrolysis specimens were nitrated and their intrinsic viscosities were converted to degrees of polymerization to determine how many bonds had been broken in a 30 x 10^{-4} s time frame. It was found that more than four times as many bonds were broken in regenerated cellulose as in cotton (Michie et al.). Further evidence that supports the more rapid hydrolysis of regenerated cellulose as compared to cotton has to do with leveling off degree of polymerization (LODP). Nelson and Tripp (1953) found that the rate of hydrolysis curve for cotton leveled off at 220 DP as compared with rayon at 45 DP; moreover, rayon's DP continued to decrease at a higher rate than cotton. When hydrolysis is extensive, the decrease in DP gradually approaches a plateau (LODP). Once LODP is reached hydrolysis does not stop, rather the inaccessible glycosidic bonds at the edges of the crystalline regions are then hydrolyzed but at a much slower rate (Nevell, 1985).

Theoretical explanations for why rayon hydrolyses more rapidly than cotton are related to fine structure. First, cotton is much more crystalline than rayon; therefore, hydrogen-bond networks render larger areas of the fiber inaccessible to acids. Rayon, in contrast, has a larger proportion of amorphous regions; therefore, more glycosidic linkages are accessible to acids and hydrolysis proceeds at a faster rate than cotton. (Michie et al., 1961). Second, both natural and regenerated celluloses degrade to varying extents in the presence of acids, at initial rates which are greater than that calculated for the normal 1-4 β glucosidic bonds (Michie, et al). So-called 'weak bonds' account for this and there are many more in regenerated cellulose than native cellulose. Not only does increased amorphous regions in rayon mean that more weak bonds are accessible to acid attack, but more weak bonds appear to be created during the regeneration process (Michie et al.). Finally, the lower proportion of crystalline regions in regenerated cellulose lead to more rapid acid hydrolysis and in the crystalline regions the supra-molecular structure (normal chair conformation) is maintained since bond rotation is inhibited. The supra-molecular structure, which is dependent on a hydrogen-bond network, renders a high proportion of glycosidic linkages inaccessible to acid (Nevell, 1985). Since acid hydrolysis occurs at a faster rate in rayon than in cotton, faster deterioration due to acid hydrolysis should be observed in rayon artifacts as compared to cotton artifacts.

Alkaline Hydrolysis.

At temperatures above 170°C random alkaline scission or hydrolysis of cellulose occurs leading to a substantial loss of weight and a decrease in DP (Nevell, 1985). Cellulose, and in particular the glycosidic linkages in cellulose, are stable to alkalis at temperatures less than 170°C (Nevell, 1985). However, a significant reduction in molecular weight has been observed when cellulose is boiled with dilute sodium hydroxide, despite the careful exclusion of oxygen and maintenance of temperatures below 170°C (Knill & Kennedy, 2003; Nevell, 1985). Alkaline

hydrolysis causes dissolution of short chain material detached from the reducing ends of the cellulose molecule ('peeling' or 'unzipping'), which does not result in a lowering of DP (Nevell, 1985). The principal mechanism of this 'end-wise' degradation of cellulose by alkalis consists of the formation of or D-glucoisosaccharinic acids (3-deox-2-C(hydroxymethyl)-erythro and threo-pen-tonic acids). Next, through β-alkoxycarbonyl elimination the D-glucoisosaccharinic acid is released from the rest of the cellulose chain. This action exposes a new deprotonated end group, which, in turn, undergoes further alkaline degradation (Knill & Kennedy). A 'stopping' reaction competes with the alkaline degradation reaction and results in the creation of a stabilizing acid terminal unit, thus halting the alkaline degradation chain reaction. The rate of the stopping reaction depends on access to end groups: molecules in amorphous regions are more susceptible than those in crystalline supra-molecular structures (Knill & Kennedy, 2003).

Sources of Acids and Alkalis

At all stages of existence, including production, use life and collected life, rayon artifacts can come into contact with both acidic and alkaline contaminants. Environmental contaminants and pollution are other possible sources of acid in historic textiles. Sulphur dioxide and nitrogen dioxide can react with liquid water or water vapour to produce sulfuric and nitric acid respectively and artifacts can come in contact with volatile acids from unfinished wood and paper products (Tétreault, 1994, 2003). Acid can also be introduced through soiling, perspiration, and some food stains (Rice, 1972). Sources of alkaline agents of deterioration include bleaching and scouring processes during production and laundering and bleaching processes performed during the use-life of the objects or conservation cleaning after the objects entered museum collections (Schwarz & Mauersberger, 1936; Timár-Balázsy & Eastop, 1998).

History of the Use of Rayon in Fabrics and Fashion

The history of rayon's use in clothing is important in that it informs curators, researchers and conservators where in collections rayon might be found. There has been limited research on the varied ways rayon was used in fabrics and clothing. This sort of knowledge may help reveal dates and locations of manufacture of artifacts, information that in turn, contributes to a more complete knowledge of materials.

Despite wide interest in dress history, the the emergence of man-made fibres and their impact on fashion and society has not yet been extensively researched. Texts on dress history typically include little discussion on the impact of new fibres and deal with fibre content in a cursory fashion. In the more detailed accounts, mention of rayon is limited to such statements as "the development of rayon was one of the most significant textile breakthroughs of the inter-war years…rayon became a great asset to the mass market," and "as production techniques improved, making a pleasingly dull finish available by 1926, rayon began to be used for day and evening

dresses as well as fashionable knitwear" (Mendes & De La Haye, 1999, p. 75). One reason for the lack of interest in rayon might be that rayon was not extensively used by couturiers around whom a large proportion of 20th century dress scholarship revolves. A notable exception is research carried out by Susannah Handley (1999), which focuses mainly on nylon and later synthetic fibres, but does include some discussion of manufactured cellulose fibres. Handley, discusses such issues as the "democratization of luxury" when nylon was developed and the effect that synthetic fibres had on the concept of "Better Living." The use of the first manufactured fibres in clothing during the 1920s, 1930s and beyond, however, is an area ripe for further exploration with implications for the relationship between technology and clothing and consumption of fashion by new economic classes, among other issues.

Three authors who do delve into this topic area are Stewart, De La Haye and Field in their respective articles *Marketing Fabrics and Femininity in Interwar France* (2004), *The Dissemination of Design from Haute Couture to Fashionable Ready-to-wear during the 1920s* (1993) and *Dyes, Chemistry and Clothing the Influence of World War I on Fabrics, Fashions and Silk* (2001). The findings of these articles will be discussed in more detail below. Moreoever, there are authors who have researched early rayon within other disciplines, including from a textile science perspective (Kamide & Kazunari, 2001; Woodings, 2001a), from an economic history perspective (Allen, 1946; Coleman, 1969) and from a manufacturing perspective (Hottenroth, 1928).

Artificial Silk

Before rayon was robust enough to be woven into broad fabrics, 'Artificial Silk', as it was then called, was made into decorative ribbons and trimmings. The first such fibre, cellulose hydrate or Chardonnet silk[3], looked much like natural silk and was marketed at similar prices and for similar applications as silk. Woodings (2001a) makes the point that Chardonnet silk was assured an early success based on its novelty despite having only half the dry strength of silk, even less than that when wet and was much more prone to shrinkage. Chardonnet silk was thus used for decorative trimmings, ribbon, lace and embroidery in the first decade of the 20th century (Woodings, 2001a). Cuprammonium entered the artificial silk market just after Chardonnet silk and, with slightly less luster, took a somewhat lower price. An advertisement for cuprammonium rayon produced by VGF in July 1900 says: "(1) The luster is brighter than that of natural silk. (2) The luster is exceedingly valuable for fancy thread for weft in silk, woolen and cotton goods. (3) The fibres are largely used for laces, galloons, fringes, girdles, furniture stuffs, ribbons, tricots, embroidery etc. (4) The fibre dyes equal and uniform" (Kamide & Kazunari, 2001, p. 95). In the first two decades of the 20th century viscose rayon was not strong enough for uses beyond fringes,

[3] For more information on Chardonnet silk see p. 10.

tassels, braids, lace, embroidery and ribbons, etc. As, Coleman (1969) points out, however, "Fashion's whims were kind" (p.62), and Edwardian fashion and interior design favoured shiny, silky, decorative embellishments a purpose to which artificial silk was particularly suited so there was significant demand for viscose

The goal, however, was always the weaving of broad fabrics, which would bring in significantly more revenue than the much smaller market of embellishment yarns. Prior to the First World War, Courtaulds in particular was eager to put viscose to use in a wider range of applications than Chardonnet silk and cuprammonium rayon (Coleman, 1969). Luckily, Samuel Courtauld & Company was also involved in textile weaving. Thus extensive practical experimentation could be done in the company's own mills. Indeed, Courtaulds' mill at Bocking took the entire output of the Courtaulds' viscose factory for the first years of operation and with modification of weaving processes to suit the new viscose yarns, advances were made (Woodings, 2001a). Towards the end of 1906 the first broad-woven fabrics with some viscose rayon yarns, began to sell. The fabrics were striped, an effect achieved with alternating bands of rayon and cotton across the warp, and then filled with 100% cotton weft yarns. This sort of fabric was an ideal solution as the rayon did not significantly affect the bulk fabric properties. Furthermore, the viscose yarns took up more dye than the cotton yarns, and the viscose stripes thus appeared darker than the cotton stripes emphasizing the two fibre effect (Woodings, 2001a).

The shift to an acid spin bath in mid-1907 finally allowed for viscose filaments of sufficient strength to be used as filling yarns and eventually as main warps. Courtaulds branded the fabrics woven with the stronger viscose wefts, 'Luvisca,' which found application in shirting (cotton warp), blouses (silk warp), and lining fabrics (cotton or silk warps). Moreover, in 1914 Courtauld's Halstead Mill had 200 looms strung with 100% viscose warps. At the same time, viscose knitting became another outlet for viscose when Wardle and Davenport of Leek acquired a knitting machine designed for suitable for use with artificial silk yarns in 1912. At the outbreak of war in 1914 hosiery was the biggest single market for viscose both in Europe and North America (Woodings, 2001b).

In America, war, played a large role in the establishment of a lively rayon industry. Field (2001) looks at how the First World War affected fabric and clothing in the US. Chemicals, in particular dyestuffs had been produced for the most part by German coal-tar products, leading to a shortage during the war. Field suggests that such shortages led to a change in the attitudes of Americans toward the chemical industry. She identifies three factors that contributed a psychological shift: an increase in the awareness of the role chemical processes played in modern industrial society, the war legacy of an American infrastructure including experienced chemical

engineers and manufacturing plants and, finally, the realization that if dye could be prevented from crossing the ocean perhaps at some point silk might also be prevented from crossing another ocean. Field (2001) argues that these factors and the shift in mind-set was responsible for the rise in rayon production during the 1920s: "In pre-war years banks and financiers could not imagine anything substituting for silk and thus had no interest in investing in artificial silk…[Within] a brief three years of the war's end, by 1921, a corporate American artificial silk industry was well organized, consisting of three viscose manufacturers—Viscose Corporation, Dupont, Nemours and Company, Tubize Artificial Silk of America" (p. 86). Therefore it may be that in America, more so than in the pioneering European countries, envisaging rayon as a substitute for silk was a major impetus in the development of the regenerated cellulose industry.

Rayon Staple Fibre

Though filament rayon is often given more attention, likely due to its importance for the technology it foreshadows with respect to synthetic fibres, rayon staple fibre began to be produced on a greater scale in the 1920s and made up a significant portion of rayon output by the end of the 1930s (Table 4; Figure 6.) Staple fibre production was advanced in particular during WWI in Germany where cotton shortages were acutely felt due to the Allied blockade of ports. Viscose yarn was cut, cleaned and baled so that it could be used to extend cotton supplies. This initiative helped the technical development of staple fibre, but unfortunately gave the fibre the reputation of a poor war-time ersatz for cotton or wool (Allen, 1946; Coleman, 1969; Hottenroth, 1928; Woodings, 2001a). To produce staple fibre, instead of collecting the filaments on a bobbin or in a centrifugal pot, the filaments from each spinneret were gathered together into a continuous rope or tow, which is cut into short lengths varying from one and a half to six inches depending on whether it will by processed on either cotton or worsted machinery (Allen, 1946).

In Britain, Courtaulds produced staple fibre from wastes and in 1921 began marketing the fibre as 'Fibro' (Woodings, 2001a). Moreover, after buying Snia Viscosa, the large Italian producer of viscose, Courtaulds was exposed to the successes of their 'Sniafil' staple fibre process and decided in 1928 to increase emphasis on staple fibre production (Coleman, 1969; Woodings, 2001a). In spite of the economic depression, there was considerable expansion of staple fibre production in the 1930s in Germany, Italy, Japan, Britain and especially after 1935 in the USA (Figure 6) (Allen, 1946; Woodings, 2001a).

Table 4
Rayon Fibre Output 1921-1928 in millions lbs. per annum (Hague, 1957, pp. 29-31)

	Continuous Filament			Staple Fibre			
Year	**U.K.**	**U.S.A.**	**World**	**U.K.**	**U.S.A.**	**World**	**% Total***
1921	9.0	15.0	48.2				
1922	14.5	24.1	76.6				
1923	17.0	35.0	103.0				
1924	24.7	36.3	138.3				
1925	29.8	51.0	185.0				
1926	25.5	62.7	211.7				
1927	38.7	75.5	295.1				
1928	52.0	97.0	360.5				
1929	52.7	121.4	435.4	2.6	0.5	7.2	5%
1930	47.0	127.3	451.1	0.8	0.3	6.3	1%
1931	52.7	151.0	499.7	0.8	0.9	8.0	1%
1932	69.9	134.7	516.9	1.2	1.1	17.3	3%
1933	80.0	213.5	665.4	2.4	2.1	28.0	4%
1934	88.9	208.3	771.4	2.4	2.2	51.8	6.3%
1935	108.0	257.5	935.4	7.9	4.6	138.9	12.9%
1936	111.6	277.6	1020.8	24.6	12.3	300.3	22.7%
1937	115.2	320.5	1196.5	30.5	20.2	625.9	34.3%
1938	102.7	257.6	997.5	32.4	29.8	930.6	48.2%
1939	115.2	328.6	1149.6	57.6	51.3	1090.8	48.6%

*Staple fibre as a percentage of total world rayon production

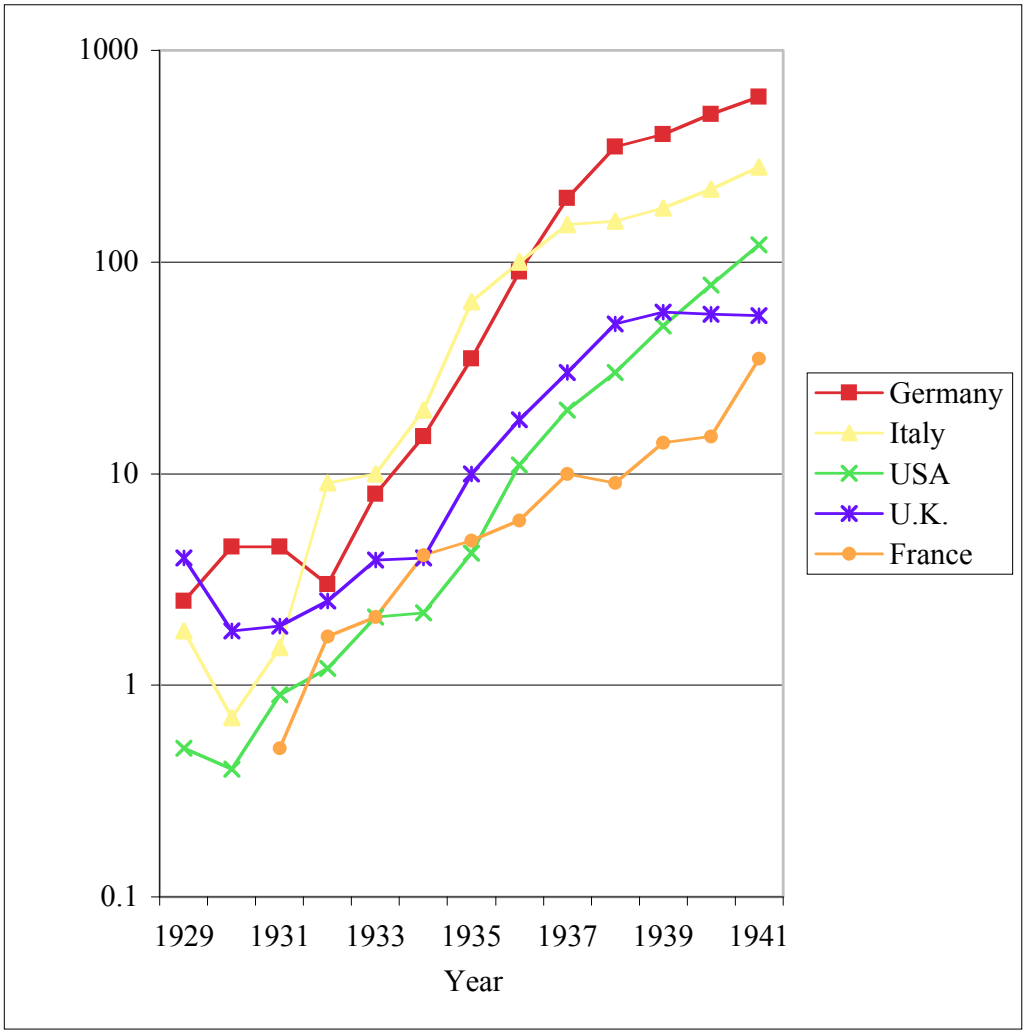


Figure 6. Staple fibre production by country, 1929-1941 (adapted from Coleman, 1969).

Staple fibre was made into a variety of different types of fabrics and garments. According to Allen (1946), it was used to create: "twills used for men's, women's and children's garments such as dresses, skirts, playsuits, shirts, slacks, housecoats, and robes; spun rayon prints whose soft texture makes them suitable for dress and sportswear purposes; spun rayon and wool twills made in several weave-patterns and a variety of duotones, light-weight spun rayon and cotton suitings…[,]spun rayon and flax prints available in patterns and plain suits" (p. 153).

Rayon and Fashion in the 1920s and 1930s

The 1920s and 1930s were important decades for rayon, marking the period during which the first manufactured fibre made inroads into the fashion sector with stronger fibres that were woven and knitted into a great variety of broad fabrics. As such, the uses for rayon fabrics extended beyond the conventional linings and shirtings and entered the world of fashion,

represented in bespoke outerwear, fashionable ready-mades and to a lesser extent, in high fashion. It was also during this period that artificial silk or 'art silk' was officially renamed 'rayon', further serving to establish early man-made fibres as a class of their own and not merely a cheap imitation of natural fibres.

In 1925 the U.S. Federal Trade Commission formally recognized the term 'rayon' for all types of 'artificial silk', including manufactured cellulosic fibres made by the nitro, viscose, cuprammonium and acetate processes, after the term was invented and endorsed by the American Viscose Company. The term, however, was much slower to catch on overseas where conservative pioneers such as Samuel Courtauld and French producers alike were reluctant to change the terminology. In 1929 Courtaulds finally announced to customers that henceforth, artificial silk would be called rayon. British government departments, though, continued to use the term 'artificial silk' for years to come, even combining silk and artificial silk together in various statistics, rendering them virtually useless (Coleman, 1969). Thus, the term rayon was used in America in the 1920s, but in Britain the term did not come into widespread general use until the end of the 1930s. It was not until the 1950s that the need to differentiate regenerated cellulose fibres from modified cellulose fibre (acetate) was recognized (Scroggie, 1950). Soon after, the difference between these two fibre groups was acknowledged and rayon fibre conformed to the contemporary definition. The practice of calling cellulose acetate 'acetate rayon' was persistent, however, into the second half of the 20th century.

In addition to a change in name, rayon producers worked very hard during the 1920s and 1930s to change the perception of rayon from a cheap wartime substitute to something more desirable. Stewart (2004) investigates how changing silhouettes in women's fashion in the 1920s and 1930s were accompanied by a discourse surrounding the fabric of which garments were made – often 'feminine' fabrics emphasized movement and thus counterbalanced what was otherwise viewed as masculine cuts of clothing. Association with just these new, modern fashions, whereby rayon's properties of good drapability, luster and slipperiness were an asset, improved the image and perception of rayon. A favourable cachet also led to rayon's use in more 'high end' fabrics; for example, 'Rosalba' was an artificial silk and natural silk blend launched by esteemed Lyonnais silk company, Bianchini Férier, in the early 1920s. Initially the fabric was used primarily in lingerie; but by the 1930s rayon blend fabrics had made inroads into ladies outerwear such as evening pajamas and draped dresses. Stewart writes that, in the French context, high stature silk firms such as Bianchini Férier worked new artificial silk fibers into blends because, "it made light silks more durable without losing the soft supple quality of silk" and that "artificial silk appealed in an era before the advent of easy-care fabrics, when most bourgeois Frenchwomen had limited wardrobes" (Stewart, 2004, p. 105). Moreover, Stewart states that the increase in numbers of

artificial silk producers gave birth to advertisements for artificial silk that stressed its aesthetic similarities and its practical differences from natural silk, "notably how easily it could be washed" (p. 105).

De La Haye (1993), also examines how new silhouettes in the 1920s influenced and encouraged the use of rayon fabrics in fashionable outerwear. De La Haye discusses early practices of copying designer fashions and producing cheap ready-mades constructed out of inexpensive, newly available rayons. Copying designer garments in the 1920s was encouraged by a variety of factors including the increase of women in the workplace earning a wage that could be spent on clothing and the simplicity of 'Garçonne Look' styles which had unstructured shapes that meant sizing issues were minimized and less fabric was required. During the 1920s couturiers created decadent beaded and embroidered silk evening dresses; manufacturers of ready-mades could not recreate the handwork and fine embellishment of designer gowns but they could imitate silk fabrics by using rayons (including acetate). De La Haye emphasizes that rayon had a significant effect upon the appearance of women's clothing during the 1920s. Though rayon had been used as cheap linings for menswear in the immediate post-war years, it had its breakthrough in the production of stockings for which the demand was kindled by the fashion for shorter skirts. By the 1920s the quality of rayon was improved such that it became available as dress fabric; it could be spun to mimic cotton, wool and linen as well as silk and could be added to fibre blends. However, despite rayon's versatility, De La Haye reports that British producers were still unable to overcome the excessively shiny appearance of early manufactured fibres, nor could they provide the natural elasticity of pure silk which helped to prevent bagging at the knees and elbows of garments made from these new fibres.

A unique aspect of De La Haye's (1993) work is that her research is largely based on an extant collection of ready-made rayon garments, the Hodson dress shop collection in Willenhall near Birmingham. The dress shop never held a sale to move unsold merchandise, which resulted in an unwitting collection that was donated to the local museum, untouched since the mid-1950s. De La Haye describes the collection as consisting of "economical and medium quality items" (p. 43). Much of the merchandise from the 1920s is made of rayon and reflects fashionable 'Garçonne' designs of the period. Many of the garments even have their original price tags, with rayon dresses costing between 10s. and 1 pound and short-sleeved knitted rayon sweaters costing 14s. 11d. (De La Haye, 1993) The Hodson collection also includes 1920s rayon evening dresses decorated with machine embroidery and rayon flower trim, rayon stockings, knitwear, hanks of rayon yarn, rayon and silk blend scarves and wool and rayon knitted suits. In addition to providing a rich source of information on 1920s dress practices, the Hodson dress shop collection, though unique, is an example of the sorts of rayon artifacts that may exist in other museum collections.

Finally, De La Haye (1993) states in stark contrast to Stewart (2004) that, "there were shrinkage problems with rayon which did not make it suitable for everyday wear during the 1920s and thus was considered a special material reserved for 'best clothing'" (p. 46). These contrasting statements are of particular interest from a conservation point of view and lead to questions of exactly how robust early rayon fabrics were and are today, especially when it comes to wet cleaning. De La Haye's remarks are certainly in keeping with the general reputation of early regenerated and modified cellulose fibers. But it is hard to believe that these fabrics would be marketed as 'durable' and the equivalent of easy care in France if they shrink or tear easily during laundering. Likely the explanation lies somewhere between zealous product promotion in France and the fact that the fabrics Stewart refers to were in all probability blended materials, whereby stronger natural fibres such as cotton and silk provide strength and support for the weaker rayon fibres (M. L. Stewart, personal communication, May 2008).

Information on the story of early rayon in Canada is scanty. *Women's Dress in the 1920's* by Collard (1981) is an interesting combination of archival and material culture scholarship, combined with personal anecdotes by the author about her teenaged years during the 1920s in a Canadian border town. Collard offers one Canadian perspective on fashion in the 1920s, briefly touching on 'rayon' (likely including acetate) use and the types of damage it often sustained. She writes:

> Rayon, until 1924 known as 'artificial' silk had been introduced some years earlier, but it was not until this decade that it was really promoted by dress manufacturers. Most of the 'art silk' knitted dresses and cardigan suits were sleazy in appearance and soon lost their original shape and fit. When left on dress hangers for any length of time they sagged and stretched into ugly lines making it very difficult to return such garments to their proper silhouettes. Plain weave rayon fabrics of rather uninteresting appearance were used to make mass produced summer dresses and blouses. These poor quality materials raveled at the seams and disintegrated if very much heat was applied when pressed. Colours used to dye the cloth bled and streaked (p. 29).

Rayon and Couture

While rayon may have been viewed generally as a cheaper substitute for silk during the 1920s and 1930s, some avant-garde fashion designers did use rayon during this period. Two such designers were Elsa Schiaparelli and Madeleine Vionnet. In August 1932, Schiaparelli launched a new silhouette, new colour and new fabric all of which were received enthusiastically by the press. The new fabric was 'Jersela' a slippery satin rayon jersey in cabbage rose colour that was exclusive to the house. Schiaparelli was known for her use of unusual materials and fabrics; for example, fabrics with crinkle effects had been included in her collection since 1932 (Blum, 2003). One particular type of crinkle effect fabric was called 'tree-bark': a rayon crepe that Schiaparelli

used both in clothing and to decorate the bedroom of her Paris apartment. The bedcover, chair cover and curtains were made of a shiny, textured rayon material (Blum, 2003, p. 76). There is no mention of the exact fibre content or the finish that was applied to the rayon crepe to create the crinkle effect; this, and the fact that there are many other examples in the catalogue of rayon garments, both in the form of photographs and extant artifacts begs for more research into what inspired Schiaparelli to use manufactured fibers and how they were received. In this context, rayon was likely used for a different set of reasons that had nothing to do with the fabric being less expensive and everything to do with its unique properties and the perhaps subversive nature of using a fabric that was not traditionally associated with high fashion.

Fabric Care and Laundering of Rayon in the 1920s and 1930s

Though rayon is a cellulosic fibre, it is almost always grouped with protein fibres in fabric care guides of the period. Rayon is likely grouped with silk in particular, as it was often used in similar applications, because in the early years it needed to be treated much more gently than cotton, and as a vestige of its original name, 'artificial silk'. For example, even in a 1947 mending and cleaning guide, it is suggested that chlorine bleach may be used with cotton and linen whereas peroxide bleach is suggested for rayon, silk and wool (Brooks Picken, 1946 p. 133). Moreover, a spot-cleaning approach is often recommended on its own for rayon whereas with cotton and linen it is almost always suggested in conjunction with full laundering (Brooks Picken, 1946 p. 133). When laundering is suggested for rayon it is once again grouped together with silk. Gentle suds in lukewarm water without rubbing or twisting are suggested. In contrast, cottons and linens are to be soaked for 15 minutes to four hours and washed in water between 100 and 140° F. Drying suggestions also differ for cotton and linen as compared to rayon and silk. It is suggested that the former are hung outside to dry. The latter, however, be rolled and pressed in a towel and kept away from direct heat or sunlight; moreover, it is suggested that rayon be handled with care as fibres are weak when wet (Brooks Picken, 1946).

Two home household science guides from the 1930s emphasize the careful handling that was suggested when laundering rayon garments of that period. In a 1930 guide to washing clothes, rayon is not singled out for any particular care except to say that clothespins should never be used with rayon. This source describes washing for the modern wardrobe as:

1. Prepare moderately warm suds, with mild, pure soap—flakes, beads or cakes.
2. Squeeze or knead the suds through the garment from three to five minutes.
3. Rinse two or three times in lukewarm water.
4. Squeeze the water from the garment.

5. Roll tightly for a few minutes in a bath towel
6. If the colours are doubtful, remove from the towel at once and shake, preferably in front of an electric fan, until dry enough to iron.
7. Iron on the wrong side with a moderate iron before the garment has become entirely dry.

(*Making smart clothes,* 1930)

A second household science guide from the 1930s has similar advice with respect to how rayon should be laundered: gentle squeezing only in warm soapy water (Jackman & Rogers, 1934). When the fabric is to be lifted out it should be supported with the hands. The author writes, "Greater care in handling is necessary owing to the fact that most artificial silks lose strength when wetted and occasionally a fabric is met with which loses most of its strength" (Jackman & Rogers, p. 74).

Shrinkage of rayon fabrics is also considered in historical laundry guides. Ahern (1941) considers this issue in her "Laundry Clinic" section in which she describes particular examples of laundry 'emergencies' and how to deal with them. Two cases of rayon shrinkage appear in this section. First, with regards to a sheer rayon dress, Ahern writes, " ever so many women wash them only to find that they shrink so much in washing that they are apparently unwearable. In many cases, women do not even bother to iron the garments, thinking that it isn't worthwhile. However, this is a mistake for most rayon sheers can be pulled out to shape and size very easily by pressing damp" (p. 116). The shrinkage of a second sort of rayon fabric Ahern discusses has a much less favourable outcome than the sheer dress. In this case marquisette rayon curtains were washed, the curtains shrank and no amount of stretching could restore their length. Ahern's advice was, "If Mrs. J. had inquired about the washing qualities of her curtains at the time of purchase, she would have learned that unless it has been specially treated, some shrinkage should be expected from rayon marquisette. With this to serve as a guide, it would have been easy for her to select a slightly longer length to allow for the expected shrinkage" (pp. 120-121). This advice suggests that the yarns and weaves of rayon play a significant role in the dimensional stability upon wetting.

Conservation of Rayon

There was a considerable gap between the introduction of rayon fibres in the early 20th century and its consideration for conservation by Zeronian in 1977, one of the first to call attention to these fibres in a conservation context. However, 1977 is not a particularly late date to be tackling rayon's preservation for the first time as conservation of cultural property was only established as a serious discipline in the early 1970s (Ruggles, 1980). Zeronian pointed out the huge man-made fiber industry and the importance of exploring how to preserve its products. Zeronian surveyed different types of man-made fibres including rayon and discusses

environmental factors that can degrade them, in addition to methods for the "identification or estimation of such damage" (p. 208). In addition to oxidation, photo-degradation and the effects of pollutants, which affect all fibres irrespective of whether they are natural or man-made, Zeronian identified polymer modification and the presence of additives as particular factors that affect the preservation of man-made fibers. Moreover, Zeronian touched upon a key problem when it comes to research on the preservation of man-made fibres, namely, that they are ever-developing and therefore current information gathered about fibres cannot necessarily be directly projected onto the past (p. 212). Zeronian also identified means of identification of man-made fibres, (burn tests, longitudinal and cross-sectional examination by light-microscope, solubility tests, staining tests, fibre density, infrared spectroscopy, differential thermal analysis and gas chromatography).

In addition to Zeronian's (1977) general publication on man-made fibres there has been some research on the specific treatment of rayon artifacts. Research has been undertaken on alkaline buffering of rayon to retard degradation and deacidification of rayon by NH_3 vapour. In addition, Ferreira (1999) has surveyed the perceived need for conservation research on manufactured fibres among conservators in the US. These areas of research are not surprising, given that there is yet little research on the conservation of rayon, and given that rayon is expected to degrade more quickly than cotton due to its molecular structure. It is also notable that there is no research on the wet-cleaning of rayon, a potentially problematic treatment but, one that could help extend the life of rayon by removing acidic degradation products, if washing could be carried out in a way that was safe for the artifact.

Block (1982) studied the potential of alkaline buffering treatment to slow degradation of rayon fabrics. Block soaked samples of plain weave 80 x 80 spun rayon cloth in solutions of either sodium carbonate (0.01%) or calcium hydroxide (0.01%) and then baked them in a 150°C oven to simulate ageing. He found that soaking new rayon cloth in the calcium hydroxide solution and allowing it to air dry could increase its lifetime by a factor of 2.5. The sodium carbonate treatment, in contrast, was not found to be effective in retarding degradation, likely due to residual sodium ions that remained in the fabric even after rinsing. Sodium has been tied to accelerated aging in paper (Block). Despite the success of the calcium hydroxide solution in increasing the rayon's lifetime, a subsequent experiment showed that though the treatment did enhance resistance to strength loss, it had little or no effect on the yellowing of the fibres (Block). The treatment appears to have reduced the rate of chain scission but not the side chain oxidation that is related to yellowing (Block). Since testing was performed on new rayon fabrics, it is unclear if this would be an appropriate treatment for aged rayon. The results are similar to those found for alkaline buffering of cotton (Kerr, Jennings, & Méthé, 1989; Kerr, Hersh, & Tucker, 1984). Despite the evidence that alkaline buffers do slow the rate of degradation of cellulosic fabrics including rayon,

this is not a technique used extensively by textile conservators in part because acidic ageing is less of a problem with textiles than it is with wood-pulp paper for which the treatments were developed.

Telford (1993) presents two case histories of early regenerated cellulose textiles. Telford developed a treatment for a dress that consisted of a silk under dress and what she identifies as a cuprammonium rayon overdress dating from 1912[4]. In the cuprammonium rayon overdress, Telford found that in addition to soiling and mechanical damage, the cuprammonium rayon appeared to be fairly degraded and brittle, being particularly weak in the weft. Wet cleaning was the desired treatment method to stabilize the cuprammonium rayon as it would have removed soiling, creasing and acidity; however, wet cleaning was ruled out as a possible treatment as the underdress and braid embellishment contained fugitive dyes. Stitched stabilization was performed, but humidification was avoided, as Telford feared that by-products of degradation might become acidic with the addition of even small amounts of water, and attack the textile.

The above treatment raised some issues such as whether the textile could have been neutralized without wet-cleaning and what effect would wet cleaning have on the tensile strength of other early regenerated cellulose textiles (Telford, 1993). As such, testing was carried out on the 1920s viscose rayon kimono. The kimono appeared to be in good condition; however, on close examination the weft threads seemed extremely weak. Samples included a control sample, one that was wet-cleaned with a non-ionic detergent, one that was treated with NH_3 vapour and finally one that was treated with NH_3 vapour and then rinsed in deionized water. The goal of the experiment was to test ammonia vapour treatment as a means of deacidifying the textile without wetting it and to ascertain whether conversion of the acids to ammonium salts would render the acids more easily removable in wet cleaning.

Three samples were tested, one was given a standard wet-cleaning treatment, the second was placed in a desiccator with a small amount of aqueous ammonia solution (15%) and had the humidity raised, the third sample was treated as with sample two but was rinsed in deionized water after exposure to the ammonia solution. Tensile strength of the fabrics before and after treatment was performed on an Instron apparatus on warp and weft fabric samples. Once the textile was wetted it contracted quickly in both warp and weft directions. It required some manipulation to reshape upon lying out to dry, an action complicated by the fragile nature of the weft. Telford suggests that the overall textile was minimally strengthened by the wet cleaning (increase of 1.05 kg/denier in the weft and 0.3 kg/denier in the warp). The ammonia vapour treatment also caused

[4] The dating of the overdress raises some questions. 1912 is an early date for cuprammonium rayon and one that is not consistent with the uses of cuprammonium rayon at that time.

minimal changes in strength, positively for the weft (increase of 1.1 kg/denier) and negatively for the warp (decrease of 0.3 kg/denier). The ammonia vapour combined with a rinse treatment produced a slight decrease in strength (0.53 kg/denier for the weft and 2.5 kg/denier for the warp). Prior to treatment all fabric samples were acidic (pH 4.5). All samples, however, had neutral pH after treatment. Based on the results of this study Telford concludes that depending on the specific characteristics of the textile early rayon artifacts may be wet-cleaned if extra care is taken. She also concludes that ammonia vapour works as a deacidification treatment for regenerated cellulosic textiles, though concedes that its effects may be "too ephemeral to be worthwhile" (p. 210). The design of this experiment, however, makes any conclusions highly tentative. Since only one sample was tested per treatment, it is impossible to know if the differences noted are due to the treatments or to normal fibre and fabric variation.

Having observed that conservation information specific to manufactured fibres is not prevalent, Ferreira (1999) attempted to quantify the perceived need for conservation research related to man-made fibres. Ferreira distributed questionnaires to 310 conservators and had 65 respondents. Ferreira used Likert scale items (strongly agree, somewhat agree, neutral, somewhat disagree, strongly disagree) to explore questions about the relative challenges of manufactured and natural fibres. It was found that the conservator respondents named rayon as the manufactured fiber they most often encountered in need of conservation. However, natural fibres such as silk, wool, cotton, linen and natural cellulosics and natural rubber were more often a source of concern. Acetate, triacetate, nylon, spandex, polyester and acrylic were perceived to be in need of conservation less often than rayon. Moreover, none of the man-made fibres were identified as having an average conservation need higher than "low need." However, the majority of respondents agreed that more information was required with respect to both the degradative properties of manufactured fibres and their conservation needs.

Ferreira (1999) concluded that there was a general agreement among participants that twentieth-century materials were significant as historic artifacts and that manufactured fibres have been encountered in objects requiring conservation attention. Moreover, Ferreira concludes that, "the first item identified for future research is rayon, which is the manufactured fiber most often encountered in artifacts exhibiting degradation and is ranked highest in terms of conservation need" (p. 16). Finally Ferreira suggests a survey of twentieth-century materials in museum collections that would, "allow researchers to classify and quantify the conservation needs by fiber type/modification, composite materials, dye class, finish etc. and to assess the extent of the degradation exhibited by these objects. It would also provide insight into patterns and possible causes of degradation, as well as the various levels of conservation need represented by these objects" (p. 17). In addition to the opinions of conservators there is clear evidence that the

conservation of rayon warrants further attention: Rayon has distinct structure and properties that may compromise its longevity. Rayon was used in a variety of textile applications, which have been collected and will therefore need care. Moreover, there is period evidence indicating that rayon exhibited problems in use and care even when fibres and fabrics were new. Despite this, Ferreira presents evidence suggesting that conservators tend to use the same approaches to treatment for early manufactured fibres as they do for natural fibres. Through the development of an identification protocol, determining what rayon looks like in 1920s and 1930s dresses and through surveying rayon condition, it is the hope that this research project will help change the way conservators approach early manufactured fibres.

CHAPTER THREE: MATERIALS AND METHODS

Sample Selection

A sample of 1920s and 1930s dresses likely to contain rayon was drawn from the Clothing and Textiles Collection with permission of the curator. This broad sample of 46 dresses consisted of women's dresses from which fibre samples could be safely removed. The search terms: 'rayon', 'acetate', 'synthetic' 'nylon' or no fibre content entry in the materials field of the collections database were used to generate the sample. In addition to fibre content, the sample was limited using the parameters: date range (1920 – 1939), item name (dress) and gender association (female adult). The date range of 1920 to 1939 was chosen as it represents the early years of rayon production, but is late enough that initial experimentation had been concluded, and the fibres were being produced on a large scale. Women's dresses were chosen both to make use of the Clothing and Textiles collection and because women's wear was one of the first areas where broad fabrics made of rayon or rayon blends were utilized (De La Haye, 1993). Fibre identification techniques were performed on this broad sample to allow for the identification of dresses made wholly or in part of rayon and to evaluate the relative merits of identification techniques. A list of the broad sample of artifacts can be found in Appendix A.

To facilitate analysis of rayon, a second level of sampling was defined, consisting of all dresses in the broad sample made wholly or in part of rayon. Analysis of this sub-sample made possible the characterization of rayon use in dresses from the 1920s and 1930s in the Clothing and Textiles Collection and sought to answer several questions: Of the rayon dresses, what percentage is 100% rayon as compared to combined or blended fabrics? What percentage of rayon fabric is cuprammonium versus viscose rayon? What percentage of the rayon fabrics are made of fibres delustered with pigment? What percentage of the rayon fabrics is made of staple fibre as compared to filament fibre? In what yarn and fabric structures is rayon most often found? With which other fibres are the rayon fibres most often combined? Finally, this sub-sample was used to determine the condition of rayon dresses from the 1920s and 1930s.

Fibre Identification

A number of fibre identification techniques were tested for their usefulness in identifying the rayon dresses within the broad sample, in order to develop a simple, effective technique or combination of techniques for identifying different rayon fibres. The fibre identification techniques bright field microscopy, acetone solubility, hot stage microscopy, polarizing microscopy and refractive index mounting liquids and the Becke Line Method were chosen for several reasons. First, since the goal of the study was to identify rayon from the 1920s and 1930s, methods had only to aid in definitively identifying cuprammonium and viscose rayon. The ability

to definitively identify non-rayon synthetics and modern types of rayon including high-wet-modulus rayon and Lyocell was not a priority, although the protocol needed to be able to eliminate these fibres. Second, techniques were chosen that were either non-destructive or could be performed on very small samples. Third techniques that minimized the use of chemicals potentially harmful to human health and the environment were chosen. Finally, methods of identification that had the potential to be expanded to include other manufactured fibres at a later time were chosen. At times more than one test was performed to identify one class of fibre. This was done in order to evaluate the techniques' relative merits; for example, both acetone solubility and comparing mountant and fibre refractive indices were undertaken to distinguish and eliminate acetate, the only confounding manufactured fibre from the 1920s and 1930s.

Fibre Sampling

Fibre samples were taken from the warp and weft yarns and all supplementary yarns from the main dress fabrics in all artifacts from the broad sample of 1920s and 1930s dresses. Embellishments, decoration and lining fabrics were not sampled. In two part dresses such as those consisting of a sheer lace overdress and an opaque underdress, however, both fabrics were sampled. In order to facilitate the needs of various identification techniques, 1 cm pieces of yarn were cut whenever possible; alternately, several smaller samples were removed. Sample fibres were cut from frayed seam allowances when possible or from other areas that did not damage the integrity of the object or its aesthetic. Sample locations were recorded on the Artifact Information Form (Appendix B, p.110). Cut samples were then placed in small sample bags labelled with a permanent pigment marker. This kept the samples organized and allowed for sampling to be performed away from the lab in which slides were prepared.

Bright-Field Microscopy

The first step of the fibre identification process was examination using bright-field microscopy. Examination using bright-field microscopy permitted distinguishing fibres based on distinct morphological features of their longitudinal section. The procedure for bright-field microscopic identification outlined in AATCC Test Method 20 was used (AATCC, 2008). Microscopy was performed on a Carl Zeiss Jena Amplival® pod.d Polarisation Microscope with the polarizer disengaged.

Samples were mounted on glass slides in liquid paraffin. This mountant was chosen as it is readily available, and does not evaporate so slides could be examined and compared throughout the study. Also, unlike water, which is readily absorbed by rayon, paraffin oil does not swell fibres. Liquid paraffin has added advantage of having the same refractive index as acetate (1.47) and thus can be used to distinguish rayon from acetate. When a fibre has a refractive index close to

the refractive index of the medium it is mounted in, internal features are visible but there is no clear edge or border between the fibre and the mountant. When the iris diaphragm is closed, darkening the field, fibre edges can sometimes be seen even if the refractive indices are close; however, when the diaphragm is open all the way fibres tends to disappear. The refractive index of rayon, however, ranges from 1.527-1.562 and fibre edge lines are clearly defined in the mountant liquid paraffin.

Fibres were sketched and visual information was recorded on a form (Appendix B, p. 110). Information recorded included the presence/absence of striations and pigment, whether the refractive index of the fibre was similar to the mountant and a preliminary hypothesis about fibre content. The form also provided a place for additional comments, which often included impressions about the size of the fibre or how darkly it was dyed. The morphological features of viscose rayon that can be seen under the microscope include an irregular cross-section, which manifests as striations in a longitudinal section; however, viscose rayon is not easily distinguishable from acetate or other extruded fibres with lobed or irregular cross-sections. Cuprammonium rayon, on the other hand, has a round or nearly round cross-section and appears as a smooth, cylindrical fibre. It can be distinguished from silk based on cuprammonium rayon's more regular appearance and diameter, although it can be easily confused with other manufactured fibres with similar round cross-sections. Cross-sections were not included in this process of fibre identification as they often require a larger sample than can be justified removing from most artifacts, and cross-sections though helpful do not usually lead to positive identification of fibres that are not already distinct based on their longitudinal section.

Acetone Solubility

Acetone solubility was tested as a method to distinguish rayon from acetate. A modified procedure that mitigated many of the drawbacks of solubility testing, including health and safety issues and disposal of waste solvent was used. A small fibre sample (2-3 mm of fibres from the yarn) was placed on a microscope slide and then covered with a glass cover slip. Working in a fumehood, acetone was added drop-wise to the slide so that it seeped under the cover slip through capillary action. The slide was then observed for dissolution of the fibre sample, which usually occurred within a few seconds. The cover slip could be moved around slightly with a gloved finger to agitate the fibre and acetone, which made the results of the test clearer. When the fibre dissolved it became fuzzy or cloudy looking and when the cover slip was agitated the fibre exhibited loss of integrity. Dissolution resulted in a positive test for acetate. All fibres that were deemed not to be natural were tested for acetone solubility.

Melting Point Testing

Hot stage microscopy permitted distinguishing rayon from other man-made and synthetic fibres since rayon does not melt or decompose at temperatures up to 300º C. Hot stage microscopy can be used to identify thermoplastic fibres by determining the melting point specific to a polymer. Since rayon is not thermoplastic—charring rather than melting when heated—a simple single melt was sufficient to eliminate other fibres. Preliminary testing was performed wherein rayon, acetate, nylon and polyester were heated to demonstrate how the fibre react to heating on the hot-stage microscope. The rayon samples tested remained unchanged, nylon and polyester softened and then form pools of liquid with low viscosity and acetate fibres softened, striations disappeared and fibres connected; however, low viscosity and pooling of the melted fibre did not occur.

All non-natural fibres underwent hot-stage microscopy. Fibre samples approximately 2 mm in length were mounted in air, positioned on the hot-stage and brought into focus. The temperature was then raised on the converter to approximately 300° C. Both the temperature on the thermometer and the fibres in the field of view were monitored. The sample was observed for signs of softening and melting, or charring.

Polarizing Microscopy

All fibres identified as man-made by bright field microscopy were viewed under crossed polars and a measurement of birefringence was taken. The same slides with fibres mounted in liquid paraffin that were used for bright field microscopy were used for polarizing microscopy. A Carl Zeiss Jena Amplival® pod.d Polarisation Microscope with an Ehringhaus type 0···6 λ tilting compensator was used for all observations. The procedure for the determination of birefringence using polarized light microscopy from Gaudette (1988, p. 228-230) was employed with some modification.

Fibre diameter was measured using an eyepiece micrometer viewed through a 50x objective lens. A relatively straight fibre was located within the field of view and positioned in the eyepiece scale for measurement. The number of eyepiece divisions that the fibre occupied was recorded on a specially designed form and was then multiplied by conversion factor of 3.92 to determine the fibre's diameter in micrometers. The conversion factor for the polarizing microscope used had been calculated prior to the experiment using a stage graticule. It was found during initial testing that fibre measurements were best taken from edge to edge of striated fibres not ignoring one striation as suggested by Gaudette (1988, p. 229).

The polarizer was then engaged and the stage was rotated to orient the fibre in a position of maximum brightness (45° position). The interference colour at the centre of the fibre was observed and recorded. The colour order was then determined. The compensator was rotated from the null position until the compensation point was reached and the fibre appeared grey or black. As the compenstor was rotated the interference colours cycled through the spectrum. If zero or one area of red interference colours was passed through on the way to compensation the interference colour at the centre of the fibre was first order; if two separate areas of red were passed through it was a second order colour. The interference colour that was observed at the centre of the fibre and the fibre diameter were then compared to the Michel-Lévy chart, which generated an estimation of birefringence. Measures of birefringence and hypotheses on the identity of each fibre were recorded on the artifact information forms (Appendix B, p. 111).

Refractive Index Test

All fibres that were found to be rayon based on the results of other fibre identification techniques were mounted in a high dispersion refractive index liquid in an attempt to further distinguish viscose from cuprammonium rayon. The liquid, produced by Cargille Labs Inc., is part of a series of liquid mixtures that contain components of very low and balanced volatility. By varying the proportions of its components, a liquid is made with a specific refractive index that can be used to match specimens mounted in it. The refractive index of cuprammonium in the $n_{||}$ direction is 1.548 to 1.562 whereas the refractive index of viscose rayon is 1.541 – 1.549. A liquid with a refractive index of 1.548 was used to mount the rayon fibres since fibres with a refractive index noticeably lower than the mountant could be identified as viscose rayon, whereas a fibre with a noticeably higher refractive index than the mountant could be identified as cuprammonium rayon. Fibres were observed using the Carl Zeiss Jena Amplival® pod.d Polarisation Microscope with the polarizer disengaged. By rotating the stage fibres were observed in the parallel position. The Becke Line method as described by Bloss (Bloss, 1961) was then employed to determine whether the refractive index of the fibre was higher or lower than the mountant. Fibres were viewed with the microscope objective focused slightly above sharpest focus and two thin lines or a halo were seen concentric to the fibre's border (Becke Lines). The focus was then raised. The lines either moved outward from the fibre edge, in which case the fibre was interpreted to have a refractive index lower than 1.548, or the lines moved in to the interior of the fibre and the fibre was interpreted to have a refractive index higher than 1.548. Observations were recorded on the Artifact Information Sheet (Appendix B, p. 114)

Artifact Characterization

The sub-sample of dresses made wholly or in part of viscose and cuprammonium rayon was examined carefully. Their fabrics were characterized and their structure analyzed for fashion features typical of the period.

Fabric Characterization

Fabrics were characterized by identifying fibre content, analysing yarn structure and determining weave structure and count. Fibres were identified through the methods described above and observed to be staple or filament as samples were removed for fibre identification. Yarn structure and degree of twist were also determined by observing the samples removed for fibre identification. The categories of level of twist into which the yarns were divided included low twist, medium twist and high crepe twist. Twist was determined qualitatively using the following rubric. If yarns were twisted such that they exhibited the characteristic kinking of crepe yarns they were identified as having high crepe twist. If yarns easily separated into individual fibres when 0.5 cm samples were removed they were identified as having low twist. Levels of twist between low and crepe were deemed to be medium twist. All information was recorded on the artifact information forms (Appendix B, p.115).

Relative fabric fineness was characterized through a quick estimate of fabric count. Fabric count was determined by two different methods. Where possible, fabric count was based on photos taken with the ProScope HR digital USB microscope. Photos were taken at 30x magnification with a ruler included in the field of view (Figure 7). Yarns in the warp and filling directions were counted over 8 millimetres and then extrapolated to 1 cm. A traversing thread counter was used, however, on very lustrous black fabrics, which did not photograph very well. In these cases fabric count was taken for each warp and weft value over 3 cm and then divided by three to create a fabric count per centimetre. Fabric counts were not collected for complex weaves as it is very difficult to ascertain these without picking apart a sample of the weave.

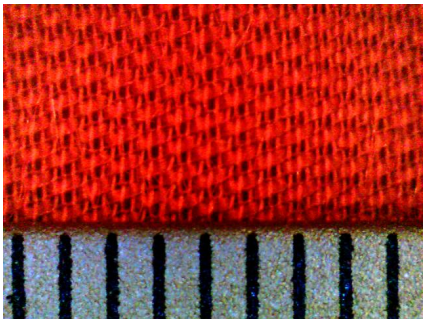


Figure 7. Photo of fabric taken at 30x magnification with a ProScope HR digital USB microscope with ruler included for fabric counting purposes.

Fabric structure, finishes, and coloration/decoration were observed with the aid of magnification. The weave or knit structures present in all fabrics, whether the fabrics were dyed, printed or had other forms of surface decoration and whether there was a visible finish was recorded.

Garment Characterization

Garments were characterized as a way to describe the kinds of dresses in which rayon was used in the 1920s and 1930s. Each garment's overall appearance and construction were briefly described on the artifact information form (Appendix B, p. 117). The presence of specific characteristics of 1920s and 1930s fashion (Mendes & De La Haye, 1999) was noted. Such features included simple cuts, dropped waists, and cuts of dresses whose primary location of support is the shoulders for day wear in the 1920s. Straight cuts, sometimes tabard-style with side inserts, low-cut necks and backs with thins shoulder straps were common for 1920s evening-wear. Features of 1930s dresses include bias cuts, slightly bloused bodices, belts to emphasize the waist, waist at a natural location, gently flared skirts and cape sleeves. Backless evening gowns were also an innovation of the 1930s. Consistency with period style was used to roughly confirm the dates given in the artifacts' database entries.

Condition Characterization

The condition of each dress containing rayon fibres was assessed and recorded. The form was designed to expedite the process of condition reporting and to standardize the information collected so it could be easily translated into qualitative and quantitative data (Appendix B, p.118). Several details of condition were assessed (Table 5), including colour alteration, distortion and damage, which are indicators of degradation or weakening of the fibres. Severity of the damage was also noted in the 'comments' section of the form. Soiling and staining was described primarily in association with other types of damage since soiling is not highly dependent on fibre type. A small area on the form was also provided to describe any soiling of note.

Analysis of Results

A comparative analysis of the results of the different fibre identification tests was performed. By providing accurate data, hot-stage microscopy acted as a benchmark for eliminating synthetic fibres and acetone solubility acting as a benchmark for eliminating acetate. The percentage of correct identifications was calculated for all tests as a measure of the reliability. The results with respect to reliability were associated with the presence of specific characteristics including the presence of dark dye and pigment in the fibres, the nature of striations and the experience of the operator, to determine what tests were appropriate in which circumstances.

Rayon fabric and garment characteristics as well as condition data were tabulated and the frequencies of key characteristics determined where appropriate. Due to the small sample size, more complex statistical analysis was inappropriate.

Table 5
Parameters used for observation of condition in rayon dresses

Condition Category	Parameter
Colour Alteration	fading
	yellowing/graying
	dye transfer
Distortion	stretching/bagging
	evidence of shrinkage
Damage	tears/cuts/broken yarns
	splitting
	holes/losses abraision/thinning
	unravelling/fraying
	pilling/snagging
	weakness
	embrittlement
Other	pest damage
	mould

CHAPTER FOUR: RESULTS AND DISCUSSION

Fibre Identification Results

Fibre identification was performed on 102 yarns from 46 dresses in total. Twenty-five dresses were found to consist of rayon, wholly or in part. Fourteen fabrics consisted of 100% rayon, whereas 15 fabrics blended rayon with another fibre. Notably, seven of the blended fabrics combined rayon and acetate.

Bright Field Microscopy

Bright field microscopy is a standard first step in fibre identification. The results of this research reinforce the hypothesis that basic microscopy is both an effective means of identifying natural fibres and an important initial step in the identification of man-made fibres. Though bright field microscopy was not usually the terminal step when identifying man-made fibres, it provided important information about the fibre that, when added to information derived from subsequent tests, led to a definitive identification. Acetate and viscose rayon would have been difficult to differentiate if not for their differing refractive indices relative to the liquid paraffin mountant. Although strictly speaking the morphology of viscose rayon and acetate differ slightly, both fibres have striated longitudinal sections. Reliably telling apart rayon and acetate is critical for conservators as the fibres have different properties; significantly, acetate is soluble in acetone, a solvent used, at times, in the textile conservation laboratory for spot cleaning and adhesive removal. Identification is particularly important for fabrics dating from the period of study, the 1920s and 1930s, as numerous fabrics combining rayon and acetate were identified, including some in which the yarns were combined or blended.

Most fibres within the sample were easily identified as 'natural' or 'man-made' based on their observable characteristics. Convolutions, irregular surface topography, a fine diameter and/or the presence of a lumen helped identify natural fibres. Forty-six of 102 fibres observed were natural fibres. Natural fibres that posed the most difficulty to identification by simple microscopy included silk and mercerized cotton. Silk was identified based on its relatively smooth longitudinal section, and its fine, irregular fibre diameter. At times it was tricky to distinguish between a silk fibre and a distorted man-made fibre. Furthermore, if the fibre was darkly dyed or less successfully mounted, the uneven surface topography of silk, produced by its irregular fibre diameter, was difficult to see. Mercerized cotton was also a difficult natural fibre to identify using simple microscopy. The mercerization process swells convolutions and as a result the characteristic ‘twisted ribbon’ structure of cotton fibres was less discernible. Eliminating these two

fibres was aided by engaging the polarizer, which emphasized irregularities in the fibre diameter. This technique will be discussed in more detail in the polarizing microscopy section below.

The presence of striations, pigment and/or a regular diameter distinguished man-made fibres. Fifty-six of 102 fibres observed were manufactured fibres and 14 of those yarns were delustered with pigment (Appendix C) and all viscose and cuprammonium fibres were striated. To bolster the benefit of bright field microscopy to the identification of manufactured fibres, liquid paraffin was chosen as a mountant for its specific optical properties. Although acetate and rayon have similar morphological properties, their optical properties vary such that the two fibres can be distinguished based on their differing refractive indices. Acetate and liquid paraffin have the same refractive index; therefore relative refractive index observed by bright field microscopy can be used to eliminate acetate.

When observed using bright field microscopy, fibres from twelve yarns appeared to have faint or non-existent edge lines that disappeared when the diaphragm was opened fully (Figure 8). The edge lines could, however, be distinguished if the light reaching the stage was limited by closing the diaphragm most of the way. These observations indicate that the refractive index of the mountant and the fibre were the same. In the case of delustered fibres, similar refractive indices of fibre and mountant were particularly clear: fibre-shaped clusters of dotted pigment were observed, but no fibre edge line could be seen when the field was brightly illuminated (Figure 9). Since acetate and liquid paraffin have the same refractive index, fibres that were observed to have the optical property, refractive index in common with the mountant liquid paraffin, were eliminated as acetate fibres (Table 6).

In contrast, fibres from 42 yarns exhibited defined edge lines and interior features such as striations even when the diaphragm was opened completely (Figure 10). These fibres were identified as not having the same refractive index as liquid paraffin and therefore could not be eliminated or identified at the bright field microscopy level of analysis.

Dark dye confounded the results of this technique. In three yarns (10, 91, 92 a, 92 b) the fibres were dyed too darkly to judge whether the refractive index of the fibre was similar to that of the mountant. The edge lines would have been the same colour as the fibre and therefore were not discernable regardless of the fibre and mountant's relative refractive indices. Other fibres were dyed darkly but not so darkly that the operator felt edge lines would be indistinguishable. In these cases (26, 27, 52b, 68, 69a, 83) whether edge lines were present or not was interpreted with mixed results. The tendency was to interpret fibre edge lines as being absent indicating the fibre to be acetate, when in reality the fibre was viscose and the edge-lines were masked by the fibre dye.

Figure 8. Fibre and mountant with similar refractive indices: Acetate mounted in liquid paraffin (mag. 400x).

Figure 9. Fibre and mountant with similar refractive indices: Delustered acetate mounted in liquid paraffin (mag. 400x).

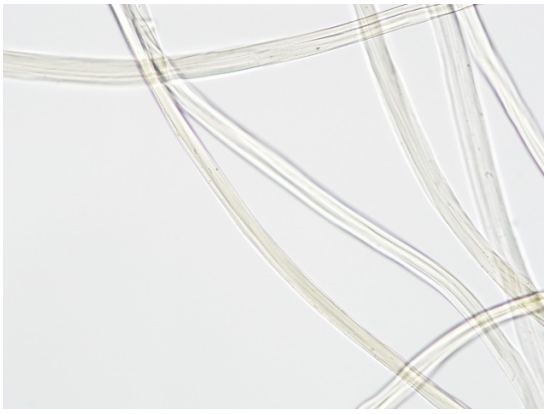


Figure 10. Fibre and mountant with dissimilar refractive indices: Viscose rayon mounted in liquid paraffin (mag. 400x).

Table 6

Comparative results of the elimination of acetate based on refractive index and acetone solubility

		Refractive Index Observation (yarn #)	Acetone Solubility Observation (yarn #)
Acetate Fibres	**Similar to Liquid Paraffin**		**Soluble**
	Correct:	6 16 17 a 22 23 24, 70 74 75 77 90	**Correct:** 6 16 17 a 22 23 24 26 27 36 52 b 68 a 69 a 70 74 75 77 83 90 92b
	Not Confident:	36	
	Incorrect:	26 27 52b 68 69a 83	
	Not Possible:	92b	
Other Fibres	**Dissimilar to Liquid Paraffin**		**Insoluble**
	Correct:	5 9 11 15 25 29 33 35 38 41 42 43 48 49 50 51 52 a 57 58 59 60 61 62 67 71 73 76 78 86 87 89 93 94 95 102	**Correct:** 5 9 10 11 14 15 25 29 33 34 35 38 41 42 43 48 49 50 51 52 a 57 58 59 60 61 62 67 71 73 76 78 86 87 89 91 92 a 93 94 95 102
	Not Confident:	14 34	
	Incorrect:		
	Not Possible:	10 91 92a	

Blended yarns were also problematic. In yarn 52 the refractive index was noted as dissimilar to the mountant; however, subsequent tests revealed that there were both fibres with a dissimilar refractive index to liquid paraffin and acetate fibres with a similar refractive index to the liquid paraffin. The observation was likely made with the diaphragm opened widely. Since fibres with clearly defined edge lines and interior features were observed it is probable that fibres were not viewed with the diaphragm closed and therefore, the acetate fibres were not detected.

The relative reliability of using refractive index to distinguish acetate at the bright field microscopy stage can be demonstrated by indicating whether refractive index observations were consistent with the fibres' identification as determined by acetone solubility and hot-stage microscopy. A correct interpretation of similar fibre and mountant refractive indices was made 45 times out of a total of 57 attempts and therefore the technique had a 79% success rate. The refractive indices of twelve yarns were not correctly interpreted; five cases were simple misinterpretation. In each of the five misinterpreted cases the fibres were darkly dyed, including four black fibres (26, 27, 68a, 69a) and one dark blue fibre (82). In three cases correct interpretations had questions marks beside them, indicating that although the correct observation was made, confidence was lacking in the result (14, 34, 36). These were fibres there was some dye so it was difficult to determine whether there were edge lines visible or not. In four cases (10, 91, 92 a, 92 b) the fibres were so darkly dyed that no attempt was made as observing the refractive index. Finally, yarn 52b failed to be noticed at all; it was the acetate fibre in a viscose/acetate blend.

Acetone Solubility

All man-made fibres, as determined by bright field microscopy, were tested for their solubility in acetone on a microscope slide. Fibres that dissolved became cloudy, and when the slide cover was agitated a loss of fibre integrity was observed. When the acetone had completely evaporated a powdery residue in the colour of the fibre remained on the slide. Fibres that were not soluble remained intact and no change was observed. In the case of blended yarns there was some cloudiness; however, when the glass cover slip was agitated a number of fibres clearly remained intact. Also, when the acetone had completely evaporated both intact fibres and fibre residue remained on the slide.

In 15 yarns of the 56 yarns tested (26%) all fibres were soluble in acetone. In 38 yarns (67%), all fibres were acetone insoluble man-made fibres (Table 6). In 2 yarns (3.5%), there was both acetone soluble and acetone insoluble manufactured fibres and in three further yarns (5.3%), half the fibres in the yarn were soluble in acetone and half the fibres were acetone insoluble natural fibres. In the case of yarn 52 results were somewhat ambiguous. There appeared to be some dissolution; however, several fibres remained intact. Only one fibre type had been observed

during bright field microscopy (viscose) and at first it was postulated that the fibre dye was not fast to acetone. However, when the original slide was reviewed two different types of fibres were indeed visible. When the acetone evaporated completely the undissolved portions of yarn were remounted. Only one type of fibre remained leading to the conclusion that the yarn was blended. The effect of roughly half the fibres dissolving was not subtle; however, since two types of fibres were not identified during the initial bright field microscopy the operator was searching out a possible explanation for the effect (ie. dye not fast). Missing the two types of fibres during initial bright-field microscopy was due to a lack of experience. Great attention is needed, but more importantly, fibres should always be viewed with diaphragm opened in a range of openings, including with very low levels of light reaching the stage to ensure that blends are not missed. If this precaution is taken it would be unlikely to miss a blended yarn at this stage of identification.

Hot-Stage Microscopy

The thermal properties of all yarns that contained man-made fibres were examined with the polarizing microscope fitted with a hot-stage. Table 7 shows the results of hot-stage microscopy, indicating whether the fibres melted, charred or remained unchanged. Fibres from 19 yarns melted, while in 39 yarns softening and melting was not observed. Six fibres had become charred by the time the converter for the hot-stage microscope was turn off at 300°C.

As the temperature was raised, some fibres had the tendency to 'jump around' irrespective of whether they eventually melted or not. As fibres approached their melting point internal features were lost, striations swelled and disappeared, overlapping fibres joined together before eventually becoming a pool of liquid. Although there were no thermoplastic fibres found in the sample, during preliminary testing, known samples of both nylon and polyester were melted. In general, the transitions in acetate fibres were not as easy to see as those seen in thermoplastic synthetic fibres during preliminary testing. Synthetic fibres had clearly turned into pools of liquid with low viscosity. Acetate fibres, on the other hand, never achieved as low viscosity a liquid despite acetate's low melting point relative to nylon and polyester. Instead, fibres swelled/flattened and connected and the striations disappeared. It was found useful to use a metal fabric pick to nudge the covering slide slightly. If the fibres had melted the softened fibre smeared when the cover slip was repositioned. Fibres that did not melt–(viscose rayon or cuprammonium rayon in this sample)–either remained unchanged or charred, darkening as the temperature approached 300° C.

Table 7
Results of hot-stage microscopy on yarns containing man-made fibres

Observation	**Yarn #**
Fibre **melted**	6, 16, 17a, 22, 23, 24, 26, 27, 36, 52b, 68a, 69a, 70, 74, 75,77, 83, 90, 92b,
Fibres **charred**	14, 15, 41, 59, 60, 86
Fibres were **unchanged**	5, 9, 10, 11, 25, 29, 33, 34, 35, 38, 42, 43, 48, 49. 50, 51, 52 a 57, 58, 61, 62, 67, 71, 73, 76, 78, 87, 89, 91, 92a, 93, 94, 95, 102

Polarizing Microscopy

A qualitative measure of birefringence was generated for fibres from each yarn. Interference colours were observed with the polarizing microscope, and then compared to the Michel-Levy Interference Colour Chart. Fibre identifications were then made based on birefringence (Table 8). Fibre diameters ranged from 11.75 μm to 39.2 μm and birefringences ranged from 0.000 to 0.033. Ten fibres were too darkly dyed for observation of interference colours. The results of each step in the process (measuring fibre diameter, observing interference colour, determining colour order and concluding fibre birefringence) can be found in Appendix D.

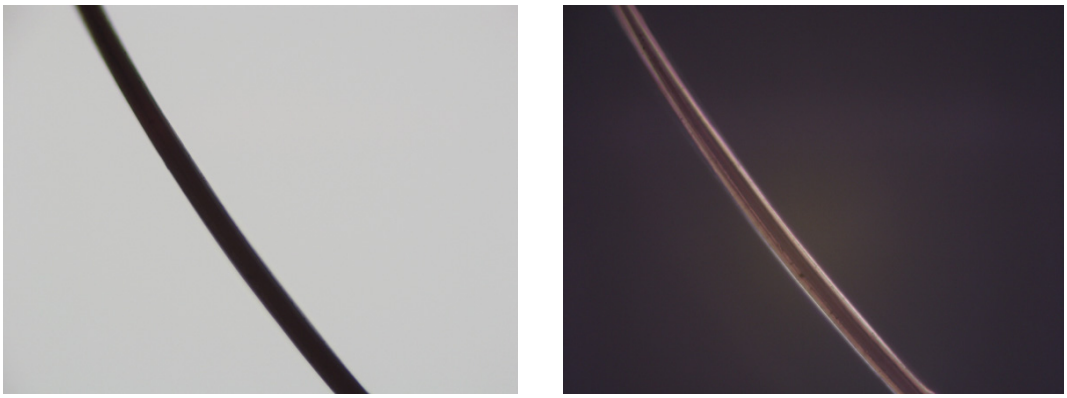
Of the 58 fibres observed under crossed polars, 35 (73%) were correctly identified based on their birefringence (Table 8; Table 9). An identification was considered correct if the birefringence estimation for the fibre fell within the reported range of birefringence for a particular fibre (0.002 to 0.005 for acetate; 0.021 to 0.037 for cuprammonium; 0.020 to 0.028 for viscose, plus or minus 0.002 (*Identification of textile materials,* 1975), and if the identification was supported by other fibre identification tests performed on that fibre including bright-field microscopy, acetone solubility and hot-stage microscopy. In 19 cases polarizing microscopy did not produce a clear, correct identification for the fibres observed. Nine times the fibre was dyed too darkly to see interference colours clearly (9, 38, 41, 48, 68a, 69a, 83, 86, 94) (Figure 11). In 4 cases the fibres appeared to be birefringent, but the estimation of their birefringence fell below the published range for the fibre (viscose in three cases and cuprammonium in one case). In three cases fibres' numerical birefringence reading was higher than the reported range (viscose rayon in two cases and acetate in one case).

Table 8
Fibre identification of yarns containing man-made fibres based on qualitative birefringence as determined by polarizing microscopy

Fibre Identification		Yarn #		
Acetate birefringence 0.00-0.007	**Correct**[3]	16, 17 a, 23, 24, 26, 27, 36, 52 b, 70, 74, 75, 77, 90	**Incorrect**	73, 91
Viscose birefringence 0.018-0.030 presence of striations	**Correct**	5, 10, 14, 15, 29, 33, 34, 35, 49, 51, 52 a, 57, 58, 71, 76, 78, 89, 93, 95, 102	**Incorrect**	6, 92b
Cuprammonium birefringence 0.019-0.039 round smooth fibre	**Correct**	42, 43, 61, 62, 87	**Incorrect**	
Inconclusive birefringence 0.008-0.017		11, 22, 50, 67, 92 a		
Inconclusive birefringence 0.031-0.36 presence of striations		25, 59, 60		
Inconclusive fibre too dark for interpretation		9, 38, 41, 48, 68 a, 69 a, 83, 86,		

Finally, in one case the fibre did not seem to be birefringent at all even though other tests showed it to be viscose rayon. The literature indicates several fibre characteristics that have the potential to limit the efficacy of polarizing microscopy (*Identification of textile materials,* 1975). Fibres that are darkly dyed, heavily delustered, crimped, or highly twisted may interfere with the transmission of light and thus the correct interpretation Though many fibres exhibit one or more of the potentially limiting characteristics, dark dye appears to be the only factor that consistently negatively affected polarizing microscopy in this sample (Table 9).

[3] Correct/incorrect based on results of acetone solubility.



a) b)

Figure 11. Darkly dyed viscose rayon (mag. 400x). a) Bright-field microscopy; b) Under crossed polars. Interference colours masked by dark dye.

In four fibres (59, 60, 22, 73) the birefringence was incorrectly identified although they did not have any of the potentially limiting characteristics. In fibres 59 and 60 striations appeared to be numerous and deep; therefore, it was decided to skip one striation in the measurement of the fibres as suggested by Gaudette (1988). If the fibres had been measured from edge to edge they would have fallen into the correct range for viscose. In the case of one fibre 22 the source of error was likely simple misinterpretation of interference colour as green when it was likely actually grey. The non-colours at the beginning of the spectrum (greys and pale greens) are the most difficult to interpret. Finally, fibre 73 is a mystery. Although other tests clearly identified the fibre as viscose, the pale pink dye and lack of delustrant should not have interfered, yet it did not appear birefringent at all.

Table 9

Limiting factors and incorrect qualitative birefringence as determined by polarizing microscopy

Yarn #	Delustered	Highly Twisted	Darkly Dyed	Birefringence Inconsistent with Identification or Impossible to determine
5		●		
6			●	●
9			●	●
10		●	●	
11			●	●
14		●		
16	●	●		
17 a	●			
22				●
23				
24	●		●	●
25	●	●	●	
33		●		
34		●		
35		●		
36	●		●	
38			●	●
41			●	●
42	●			
43	●			
48			●	●
49		●		
50			●	●
59				●
60				●
61	●			
62	●			
67		●		●
68 a		●	●	●
69 a		●	●	●
70	●			
71		●		
73				●
76		●		
77	●			
78	●			
83	●		●	●
86			●	●
91	●	●		
92 b	●			●
94			●	●
95		●		

High Dispersion Refractive Index Mounting Liquids and the Becke Line Method

The final method tested for use in the identification of rayon fibres was high dispersion refractive index mounting oils used in conjunction with the Becke Line method or the method of central illumination (Bloss, 1961). This technique made use of a mountant with a refractive index of 1.548. Rayon fibres were viewed in the $n_{||}$ position and Becke line movement was observed as an indication of whether the $n_{||}$ refractive index of the fibre was higher or lower than the mountant. In 17 cases Becke lines showed clear and significant inward movement when the focus was raised, in 21 cases the Becke lines moved outward when the focus was raised and in one case there was no Becke Line movement when the focus was raised (Table 10). Based on Becke Line theory, the fibres in which lines moved toward the centre of the fibre have a higher refractive index than 1.548. All five cuprammonium fibre samples and twelve of the 33 viscose fibres (36%) fell into this group. In the 21 fibres where Becke line movement was outward, the $n_{||}$ refractive index of the fibre is lower than 1.548. All 21 of the fibres with a refractive index lower than 1.548 were viscose rayon fibres (64%).

Fibre Identification Discussion

In addition to definitively identifying rayon within the artifact sample from the Human Ecology Clothing and Textiles Collection at the University of Alberta, testing various methods of fibre identification served this study's goal to assess the relative merits of each technique. Results were varied and some surprising insights were gained. For example, at the outset of this project the analysis of optical properties using polarizing microscopy showed the greatest potential as a

Table 10
Movement of Becke Lines in viscose and cuprammonium rayon fibres in the n|| position, mounted in high dispersion refractive index oil 1.548

Observation for n||	**Yarn #**	
	Viscose Rayon	Cuprammonium Rayon
Becke Lines moved **outward** when focus was **raised**	9, 10, 11, 25, 88, 41, 48, 52 a, 58, 59, 67, 71, 73, 76, 78, 86, 89, 91, 93, 94, 95	
Becke Lines moved **inward** when focus was **raised**	5, 14, 15, 29, 33, 34, 35, 50, 51, 57, 60, 92a	42, 43, 61, 62, 87
No movement of Becke Lines when focus was **raised**	102	

tool for the identification of rayon in the field of textile conservation. Forensic literature indicated that it is the technique most often used in that field – a field that holds many concerns in common with the field of textile conservation, such as access to small samples sizes, and the need to preserve samples (Gaudette, 1988). Results of this study, however, indicate that identification of fibres based on polarizing microscopy and the optical property birefringence alone is not always possible and particularly without a high level of experience. Similarly, although it was an initial goal to find methods of identifying rayon that did not involve chemical solubility testing, the inclusion of an acetone solubility test proved to be one of the most useful tests for quickly differentiating rayon fibres from the only other man-made fibre that existed during the 1920s and 1930s, acetate. Conservators should not, however, depend on an acetone solubility test alone if fibres appear to be man-made, unless provenance and dating are absolutely certain. There is always the chance that garments may have been hastily or incorrectly dated and for that reason several identification tests should be performed if there is any doubt surrounding the artifact's age. If the garment post-dates the 1930s synthetic fibres may complicate the picture, particularly when it comes to identifying unstriated cuprammonium rayon.

Confounding Factors

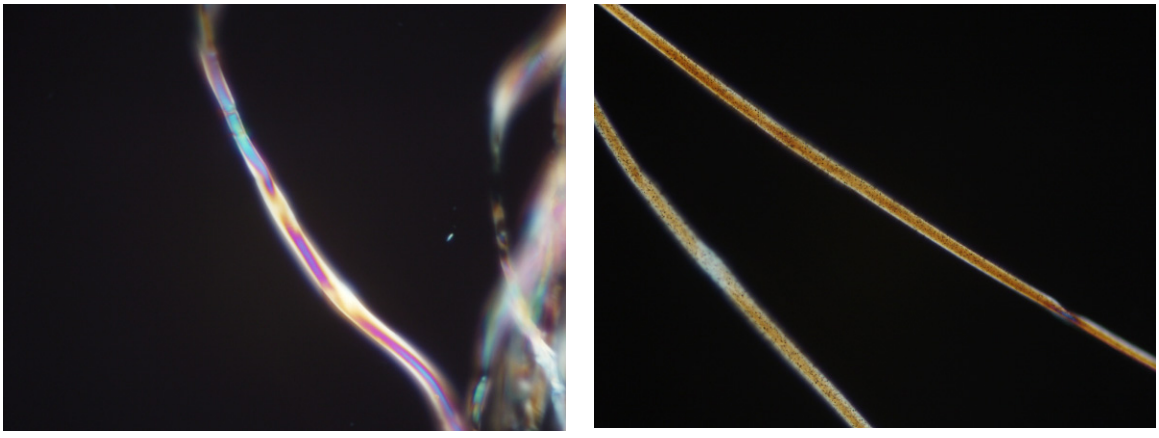
A small number of confounding factors influenced the efficacy of techniques tested for the identification of rayon. The two most problematic confounding factors were, the presence of dark dye on fibres, which hindered both bright field and polarizing microscopy, and the need for a high level of experience for the interpretation of optical properties with polarizing microscopy.

In the case of bright field microscopy, darkly dyed silk and man-made fibres were the most problematic to identify, as the dye made striations and fibre topography were difficult to see clearly. Some steps could be taken to make an identification despite the dark dye. First, a rough impression of fine diameter at highest magnification was helpful for identifying silk fibres, as silk fibres are much finer than manufactured fibres, particularly those manufactured fibres dating from the 1920s and 1930s. Second, searching out a cut end of the fibre gave an indication of cross-sectional morphology. Silk has a roughly triangular cross-section whereas rayon is either round or serrated in cross-section. Third, closing the iris diaphragm to allow minimal light through to the stage usually allowed striations to be seen on all but the most darkly dyed fibres. Finally, though not definitive, qualitative observations of fibre behaviour when the slides were assembled could also be used to support identification of darkly dyed fibres. Highly twisted silk fibres, for example, were much more difficult than highly twisted rayon fibres to untwist and mount. Silk fibres were weaker, more friable and often broken before they could be untwisted.

Polarized light microscopy also proved to be a helpful and easy to interpret tool for identifying silk. It is not possible to determine a qualitative reading for the birefringence of a silk fibre using polarizing microscopy, as they do not reach a point of extinction. However, if the polarizer is engaged, irregular surface topography of silk is emphasized and the edges are highlighted in rainbow interference colours (Figure 12 a). Man-made fibres, in contrast, have a more regular surface topography and therefore exhibit consistent interference colours when viewed through the polarizer. When the stage is rotated there are clear points of extinction and maximum brightness (Figure 12 b).

Dark dyes also interfered when trying to determine whether fibres had similar refractive indices to liquid paraffin. Darkly dyed fibres were more difficult to interpret, as a clear edge was visible even when refractive indices matched, due to the colour change between fibre and mountant. With practice, however, it did become easier to differentiate between the colour change and edge-line. It is likely that with experience dark dye would become an inconvenience, but not a limiting factor in determining the similarity of refractive indices in fibre and mountant. Furthermore, Becke Lines could be used to help interpretation; when observing acetate fibres no Becke Line movement is detected when the focus was raised and lowered, as there is no difference in refractive index.

In polarizing microscopy, the issue of darkly dyed fibres was not as easily overcome. For the most part, during bright field microscopy the operator was aware when dyes were interfering with observation. During polarizing microscopy dyes could affect interference colours unbeknownst to the operator. This represents a key difference in the degree of impediment that



a) b)

Figure 12. Silk and cuprammonium rayon under crossed polars (mag. 400x). a) Silk with irregular diameter highlighted by interference colours. b) Cuprammonium rayon with consistent line of interference colours emphasizing even diameter.

dark dyes created with polarizing microscopy. For example, in yarn 6, interference colours appeared to be red, but in reality red dye was masking the lighter, grey interference colours of acetate.

Many fibres were simply dyed too darkly for any interference colours to be seen clearly when the polarizer was engaged. Surprisingly, this is an issue that is not dealt with in the forensics literature; however, the Textile Institute recognizes that deeply dyed fibres can be a limitation, where the coloration of the fibre may mask the interference colours (*Identification of textile materials,* 1975). Of the fibres that had dye masking the interference colours under crossed polars it was usually obvious whether they had a low birefringence like acetate or a medium/high birefringence like rayons or other synthetic fibres as some interference colours were visible near the edges of the fibres; however, these bands of interference colours were not substantial enough to determine the colour at the centre of the fibre for comparison to the Michel-Levy chart. In these cases other tests were required to complete identification of man-made fibres.

Fibre characteristics that may confound polarizing microscopy as reported elsewhere do not appear to have greatly affected fibre identification in this sample. High twist is one such factor. Though many of the yarns in this sample were highly twisted there were only two cases where fibres were both from highly twisted yarns and were not correctly identified by polarizing microscopy. In yarn 66, distortion due to twist may have been a factor contributing to the incorrect identification due to lower birefringence than expected for viscose. In yarns 68 a and 68 b, however, the incorrect identification is more likely due to the darkness of the dye on the fibre, as darkly dyed fibres were problematic in many other samples and many other highly twisted fibres did not pose problems for polarizing microscopy. Additional factors that have been reported to confound the results of polarizing microscopy include: distortion of cross-sectional shape resulting from the texturization of filaments, distortion as a result of high twist in yarns especially if the fabric has been heat set and high levels of delustering pigment where the delustrant prevents or restricts the transmission of light. Also, bicomponent fibres cannot be reliability identified based on qualitative birefringence as determined by polarizing microscopy (*Identification of textile materials,* 1975). Distortion due to high twist and high levels of delustering pigment had the potential to affect identification as many crepe twisted yarns were found in the fabrics in this sample and since fibres were being delustered using pigment starting in the late 1920s. However, there is a low likelihood of heat set and bicomponent fibres confounding fibre identification in 1920s and 1930s garments as they did not exist at that time. Factors other than dark dye did not appear to confound results in this sample.

Distortion of fibres did, however, affect simple bright-field microscopy. Fibres can become flattened or squished and this can affect how the operator initially identifies fibres. For example when yarn 92a was first observed, it was thought that the fibre looked trilobate. The fibre did not have striations typical of a viscose fibre, rather it looked as though it had one trough down the centre of the fibre (Figure 13). Trilobate is a shape in which nylon is often extruded and based on the observation of that morphology it was postulated that the fibre might have been an early synthetic fibre, likely nylon. However, subsequent testing demonstrated that the fibre was viscose. The trilobate appearance was likely due to distortion of the fibres.

Acetone solubility and hot-stage microscopy had few confounding factors. Both acetone solubility and hot-stage microscopy were a simple tests that worked no matter how deeply dyed fibres were and regardless of shape or any other characteristic. One factor that could be somewhat confusing to the operator when performing hot-stage microscopy on rayon fibres was that some fibres charred while others remained unchanged. Conservators should be aware that rayon fibres do not always char when heated to 300° C and the fact that fibres remain unchanged is not an indication of an anomalous fibre.

Advantages and Disadvantages

Bright Field Microscopy

Although bright field microscopy has some disadvantages, it also has many advantages and its use remains a necessary part of fibre identification. The results of bright field microscopy were for the most part easy to interpret; however, a degree of experience is necessary to be

Figure 13. Viscose rayon distorted so than it resembles a trilobate fibre (mag. 400x).

effective in observing the identifying visual characteristics of both natural and man-made fibres. The only significant obstacle to observing visual characteristics was dark dye, but there are several methods of overcoming its effect discussed above. Similarly, when trying to determine whether mountant and fibre had similar refractive indices some experience was required for consistent results and once again darkly dyed fibres were more difficult to interpret. Ease of interpretation carried over into a high level of accuracy. The similarity of refractive index of fibre and mountant was correctly interpreted 84% of the time. Incorrect interpretation occurred roughly 16% of the time and only in cases when the fibre was darkly dyed or when there were blended yarns. With further experience looking at deeply dyed fibres and armed with the knowledge that rayon and acetate fibres were often blended in yarns, this number could be significantly decreased and mounting in liquid paraffin could be used as an effective tool for differentiating acetate fibres from other natural and manufactured fibres.

Acetone Solubility

A modified acetone solubility test was particularly useful in the identification process of rayon as it quickly and clearly demonstrated that the fibre was acetate rather than rayon or other synthetic fibres. It was important to eliminate acetate in this sample as the study sought to examine the character and condition of rayon in 1920s and 1930s dresses. More generally it is important for conservators to determine whether a fibre is rayon or acetate due to their differing properties. Acetate is soluble in acetone, a solvent sometimes tested for solvent spot cleaning of textile artifacts. It is also more sensitive to heat than rayon and has poor resiliency so it, therefore, does not recover well from crushing or wrinkling (Joseph, 1986).

The great advantage of the modified acetone solubility procedure was that there is little opportunity for error and results were interpreted with 100% accuracy. There was some concern that such a small amount of solvent, on a microscope slide, might hinder or delay dissolution; however, that was not the case; fibres dissolved in a matter of seconds with agitation. Moreover, the ease of interpretation was improved with the modified technique as fibre residue could be seen on the slide when fibres dissolved, and remained on the slide after the acetone had completely evaporated. In contrast, when solubility testing is carried out in beakers of solvent fibres are difficult to see and the acetate solute completely disappears in the acetone solvent. This feature was particularly helpful when yarns were blends of acetate and a second fibre. On the microscope slide, intact fibres and dissolved fibre residue could be seen once all the acetone had evaporated and this improved the chances of making an accurate interpretation of the fibre types in the yarn.

A further advantage of the modified acetone solubility test is that it does not use expensive equipment – most conservation laboratories are outfitted with a fume hood, illuminated

magnifying lamps, and acetone. Moreover, this technique uses a minimal amount of solvent and clear results can be seen with a very small sample size provided the sample includes all fibres from across the yarns and not just one fibre. This will ensure that blended yarns are identified. The only significant drawback to the modified acetone solubility test is that even though a small sample size is used, the test is destructive.

Hot-stage Microscopy

Hot-stage microscopy had both advantages and disadvantages as a test for identifying rayon fibres. Results were relatively easy to interpret even with limited experience. Moreover, hot-stage microscopy provided more information about the sample than other tests. For example, while acetone solubility only confirms the presence or absence of acetate, hot-stage microscopy indicates whether the sample consists of acetate, a thermoplastic synthetic fibre or another type of fibre. Also, hot-stage microscopy has the advantage over solubility testing of not making use of solvents that can be a health hazard and must be disposed of in an appropriate manner. Although the minute amounts of acetone used in the identification of acetate are relatively easy to dispose of through evaporation, this is not always the case for many of the solvents used in the identification of rayon and synthetic fibres, in which waste must be collected and removed by chemical disposal specialists.

Hot-stage microscopy was chosen over the burn test, a common identification technique based on thermal behaviour. Burn tests require simpler equipment, but are less controlled and don't offer the potential for identification based on melt temperature. Furthermore, hot-stage microscopy can be performed with a much smaller sample size than traditional solubility tests and the results are easy to interpret.

Potential drawbacks to hot-stage microscopy include the expense of equipment, the time it takes to complete the test and its destructive nature. If conservation laboratories or institutions do not have a microscope that accommodates a hot stage it would be an expensive tool to purchase. Also, after the hot-stage reaches 300° C and the converter is turned off the operator must wait for the stage to cool somewhat before the slide can be removed. Moreover, the stage must be almost completely cooled before a new sample can be tested. The total time for heating up and cooling down was approximately 30-45 minutes. Timing, however, is not likely to be an issue if only a small number of samples are being tested. Similar to the acetone solubility testing, hot-stage microscopy is destructive; however, a very small sample is needed to get clear and definitive result.

Polarizing Microscopy

At the outset of this research project, polarizing microscopy was chosen as an identification technique due to its numerous advantages including its versatility in identifying all different types of fibres and its non-destructive nature. However, many disadvantages of polarizing microscopy became apparent during the course of the study. First, the results of polarizing microscopy were by far the most difficult to interpret and the least accurate. Working out the sources of error is somewhat problematic because there are many steps involved in determining qualitative birefringence by polarizing microscopy. It was found, however, that there were opportunities for error at several points in the procedure including when measuring the fibre diameter, interpreting the interference colours, determining the fibre's order using the compensator and when using the Michel-Levy chart to determine birefringence. Moreover, as discussed above, deeply dyed fibres posed difficulty, affecting how interference colours were construed.

Measuring fibre diameter was the first step in the procedure that was vulnerable to error. The forensic literature indicates that fibres with an irregular cross-section be measured in a certain manner. Instead of measuring the fibre from edge to edge it is suggested that one striation be ignored (Gaudette, 1988; Grieve, 1990). However, during preliminary testing it was found that when one striation was ignored, consistently incorrect qualitative birefringences were produced for known fibres. It was determined that for this project fibres would be measured from edge to edge as this technique produced more correct results (Batcheller, personal communication, August, 15 2008). Some fibres in the research sample, however, had what appeared to be very deep striations. In these cases it was found fit to switch to the Gaudette (1988) and Grieve (1990) procedure and ignore one striation when measuring fibre diameter. In several cases this brought the estimated birefringence into a range that was consistent with the fibre type as determined by other fibre identification techniques. Thus, the issue of how to measure the fibre remains a source of error: it is not optimal to have procedure based on a qualitative interpretation of whether striations are deep or not. The manner in which fibre diameter is determined is a potential pitfall for conservators and more research is needed to determine if and when striations should be ignored in measuring fibre diameter.

Lack of experience, however, was likely the key source of error in polarizing microscopy in this study. Similar to bright field microscopy, the more exposure to how fibres look under the microscope the more proficient the operator becomes at differentiating between features and microscopic 'noise.' Visual anomalies could be due to any number of factors including that a fibre is compressed, distorted, dirty, split or incorrectly mounted. In polarizing microscopy there are many steps that need experience including measuring the fibre diameter, determining whether dye

is interfering with interference colours, reading the Michel-Levy chart and operating the compensator. Experience is gained only by performing the technique often. In practice, fibre identification is only one small part of a textile conservator's job; moreover, many of the fibres to be identified are natural fibres since the collections in museums where many conservators work, contain mostly artifacts that predate manufactured fibres. It would be difficult to build and maintain the level of experience with the technique that would allow for consistently accurate identifications unless a conservator works often with synthetic fibres.

Polarizing microscopy was found to be helpful as a supporting technique to other identification procedures. As discussed above, engaging the polarizer was helpful in emphasizing the irregular diameter of natural fibres. Although accurate qualitative numerical measures of birefringence were not always reliable, more general observations of fibres optical properties could be helpful. Identifying a fibre as having low birefringence, that is appearing greenish-white to grey under crossed polars indicates the fibre is acetate or a member of the acrylic family. In contrast, if the fibre displays medium or high interference colours—that is any colours from orange through the spectrum to blue or violet—that information can be used to support an identification of either a rayon or synthetic fibre (not acetate or acrylic). Since polarizing microscopy, even at this more basic level, requires some experience, conservators may wish to take polarizing microscopy training to familiarize themselves with the technique and to see how challenging it is before investing in such a microscope.

High Dispersion Refractive Index Mounting Liquids and the Becke Line Method

Becke lines and refractive index liquids were chosen as an identification technique in the hopes that it might provide a reliable confirmatory test for differentiating viscose and cuprammonium rayon by a method other than observing the presence or absence of striations in their longitudinal sections.

The high dispersion refractive index oil with a refractive index of 1.548 was ordered because the Textile Society's *Identification of Textile Materials* indicated that the refractive index of $n_{||}$ for normal tenacity viscose (Courtaulds Triple 'A') is 1.542; whereas, for cuprammonium the refractive index of $n_{||}$ is 1.553. Therefore, the 1.548 refractive index oil lies between the values for viscose and cuprammonium and Becke line movement would indicate whether the fibre's refractive index was higher or lower than the mountant when the fibre was oriented in the parallel position. Further reading in the forensics literature, however, revealed published refractive index values that were ranges: for viscose $n_{||}$ 1.541-1.549 and for cuprammonium 1.548-1.562 (Gaudette, 1988). These ranges of refractive indices unfortunately straddle the mounting oil's refractive index potentially making the observation of Becke Lines less helpful.

It was decided, however, to proceed to test this method for several reasons. First, refractive index is based on crystallinity and the literature review indicated that early viscose fibres were not stretched as much as contemporary rayons and were therefore likely less crystalline. It seemed logical that for viscose fibres from the 1920s and 1930s $n_{||}$ might be on the lower end – below the 1.548 of the mountant. The second reason to proceed was that useful information would be determined about how easy to interpret and how sensitive the high dispersion refractive index oils and the Becke Line method were. Moreover, the experiment could demonstrate how easy the refractive index oils are to work with as they have potential application for the identification of other man-made fibres notably thermoplastic synthetics for which this technique might be more applicable.

The Becke Line method was fairly easy to interpret. With limited experience the operator could clearly see in which direction the Becke Lines were moving. Moreover, a qualitative interpretation of how close or far the refractive index of the fibre was from the mountant was possible depending on the degree of movement of the lines when the focus is raised. For example, in the viscose samples with $n_{||}$ refractive indices higher than 1.548 the operator could see that the difference in refractive index between fibre and mountant was slight as there was minimal though detectable line movement. In contrast, the Becke Line movement in cuprammonium fibre samples was clearly greater, indicating a larger difference in refractive index.

The results of the Becke Line test were not consistent with results from bright field microscopy and hot-stage microscopy identification tests that indicated specific fibres to be either cuprammonium (not striated, does not melt) or viscose rayon (striated, does not melt). Although, all fibres that exhibited outward line movement and therefore had a refractive index lower than 1.548 were viscose rayon, fibres that had a refractive index higher than 1.548 did not consist exclusively of cuprammonium fibres. Rather, both cuprammonium and some viscose rayon fibres proved to have a higher refractive index than the mountant. Therefore, the refractive indices of some viscose fibres in this sample overlap with the refractive indices of cuprammonium rayon fibres as stated in the forensics literature (Gaudette, 1988) and this makes the test difficult to interpret. If all the viscose fibres had had refractive indices consistent with values reported in the Textile Society's *Identification of Textile Materials* (1975) then the Becke Lines should have moved outward in the $n_{||}$ for all viscose fibres. Becke Lines, however, only moved outward in the $n_{||}$ position 64% of the time.

Use of the refractive index mounting liquids can be performed safely. The Cargille catalogue from which the mountant was ordered indicated that the high dispersion refractive index

oils in these ranges were "inert;" however, the MSDS form indicated that inhalation of vapours from the liquid could be hazardous (though not likely in conditions consistent with intended use) and that it should be used in the fume hood. This posed a problem as the polarizing microscope could not be set up in the fume hood. The height and angle of the eyepieces were such that the sash of the fume hood could not be sufficiently lowered to create air draw. It was found, however, that when the slide had been made up and in the fume hood wearing gloves and was then removed for observation on the microscope no fumes were noticeable (the MSDS form indicated that vapours smelled of naphthalene or mothballs). Even though no fumes were detectable, for safety reasons, observations sessions were carried out in a well-ventilated area for 30-minute periods at a time and the slides were stored in the fume hood when not in use. However, if a lab wishes to use high dispersion refractive index oils often, observation of slides should be done in the fume hood if possible or alternately with a well set up local extraction apparatus that draws vapours away from the operator's breathing zone. If a safe set up could be created, given that the technique was easy to interpret, the method may be appropriate for identifying other fibres such as synthetic fibres where optical properties are more diverse and could be used as an identifier.

Protocol for Use by Conservators

There is no standard model for how to identify rayon in conservation practice. Since, strictly speaking, early manufactured fibres are morphologically distinct it is tempting to believe that rayon can be identified based on its longitudinal section alone. Rayon, however, can easily be confused with either acetate or other man-made fibres. This is illustrated in the database entries in the materials field for dresses in the broad sample. For many dresses the material is listed as "rayon?" indicating that fibre identification, either visually or by bright field microscopy, was not definitive (Appendix A). Moreover some of the identifications included in the database were incorrect and many of the dresses were not identified. The errors and the lack of information for these dresses supports the importance of a reliable protocol for identifying rayon fibres.

With respect to developing a rayon identification protocol for use by conservators, this study overwhelmingly indicates that there is no one best way to identify rayon. Rather, it was found that bright field microscopy, acetone solubility, polarizing microscopy and hot-stage microscopy all contributed to identification. Depending on the specific characteristics of the fibre and the artifact from which it was taken, different combinations of tests were required to attain a reasonable level of certainty in the identification. Factors that should be taken into account include the provenance and date of the artifact, whether the fibre exhibits characteristics that may confound certain tests, whether or not a large enough sample can be removed and whether it is possible to destroy some of that sample, what facilities and apparatus are available to the conservator and finally what margin of error is acceptable for the task at hand. Once these factors

are considered one or more of the tests are performed, each technique is able to eliminate one or more fibre groups, eventually leading to the identification of rayon (Figure 14).

If the provenance and date of an artifact are known and trusted then the identification protocol may be quite simple. If the garment dates prior to 1939 then the possible identity of a manufactured fibre is limited to viscose rayon, cuprammonium rayon or acetate. Nylon was not used in textile applications until 1940 (only in hosiery until the late 1940s), Acrylic arrived on the market in the late 1940s and polyester was not made available until 1951 (Joseph, 1986). In this case observation with bright-field microscopy, including observation of the presence or absence of striations and similarity of fibre and mountant's refractive index would identify the fibre. If there is any doubt, a quick modified acetone solubility test would offer confirmation. Alternately, hot-stage microscopy could be used; however, it was found in this study that the modified acetone solubility test was an inexpensive, quick and easy to interpret form of identification. If the fibre sample cannot be destroyed and there is access to a polarizing microscope a qualitative measure of birefringence may be helpful in confirming the identification made by longitudinal characteristics and refractive index.

If the provenance and date are unconfirmed, identification with a combination of several techniques may be necessary. The three most useful tests used in combination are hot-stage microscopy, acetone solubility and polarizing microscopy. If the fibre in question does not melt, is not soluble in acetone and shows some moderate level of birefringence then it can be identified as rayon. Presence of striations can differentiate viscose from cuprammonium. If the fibre dissolves in acetone it is eliminated as acetate. If the fibre melted and is birefringent it is eliminated as a thermoplastic synthetic fibre.

Although polarizing microscopy was found not to be an effective identification technique in and of itself, if the facilities are available, it was found that engaging the polarizer could be very helpful for confirming what was seen without the polarizer and the results from other types of identification testing.

Dark dye was the one factor that this research found to be problematic for identification. If the unknown fibre is darkly dyed, acetone solubility and hot-stage microscopy were the techniques least affected by dark dyes. If a non-destructive test is needed, other techniques beyond this study may need to be pursued such as stripping the dye from the fibre or determining the refractive indices of $n_{||}$ and $n_{\perp}$ using a series of high dispersion refractive index oils. Another potentially limiting characteristic of this identification protocol is that it was developed for the identification of rayon fibres from the early 20^{th} century, viscose and cuprammonium. There may

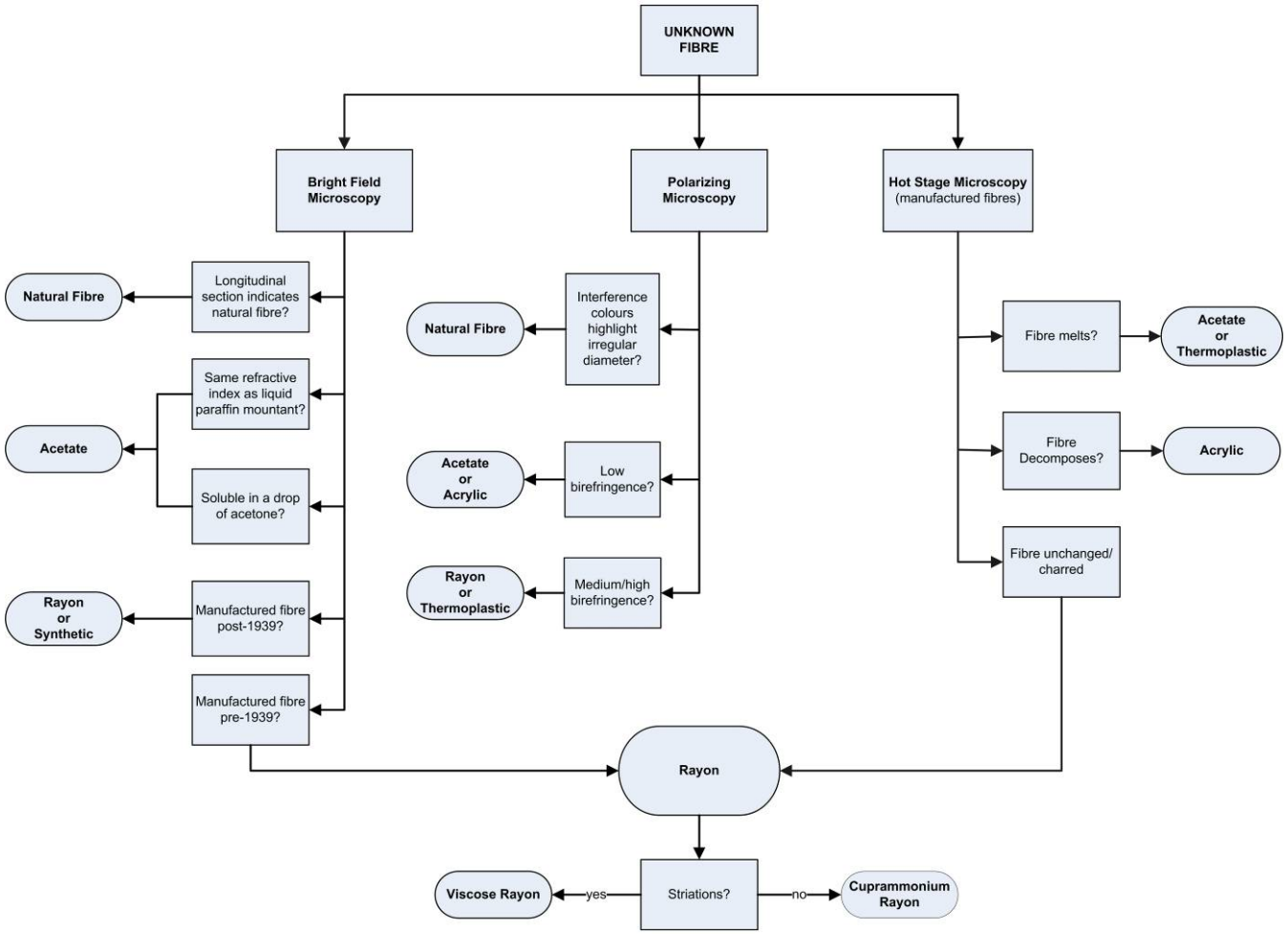


Figure 14. Protocol flowchart for the identification of early rayon by conservators

be some weakness in the protocol if there is a need to identify rayon fibres from the later 20th century such as high-wet-modulus and high tenacity rayon fibres have indistinct or non-existent striations and are therefore more difficult to differentiate from cuprammonium rayon (Joseph, 1986).

Rayon Artifact Characterization Results

Identifying rayon in the 46 dresses that made up the broad artifact sample for this research project not only informed the development of a rayon identification protocol, but also indicated where in the sample rayon was used. Identification of rayon was the first step in characterizing early rayon and it was found that 29 fabrics in 25 dresses from the 1920s and 1930s consisted of rayon either wholly or in part. Of those 30 fabrics, 15 (52%) combined rayon with another fibre type while 14 (48%) were single fibre fabrics.

Rayon Yarn Characterization Results

Of the 41 yarns consisting wholly or in part of rayon, 31 were identified as viscose rayon, five were identified as cuprammonium rayon and five other yarns were identified as combinations of viscose rayon and acetate. In all but five cases, yarns exhibited simple multifilament single yarn structure, including one viscose/acetate multifilament blend. Of the exceptions, four yarns (35, 36, 9, 92) were two-ply, spiral, combination yarns with one single of acetate plied with a second single of viscose. The spiral structure was created due to one ply having a hard, crepe twist and the second ply having low twist or no twist at all. In yarns 35 and 36 the viscose ply had a crepe twist whereas the acetate had low twist. Conversely, in yarns 91 and 92 the viscose plies were minimally twisted and the acetate plies were highly twisted. The final yarn that did not exhibit simple single yarn structure was number 67, a balanced, two-ply yarn with crepe twist, in which both plies consisted of viscose.

Although in combination fabrics cuprammonium rayon was mixed with mercerized cotton and viscose rayon was mixed with silk and cotton, at the yarn level there was no combining of these fibre types. Moreover there was no combining of silk and cuprammonium either at the yarn or fabric level.

Of the yarns with simple single yarn structure, 22 had low to no twist, eleven had high crepe twist and three yarns had medium twist. Medium twist was defined as yarns that were not so highly twisted as to exhibit the characteristic kinked appearance of crepe yarns, but not so minimally twisted that fibres from 0.5 cm samples separated into individual fibres. Fibre length was consistently uncut filament among all yarns. There was no evidence of rayon filament cut into staple fibres found in this sample of rayon dresses from the Clothing and Textiles Collection.

Fabric Characterization Results

From the sample of 1920s and 1930s dresses, 29 fabrics that consisted wholly or in part of rayon were identified. The fabric types containing rayon were varied, however, 77% of fabrics were lace, plain weave or crepe fabric structures and 23% of fabrics consisted of other structures (Figure 15). Fabric structures can be divided into two categories, woven fabrics and lace fabrics. There were eight fabrics within the lace fabric category; three consisted of machine made, bobbinet structure lace and five consisted of warp knitted raschel lace. All three bobbinet laces were made wholly of viscose rayon. Three of the raschel warp knitted laces also consisted wholly of viscose rayon; however, in the other two laces silk made up the ground net and viscose was used for the figured portions of the lace.

Twenty-one fabrics fell into the woven fabric category (Table 11; Figure 15). Ten fabrics were crepe fabrics, five were plain weave fabrics, two were velvet fabrics, two had a mattelassé double weave structure, one had a simple satin weave structure and one was a twill weave. Of the ten crepe fabrics four were true crepes with highly twisted yarns in one or more directions and a 1x1 plain weave structure, three fabrics were double faced, satin backed crepe and a further three crepe fabrics were a momie weave structure. Momie weave is made on a loom with a dobby attachments which allows for a complex repeat of tiny floats in the weave to produce the pebbly surface of a crepe (Humpheries, 2004). Fibre content in the crepe fabrics consisted of combinations or blends of fibre types with two exceptions (D, F), which were made wholly of viscose (Table 11). Seven crepe fabrics combined viscose and acetate; including, two in which both warp and filling yarns were combination ply yarns of viscose and acetate, and three combination fabrics where viscose made up the yarns in one direction and acetate made up the yarns in the other direction. Two satin backed crepe fabrics (A, C) were combination fabrics with simple single viscose crepe yarns in one direction and simple single acetate yarns with low twist in the other direction. Finally, one true crepe fabric combined cuprammonium rayon in the warp direction and mercerized cotton in the filling direction.

Four of the five plain weave fabrics consisted wholly of one fibre, including two that were viscose (YY, MM) and two that were cuprammonium (N, II). The fifth plain weave fabric (K) combines viscose warps with blended viscose and acetate filling yarns. The one satin weave fabric (BB) was wholly viscose rayon. Of the mattelassé fabrics one consisted wholly of viscose rayon and the other was a mixture of silk and viscose with one set of warps and wefts in the double cloth fabric structure consisting of pink silk and the other set of warps and wefts consisting of white viscose rayon. Both velvet fabrics consisted of a silk warp and weft ground fabric and a viscose pile. Finally, the twill fabric was a combination of viscose and silk.

Table 11
Structure and fibre content of fabrics consisting wholly or in part of rayon

Weave Structure (Fabric #)	**Frequency** (% of total)	**Fibre Content**					
		100% Viscose	100% Cuprammonium (Cupro)	Viscose – Acetate	Viscose – Silk	Cupro – Mercerized Cotton	Viscose – Cotton
True Crepe (P, Q, R, U)	4 (13%)			2 (P, R)		1 (U)	1 (Q)
Momie Crepe (F, G, W)	3 (10%)	1 (F)		2 (G, W)			
Satin Backed Crepe (A, C, D)	3 (10%)	1 (D)		2 (A, C)			
Plain Weave (II, K, MM, N, YY)	5 (20%)	2 (MM, YY)	2 (II, N)	1 (K)			
Mattelassé (J, S)	2 (6%)	1 (J)			1 (S)		
Velvet (E, L)	2 (6%)				2 (E, L)		
Satin (BB)	1 (3%)	1 (BB)					
Twill (O)	1 (3%)				1 (O)		
Bobbinet Lace (I, M,V)	3 (10%)	3 (I, M, V)					
Raschel Knit Lace (B, H, T, X Y)	5 (16%)	3 (B, T, Y)			2 (H, X)		
Totals	29 (100%)	12	2	7	6	1	1

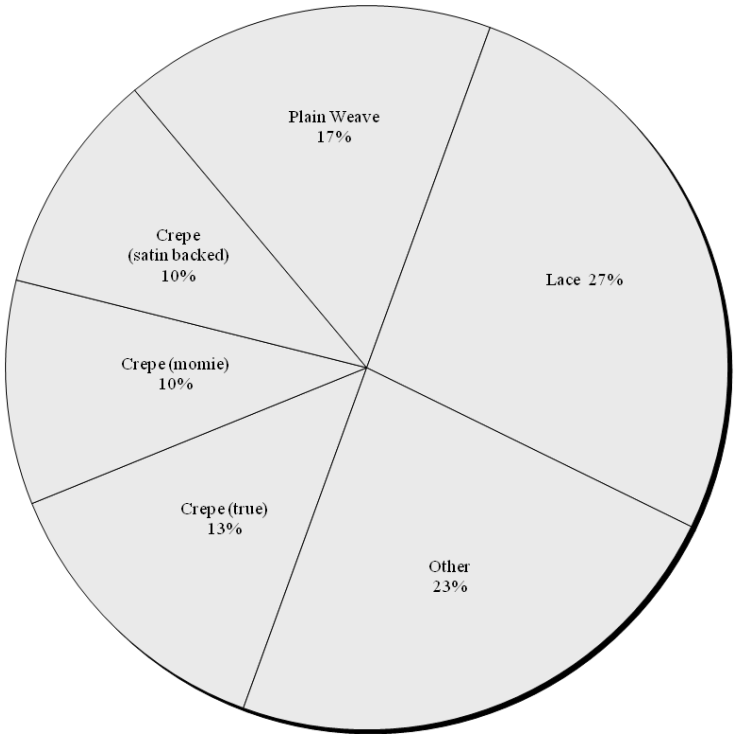


Figure 15
Weave structure for fabrics consisting wholly or in part of rayon (n = 29)

Fabric count was determined for all the simple weave fabrics, and in conjunction with a qualitative assessment of yarn bulk and openness of weave, the weights of the rayon fabrics in the artifact sample were assessed (Table 12). There were a range of fabric weights found; however, the majority of woven fabrics were lightweight. Within the group of ten crepe fabrics the three satin backed crepes were unbalanced, heavier fabrics. Two (A, C) had lower counts of bulkier yarns and one (D) had a higher count, but finer yarns. The seven other crepe fabrics (true crepe and momie) can be divided into two groups by weight. The first group includes two very similar fabrics (G, W), which are heavier fabrics with balanced, low counts, made from bulky yarns. The fabrics in these dresses more closely resemble wool crepes than silk crepes. The second group includes fabrics that are lighter and more akin to silk crepes.[4] Fabric weight was achieved in three of the lighter rayon fabrics (F, P, U) through an unbalanced, higher warp count weave using finer yarns. In the two other fabrics (Q, R) a balanced, more open weave structure with a lower count led to a fine 'silk-crepe-like' fabric. The majority of plain weave fabrics (II, K, MM, YY)

[4] However, it should be borne in mind that the rayon fibre filaments are not as fine as silk; moreover, the fibre density of silk is less than that of rayon therefore the mass of rayon fibres and thus rayon garments is greater than that of a similar silk garment.

Table 12
Fabric counts of simple weave fabrics containing rayon

Fabric Weight	***Fabric Letter***	***Fabric Type***	***Fibre Type***	***Fabric Count per cm (warp x filling)***
Heavier Dress Fabrics	A	Crepe (satin backed)	Viscose x Acetate	38 x 24
	C	Crepe (satin backed)	Acetate x Viscose	52 x 29
	D	Crepe (satin backed)	Viscose	59 x 35
	G	Crepe (momie)	Viscose Acetate x Viscose Acetate	28 x 28
	W	Crepe (momie)	Viscose Acetate x Viscose Acetate	30 x 31
Medium/Light Dress Fabrics	F	Crepe (momie)	Viscose	56 x 36
	P	Crepe (true)	Acetate x Viscose	68 x 26
	U	Crepe (true)	Cuprammonium x Mercerized Cotton	64 x 44
	Q	Crepe (true)	Cotton x Viscose	38 x 30
	R	Crepe (true)	Viscose x Acetate	35 x 30
	II	Plain Weave	Cuprammonium	39 x 29
	K	Plain Weave	Viscose x Viscose-Acetate	31 x 21
	MM	Plain Weave	Viscose	50 x 27
	YY	Plain Weave	Viscose	40 x 28
	BB	Satin	Viscose	40 x 27
	O	Twill	Silk x Viscose	49 x 28
Light/Sheer Dress Fabric	N	Plain Weave	Cuprammonium	34 x 34

were light/medium weight and had unbalanced weave structures with counts ranging from 31-50 yarns/cm in the warp direction and 21 – 29 in the filling direction. One plain weave fabric (N) was a very light-weight, sheer fabric with a low, balanced fabric count. Finally, both the twill and the satin weave fabrics (BB, O) were light/medium weight dress fabrics with unbalanced counts. There does not appear to be a pattern relating counts and fibre types and although two of the true crepes and two of the momie crepes appear to have similar counts there is not enough evidence to suggest that count and weave type are related.

Embellishment of rayon fabrics in the artifact sample consisted of both patterning through texture, including weave structure and supplementary textile components, and patterning through colouration, including printed effects and differential dyeing. The eight lace fabrics (B, H, I, M, T, V, Y, X) were either embellished through lace structure or not embellished at all. Three laces (B, H, Y) were black raschel warp knits and had floral motifs incorporated into the lace structure. One lace fabric (I) was black and had a bobbinet structure with a white needle-run floral motif. Two raschel knit laces did not incorporate floral motifs: one (T) was black and was structured with a rectangular geometric motif. Another one (X) was light brown and had a

curvilinear abstract motif as its structure. In the two final lace fabrics (M, V) there was no embellishment, the fabrics are plain pink and blue bobbinet laces respectively. Weave structure also produced embellishment in the two mattelassé fabrics (J, S). In one fabric (J) both sets of warp and weft yarns were black and their structure produced a raised, abstract curvilinear pattern. In the other fabric one set of yarns was pink, the other white and the weave structure produced a 'flecked' pink and white pattern.

Of the simple plain weave fabrics (II, K, N, MM, YY) two fabrics were printed with a floral motif (K, MM) while the remaining plain-woven fabrics were unembellished, with two of the three fabrics making up underdresses (YY, II). Of the three momie weave crepes one was unembellished (F) and two had areas of embroidery and beading (G, W). Two of the true crepes were unembellished (P, R), one was printed with a floral motif (Q) and one had areas of embroidery (U). The satin back crepes (A, C) were slightly patterned through the satin back structure of the fabrics, which created a ribbed and "wave-like" pattern in the two fabrics respectively. Finally, the two velvet fabrics (E, L) were dyed red and brown respectively and had no additional embellishment and the two satin (D, BB) and one twill (O) fabrics were unembellished and were dyed yellow-green, black and black respectively.

Garment Characterization Results

In addition to various fabric structures, the 25 rayon or rayon blended dresses from the 1920s and 1930s in the Clothing and Textile Collection also varied. The dresses took on a variety of different silhouettes and both day and evening dresses were represented in the sample. Ten dresses in the artifact sample appear to be day dresses, while the remaining 15 dresses appear to be evening gowns (Appendix F).[5] The distinction between day dresses and evening dresses was made based primarily on skirt length and richness of fabrics. Dresses with longer skirts and richer fabrics were interpreted as evening gowns. For example, a long, sheer white gown and a red velvet gown were identified as evening dresses (Figures 16, 17), whereas as a shorter pink dress was identified as a day dress (Figure 18).

The dates that the database provides indicate that the rayon dresses in the sample are not spread evenly across the 1920s and 1930s (Table 13). Two dresses are dated between 1920 and 1929 and a further five dresses are dated 1925-1935. The remaining 18 dresses are dated to the 1930s. Based on observation of silhouette and the set out characteristic features of 'drop-waisted,' 'straight cut' and 'supported from the shoulders' for 1920s dresses and 'bias-cut,' 'bloused bodice,' 'natural waisted,' 'belted,' 'cape sleeves' and 'slightly flared skirts' for 1930s dresses,

[5] Accession numbers of day dresses: 1972.8.4a, 1977.5.37, 1985.70.6, 1985.74.55, 1986.31.6a, 1988.40.3a, 1988.51.7, 1989.33.10, 1999.53.49, 2004.26.1. All other dresses are evening dresses.

Figure 16
Sheer white evening dress, 1986.43.7

Figure 17
Red velvet evening dress, 1979.1.10

Figure 18
Pink day dress, 1988.40.3a

most of the dresses appear to date from the 1930s and therefore most dresses were dated correctly. Only the three dresses (1999.53.49, 2006.24.8, 1972.8.4) seen in Figures 19, 20 and 21 are consistent with the predominant 1920s silhouette. The dresses seen in Figures 19 (1999.53.49) and 20 (2006.24.8) were dated 1920-1929 in the database; however, the dress in Figure 21 (1972.8.4) was dated to 1935 and may in fact date from the thirties despite that it does not fit within the 1930s silhouette parameters used in this project.

Figure 19
Garment 1999.53.49 with a 1920s silhouette

Figure 20
Garment 2006.24.8 with a 1920s silhouette

Figure 21
Garment 1972.8.4. Database indicates from the 1930s; however, may date from the 1920s

Condition Characterization Results

A review of the condition of the 25 dresses with main fabrics consisting wholly or in part of rayon revealed that most of the dresses were in good condition with some areas of minor damage. The instances of poor condition can be divided into two categories: first, general condition issues that are common to many types of textiles and second, condition issues identified during the 1920s and 1930s as rayon specific issues.

Condition issues commonly found in many types of textiles and garments occurred in several of the rayon dresses from the artifact sample, including fading, tears, holes, and losses, abrasion, and pilling. Fading occurred in three garments (1972.8.4a, 1985.74.55, and 2004.26.1). Fading was slight in all three cases and was either overall or concentrated on the front or tops of sleeves. Many of the garments had small holes or tears in them (1988.40.3a, 1986.43.7a, 1977.5.102, 1986.31.7a, 1999.53.49, 1986.31.6a, 1987.49.1, 1977.5.37, 1983.8.4a, 1981.27.32, 1979.1.10, 2002.3.30a, 1985.70.6). Often the holes and tears appeared to be from general wear and

Table 13
Characteristic 1920s and 1930s dress features in rayon and rayon blend dresses in the sample

	1920s Characteristics			1930s Characteristics						
Accession #	**Drop-waisted**	**Straight-cut**	**Support from Shoulders**	**Bias Cut**	**Bloused Bodice**	**Emphasized Waist**	**Natural Waist**	**Cape Sleeves**	**Flared Skirt**	**Database Date**
1972.8.4a	●		●		●					1935
1973.8.15a					●		●		●	1930
1977.5.102				●			●		●	1930-1939
1977.5.37						●	●		●	1935-1939
1979.1.10					●		●		●	1930-1939
1979.9.6a				●	●	●	●	●	●	1930-1939
1981.27.32					●		●		●	1930-1939
1983.8.4a	●		●						●	1930-1939
1984.19.02				●	●		●		●	1925-1935
1985.70.6					●		●		●	1930-1939
1985.74.55					●	●	●	●	●	1937-1939
1986.31.6a					●	●	●		●	1925-1935
1986.31.7a					●	●	●		●	1930-1939
1986.43.7a					●	●	●			1925-1935
1987.49.1					●	●	●		●	1925-1935
1988.40.3a						●	●		●	1930
1988.51.7				●		●	●		●	1930-1939
1989.32.10					●		●	●	●	1935
1993.4.18a				●	●	●	●		●	1930-1939
1999.37.4				●		●	●		●	1925-1935
1999.53.49	●	●	●							1920-1929
2002.3.30a							●		●	1930-1939
2004.26.1					●	●	●		●	1939
2006.24.17					●				●	1930-1939
2006.24.8	●		●	●					●	1920-1929

tear, although there were a number of areas where physical damage appeared to be associated with perspiration stains in the underarm areas or other common sweating areas such as the chest and upper back (Figure 22). Weakening due to perspiration in these areas is also often found with

other fibres, especially silk. Three garments (1999.53.49, 2002.3.30a, 1986.31.7a) had yellowing in the underarm areas. One (2002.3.30) also had yellowing on the back bodice and another (1986.31.7a) on the chest area. Splitting and losses were associated with the yellowed underarm stains in three garments (1999.53.49, 1986.31.7a, 2002.3.30). In one garment (1979.9.6a) there are holes in the underarm region.

Abrasion damage was observed in three garments: across the front of the natural waist (1985.74.55), along the bottom edge of the hem (1985.74.55) and on the inner proper right sleeve (1988.40.3a). All over slight pilling occurred in five garments (1988.51.7, 2006.24.17, 2004.26.1, 1981.27.32, 1979.9.6a) and snagging of the long viscose floats occurred in the figures of two raschel lace fabrics (2006.24.8 and 1973.8.15a) Finally, several of the garments had split or open seams (1979.1.10, 1981.27.32, 1985.74.55, 1986.31.6a, 1986.43.7a, 1987.49.1, 1989.32.10, 2004.26.1, 2006.24.17) The seams that split were generally either the waist, shoulder or bodice side seams, which are particularly vulnerable to damage, as they are the seams worn close to the body where bodily movement causes stress.

In addition to general textile condition issues, a few rayon dresses form the 1920s and 1930s in the Clothing and Textiles Collection exhibited condition problems with that were identified as rayon specific issues during the 1920s and 1930s (Table 14) (Woman's Institute of

Figure 22
1920s dress (1999.53.49) with fabric loss associated with underarm perspiration. Although there is no evidence of yellowed perspiration stains, the holes are associated with a white residue that is likely deodorant.

Domestic Arts & Sciences, 1923; Boulton, 1951; Collard, 1981; De La Haye, 1993; Johnson, 1927). Stretching or bagging was observed in five dresses. In three dresses (1972.8.4, 1985.70.6, 2004.26.1) there was bagging at the elbows. The fabric in these areas did not hang straight and a slight rounded protrusion where the elbow stretched the fabric was visible. One dress (1986.43.7a) had stretching and bagging in the bust area and another (1977.5.37) appeared to have been stretched out in length as the hem was not straight. In three dresses, a second dimensional stability issue, shrinkage, was observed. It is likely that both relaxation shrinkage and shrinkage due to yarn crimp contribute to the diminished fabric lengths. In two dresses (1984.19.02, 1986.43.7a) the lining was exposed below the main dress fabric (Figure 23) and in a third (1985.70.6) the matching bolero jacket does not cover the rough stitching at the waist. Slipped seams were noted in two garments. In one dress (1986.31.7a) the bottom proper left side seam had slipped and in the other dress (1988.51.7) the proper left sleeve seam. Finally, evidence of dyes that were not fast was found in two dresses (1986.31.7a, 1999.37.4). Dye transfer showed up in the underarm area suggesting that the moisture from sweat made the dye fugitive. In one (1986.31.7a), dye has transferred all over the dress from the vibrant pink in the printed pattern to the lighter pink ground fabric; however, dye transfer is concentrated in the underarm areas (Figure 24). In the other (1999.37.4) the dye has only transferred in the underarm areas from the black viscose raschel knit over dress to the cream coloured silk chiffon fabric that is sewn underneath the lace in the top part of the garment bodice.

Figure 23
Dress (1986.43.7a) with evidence of shrinkage. Main fabric is short, leaving the lining fabric exposed.

Figure 24
Transfer of pink dye from plain woven fabric to bobbinet lace in underarm region in 1930s dress (1986.31.7a)

Table 14
Presence of condition issues expected for rayon by garment accession number

Condition Issue	**Garment Accession # (fibre content and structure)**
Stretching and/or bagging	1977.5.37 (viscose satin)
	1972.8.4 (viscose/acetate satin)
	1986.43.7 (cuprammonium plain weave)
	1985.70.6 (viscose mattelassé)
	2004.26.1 (viscose/acetate momie weave)
Evidence of shrinkage	1985.70.6 (viscose matte lassé)
	1984.19.02 (viscose bobbinet lace)
	1986.43.7a (cuprammonium plain weave)
Slipped seams	1986.31.7a (viscose plain weave)
	1988.51.7 (cotton/viscose true crepe)
Dye Transfer	1986.31.7a (viscose plain weave)
	1999.37.4 (viscose raschel knit lace)

Rayon Characterization Discussion

Investigating the character and condition of the 1920s and 1930s rayon in women's dresses in the Clothing and Textiles Collection had two main purposes in this project. First, to determine whether as suggested by period descriptions that early rayon takes on many forms, thus reinforcing the importance of thorough fibre identification, and second, to determine whether after between 80 and 90 years, there are any deterioration problems with the first broad rayon fabrics. Despite some methodological challenges, it was found that 1920s and 1930s rayon is manifested in various and sometimes unexpected ways. It was also found that at this time there is little evidence to suggest the presence of rayon-specific condition issues in 1920s and 1930s women's dresses.

Rayon Yarn, Fabric and Garment Characterization

Results of the examination of rayon yarns, fabrics and garments indicate that rayon dress fabrics take many forms including combinations and blends with both natural fibres and other manufactured fibres. Although the sample size was small and generalizability will be improved as many more period garments are studied, the fact that 50% of rayon fabrics were found to be combination or blended fabrics, clearly justifies care to be taken in the identification of early rayon.

Rayon fabrics made by both the cuprammonium and the viscose processes were represented in the artifact sample. Three fabrics in three dresses were made by the cuprammonium process, while 27 fabrics from 22 dresses incorporated rayon made by the viscose process. This observation is consistent with manufacturing patterns of the period. The manufacture of viscose rayon was significantly more extensive than rayon produced by the cuprammonium process, so it is not surprising that viscose was more prevalent in the 1920s and 1930s dresses in the Clothing and Textiles Collection.

What was somewhat surprising was the high proportion of fabrics that combined viscose and acetate. These fabrics raise a number of issues, not least of which are questions about the motivation for blending two early manufactured fibres. In the reviewed literature there was discussion about the common practice of blending rayon with natural fibres to improve properties; however, there was less discussion about combining two different manufactured fibres (Coleman, 1969). Though it is unclear how exactly combining viscose and acetate created a more desirable fabric, Hague (1957) gives some indication of why these two fibres may have been combined. He suggests that after 1927 and 1928 acetate or "Celanese" became popular. It is unclear whether acetate's stiffer, more silk-like hand or clever marketing led to its popularity (Hague, 1957, p. 44). In 1928, the viscose rayon giant Courtaulds entered into competition with British Celanese by

starting to make 'acetate rayon' due in part to its popularity, (Hague, 1957). Since Courtaulds made both fibres after 1928, it is less surprising that they would be combined, especially since in addition to selling rayon yarn, Courtaulds wove much of their manufactured fibres into finished fabrics in their own mills (Coleman, 1969). Furthermore, contemporary literature indicates that a reason for combining acetate and rayon is to improve appearance and draping qualities (Joseph, 1986), which may have also been a factor in 1920s and 1930s combined fabrics. Finally, the combining of rayon and acetate may have been masked by the fact that they were both called 'rayon'.

Economically, viscose rayon and acetate had different advantages and disadvantages. Viscose rayon is made from wood-pulp which is a much cheaper raw material than the cotton linters required to produce acetate. However, since acetate is produced using dry-spinning as opposed to wet spinning as with viscose, it is possible to extrude acetate at a faster rate. Therefore, in finer yarns with low deniers acetate is more economical than viscose since the cost of extrusion is a greater part of the total cost than the spinning solution. In higher deniers where the relative cost of raw materials is of greater consequence than the spinning process, viscose is more cost effective (Hague, 1957). It is clear that the economies of viscose and acetate were different, however, without more information, there is not enough evidence to determine what effect differing production costs had on the decision to combine rayon and acetate in one fabric. Properties, popularity and marketing and economics all likely played a role in the decision, which led to their combination.

One of the research questions outlined for this project was to determine whether there were more fabrics using cut staple fibre rayon in the 1930s than in the 1920s. The use of cut staple rayon did not really take off until the late 1930s and was then solidified during the Second World War (Allen, 1946; Woodings, 2001a). In 1929 spun staple fibre rayon made up only 5% of world output of rayon, whereas by 1936 it was 22.7% and by 1939 it was 48.6% (Hague, 1957). The question sought to determine whether evidence of the cut staple versus filament rayon statistics could be seen in the Clothing and Textiles Collection. Results, however, indicated that none of the yarns appear to be made from cut filament staple fibre; rather they are all continuous filament yarns. This result is particularly surprising since the majority of the rayon dresses characterized in this study appear to date from the 1930s when spun staple rayon made up a significant proportion or rayon production. That combinations of rayon and cotton fibres and rayon and wool fibres were considered a poor *ersatz* for 100% wool and 100% cotton (Allen, 1946; Coleman, 1969; Hottenroth, 1928; Woodings, 2001a) may be a possible explanation for their not being found in the sample. Garments that were highly valued are much more likely to end up in museum collections, and in particular in the Clothing and Textiles Collection at the University of Alberta

since it depends on donations for the majority of acquisitions. Moreover, since there were no rayon staple yarns found in the sample, not surprisingly, there were no combinations or blends with staple fibre yarns.

One parameter in which there was very little variation was yarn structure. Results showed that the rayon fabrics were woven mostly using simple single yarns and a few 2-ply yarns. The level of twist added to the yarns was either low to no twist or high crepe twist. Yarns with low levels of twist were likely prepared in this manner for the same reasons filament yarns often have low twist today: their filament nature means that a great amount of twist is not needed to keep the fibres together in yarns. Also, a low amount of twist maximizes the luster of fibres. The crepe yarns were likely given a hard twist to give the finished fabrics the characteristic pebbled appearance of crepe fabrics, which it appears were popular dress fabrics at this time since it made up a significant proportion of the sample.

Condition Discussion

The results of the condition survey indicate that all of the condition issues found in the rayon dresses were problems associated with the garments' use and were not associated with long-term degradation. Problems usually associated with the inherent weakening of fibres, such as embrittlement, splitting or extensive yellowing (not associated with bodily residues), were not observed in the rayon dresses surveyed. If rayon's shorter, less organized cellulose molecules do contribute to accelerated degradation, there is no evidence of it in the 1920s and 1930s rayon dresses in the Clothing and Textiles Collection at this time. Condition issues that were evident, however, were problems associated with artifact use; for example, split seams, dye transfer, and perspiration stains among others.

In this study, condition issues associated with artifact use can be divided into two groups: issues that might specifically be related to rayon and issues that are damage seen commonly on many types of textiles and no more frequently here to make a definitive statement that they are attributable to rayon. Durability issues that were identified by the literature review as problematic for 1920s and 1930s rayon garments while in use included stretching and bagging, shrinkage, fugitive dyes, and slipped seams (Woman's Institute of Domestic Arts & Sciences, 1923; Boulton, 1951; Collard, 1981; De La Haye, 1993; Johnson, 1927). All of these issues were observed in one or more of the garments (Table 17); however, no widespread trend was identified, as the problems were not noted frequently enough to make a definitive connection to rayon as the source of these condition issues. Moreover, no condition issue appeared to be associated with a particular fabric structure or fibre combination. All of the other condition issues that were observed in the rayon dresses are problems that often arise in textile artifacts including physical damage, staining and

fading. None of these condition issues occurred frequently enough to constitute a pattern of damage characteristic of rayon.

A better idea of condition issues associated with early rayon would likely be gained by examining a larger sized sample. The sample size used in this study was limited by what was available in the collection and the scope of the project. It may have been possible to find a few more rayon dresses that had been misidentified if fibre identification had been performed on all dresses of the 1920s and 1930s; however, a very clear picture requires surveying larger or multiple collections. The ideal would be to assess the condition of early rayon fabrics in comparison to natural cellulosic fabrics whose aging properties are more familiar to conservators. Rayon fabrics could be compared with cotton fabrics of similar ages and fabric structures. Cotton could then act as a benchmark that rayon condition could be compared to, not only during the course of the study but also over a longer span of time to determine at what point rayon will begin to show visible signs degradation. A methodology that compared rayon and cotton fabrics, was not possible for this project as there were very few cotton dresses from the 1920s and 1930s in the collection and the ones that did exist did not share common structures with the rayon fabrics identified. It might also be advantageous to compare rayon and silk since although chemically rayon most closely resembles cotton, it was developed as 'artificial silk' and some of its physical properties such as lustre and drape are more similar to silk. Rayon was used in more 'silk-like' applications than 'cotton-like' applications and therefore, were likely worn in different situations and cared for in different ways than cotton dresses.

Even though there were minimal condition issues with many of the dresses surveyed, some of the issues that conservators should be aware of when treating rayon garments may not have been detectable. Most notably, fugitive dyes may in fact be more of an issue than the results of this study indicate. Rayon was often dyed with direct dyes, which were not known for their fastness (Boulton, 1951). Many of the garments were dyed a single colour and therefore there was nowhere that dye transfer could be seen. Similarly, many of the dresses were unlined. Although this practise was typical of the time, shrinkage was not always readily identifiable.

The key aim of this study, with respect to artifact condition, was to determine whether there is any visible evidence that rayon fabrics and garments from the 1920s and 1930s have been damaged in a characteristic way or are degrading at an accelerated rate. The results of the condition survey do not indicate that rayon is being damaged in a characteristic way or degrading at an accelerated rate; however, a larger sample is needed to gain a more complete understanding of the condition of rayon from the 1920s and 1930s.

CHAPTER FIVE: CONCLUSIONS

Summary

Similar to natural materials, modern materials make up an important part of the historic record and as such have made their way into museum collections. The use of rayon in 1920s and 1930s garments confronts conservators with new challenges: definitive fibre identification involves more than basic microscopy and decisions about treatment can be difficult with little available research on early rayon and its conservation. Rayon is expected to degrade similarly to other cellulosic fibres; however, since it is a regenerated fibre, rayon is at risk of doing so at a faster rate. In addition, rayon can rarely be identified using basic microscopy and narrowing down the identification within the manufactured fibre category usually necessitates more advanced techniques. The purpose of this research was to develop and test a protocol for the identification of viscose and cuprammonium rayon and to determine whether early rayon dresses have any condition issues at this time. Polarizing microscopy, hot-stage microscopy, acetone solubility and the use of high dispersion refractive index oils were explored as fibre identification techniques, while the 1920s and 1930s rayon and rayon blended dresses, were surveyed for condition. Three main conclusions evolved from this research: first, a combination of bright field microscopy, acetone solubility and hot-stage microscopy is most useful for identifying rayon. Second, it was found that rayon takes on many forms even based on the small sample size examined here. Finally, the examination of this small sample of rayon dress fabrics uncovered no clear evidence of deterioration issues specific to rayon fibres after 80 to 90 years of ageing.

Fibre Identification

Definitive fibre identification of rayon is not as straightforward as with natural fibres and narrowing down the identification within the manufactured fibre category often involves more than simple microscopy. Textile conservators are faced with a wide array of possible fibre identification techniques when taking identification to the next level and it is not always clear what is the most expedient way to ascertain definitive fibre identity. This study sought to develop a protocol for the definitive identification of rayon. The relative merits of bright-field microscopy, acetone solubility, polarizing microscopy, hot-stage microscopy, and refractive index mounting liquids were evaluated as identification techniques, by performing fibre identification on 46 dresses.

The results of this research reinforce that basic microscopy is both an effective means of identifying natural fibres and an important initial step in the identification of man-made fibres. For the identification of rayon, bright-field microscopy was important in two ways: first, to differentiate viscose and cuprammonium rayon and second, to eliminate acetate, the one

confounding man-made fibre in the 1920s and 1930s. By observing their respective longitudinal section using bright field microscopy, the two types of rayon can be distinguished. Acetate has the same refractive index as the mountant liquid paraffin mountant and when fibre and mountant have similar refractive indices the edge lines of the fibres disappear. Acetate was eliminated with 84% reliability by observing this property and the more experience the operator has the higher this number should be. If the fabric and garment can be dated prior to 1939 with certainty, a manufactured fibre that is not acetate can be definitively identified as rayon.

The modified acetone solubility test could definitively eliminate acetate. The key advantages of testing fibres' solubility in a drop of acetone, on a microscope slide with fume extraction were the test's simplicity and consequent 100% accuracy. This procedure was particularly helpful with blended yarns as both the unaffected fibre and the residue of the solubilized fibre were clearly visible on the slide after all acetone had evaporated.

Polarizing microscopy was not found to be as effective a tool for identifying rayon as anticipated. Using qualitative numeric measures of birefringence did not consistently lead to successful fibre identification; the technique was only 72% reliable. Many factors, including, dark dyes, deep striations (diameter measurement issues) and the high level of experience required of the operator, confounded results. Polarizing microscopy was, however, helpful for emphasizing the irregular diameters of natural fibres, particularly in darkly dyed silk fibres where features were difficult to distinguish with bright-field microscopy. Moreover, qualitative observations of birefringence, such as 'low birefringence' when the fibre appears grey or 'moderate/high birefringence' when interference colours are observed, were helpful in eliminating acetate[6] (low birefringence), and in confirming that a fibre was indeed a manufactured or synthetic fibre (medium/high birefringence). Although forensic literature indicates that polarizing microscopy is the technique most often used in that field—a field that holds many concerns in common with the field of textile conservation (Gaudette, 1988) —it may not be suitable for identification of dyed and striated rayon fibres in textile conservation without great experience.

Hot-stage microscopy used with manufactured fibres, was found to be an excellent, easy to interpret identification technique for rayon. If unchanged or charred, the manufactured fibre could be identified as rayon. Melting, however, indicated an acetate or thermoplastic fibre. Although not examined in this sample, hot stage microscopy can identify other thermoplastic fibres, which melt at specific temperatures and acrylics, which decompose.

[6] Although it was not explored in this study, acrylic also exhibits very low birefringence.

Finally, mounting fibres in high dispersion refractive index liquid with a refractive index of 1.548 and observing Becke Lines was found not to be effective for differentiating cuprammonium rayon and viscose rayon. Results support an overlap in refractive indices of viscose and cuprammonium rayons ($n_{||}$ direction) as indicated by recent values (Gaudette, 1988) but opposed to early values (Identification of Textile Materials, 1972). The technique, however, did show promise for the identification of other fibres, such as synthetic fibres. The test was non-destructive and Becke line movement was easy to interpret. Synthetic fibres have more disparate refractive indices than do cuprammonium and viscose rayon and therefore, their identity could be determined based on Becke line movement in a series of refractive index liquids.

After testing a number of identification techniques, the best way to identify rayon fibres was found to combine bright-field microscopy with acetone solubility and hot-stage microscopy (Figure 14). Bright-field microscopy eliminated natural fibres and acetate though not definitively, acetone solubility eliminated acetate definitively and hot-stage microscopy eliminated acrylic and thermoplastic fibres, while definitively identifying rayon. Polarizing microscopy was a helpful supporting technique.

Rayon Characterization

Fibre identification techniques were also used to define the sample of rayon from 1920s and 1930s dresses in the Clothing and Textile Collection. The characteristics of the dresses were observed at the fibre, yarn, fabric and garment level in an attempt to describe how rayon from the 1920s and 1930s is manifested in women's dresses.

Based on the results of this study it can be concluded that rayon takes on many forms in dress fabrics from the 1920s and 1930s even when examined in a small sample such as the one used for this project. Fibre type, fibre combination, yarn structure, fabric structure and garment range were all varied. Fibre identification on 46 dresses revealed that twenty-five dresses consisted of rayon, wholly or in part. Fourteen fabrics consisted of 100% rayon, whereas 15 fabrics combined rayon with another fibre. Notably, seven of the blended fabrics combined rayon and acetate. Ten different fabric structures were found in the sample with lace (raschel and bobbinet), plain woven and crepe fabric structures (true crepe, momie crepe, satin backed crepe) making up 79% of the rayon fabrics and velvet, twill, satin and mattelassé making up the remaining 23%. Garments included day and evening dresses in a variety of styles.

At the yarn level, structure consisted mainly of simple single construction although there were several two-ply yarns identified. Yarns had either low twist or crepe twist with only three

yarns falling between those two extremes in terms of twist. All the yarns examined were continuous filament and no yarns made up of cut-staple fibres were observed in this sample.

At the fabric level true crepe, momie crepe, satin backed crepe, plain weave, satin, matte lassé, velvet, twill, raschel warp knit lace and machine made bobbinet lace were all represented in either 100% rayon or rayon blended fabrics. The most common fabric structures were plain weave and raschel warp knit lace of which there were five examples respectively. The review of the literature (Hottenroth, 1928; Schwarz & Mauersberger, 1936; Stewart, 2004) indicated that in the 1920s and 1930s rayon fibres were very often combined with natural fibres to improve their properties. With cuprammonium fabrics there were two few samples to draw any strong conclusions; however, with viscose rayon, the number of combined fabrics exceeded the number of wholly viscose fabrics eleven to seven. However, it was found that the fibre viscose was most often combined with was not a natural fibre, but rather acetate. Seven fabrics combined acetate and viscose rayon, while only one combined viscose and cotton and six combined viscose and silk. Therefore, the combining of rayon with other fibres was indeed happening during the 1920s and 1930s as the literature indicated; although the practice was not dominated by natural fibres combinations as was expected, rather it was often combined with acetate. It is possible that the literature did not emphasize the combining of these two fibres since they were both considered either 'artificial silk' or 'rayon' at that time.

A variety of styles of dresses proved to have rayon or rayon combination fabrics as their main fabrics. The majority of the dresses appear to be from the 1930s, however, with only two garments appearing to date to the 1920s. Rayon was used in both day and evening dresses of the 1920s and 1930s as ten dresses from the sample of rayon dresses are day dresses and fifteen are better described as evening gowns. The varied forms that rayon takes on at the fibre, fabric and garment levels has significant implication for rayon identification practises and suggests that it is important to go beyond simple microscopy for identification.

Condition Characterization

Dresses in which the main dress fabric consisted of rayon or a rayon in combination with another fibre were observed for evidence of degradation and damage. The condition review of the 25 dresses with main fabrics consisting wholly or in part of rayon revealed few condition issues. Most of the dresses were in good condition with some areas of minor damage. Condition issues that were identified by the literature review as potentially problematic in rayon garments, included, stretching and bagging, shrinkage, fugitive dyes, and slipped seams. All of these issues were observed in one or more of the garments; however, none of these condition issues were widespread enough to definitively tie them to the fibre rayon or to a particular fabric structure.

Recommendations for Future Research

The results of this study have made clear several key areas in which further research would be beneficial. In the area of fibre identification more research into polarizing microscopy would benefit the textile conservation profession. Despite the findings of this study–that it is difficult to identify fibres using polarizing microscopy alone–this technique still holds promise since it is non-destructive, can identify many different fibres and is used to identify fibres in the field of forensics. Specifically, research must be undertaken on specific procedures to ascertain which techniques are most easy to interpret by conservators who use the polarizing microscope only sporadically. Research is needed on the appropriate method of measuring fibre diameter in fibres with irregular cross-sections. While testing polarizing microscopy in this project it was unclear whether skipping a striation when measuring fibre diameter is always appropriate. Finally, research is needed on ways to overcome the limitations presented by darkly dyed fibres; specifically, it would be interesting to know whether stripping dyes from fibres would be a practicable technique for use in the conservation laboratory.

The use of refractive index mounting liquids holds promise for the identification of synthetic fibres and is a technique that should be tested for conservation applications. Observation of the Becke Lines when observing fibres in these mountants was straightforward, the liquids are available and can be used on ordinary microscopes but their use is not widespread in the field. A specific protocol for fibre identification based on this technique would make its application easier for conservators. Finally, further research on fibre identification that expanded the protocol for identifying rayon fibres developed here to include other sorts of manufactured fibres would be worthwhile research, helpful to conservators as synthetic fibres will also increasingly find their way into conservation laboratories.

Further research is also necessary on rayon degradation. More specifically, a study that compares the degradation of natural and manufactured cellulosic fibres to determine whether the molecular structure of rayon will have a decided effect on its eventual deterioration would be beneficial. This could be done using accelerated ageing or by choosing artifact samples with idea of cellulosic comparison in mind so as to examine areas of collections where comparables exist.

Rayon fibres, fabrics and garments as material culture also represent a rich topic for further study. In particular the significant presence of rayon and acetate combination fabrics warrant further investigation to determine what factors governed the decision to combine those two fibres together as it is unclear whether this practice would improve fabric properties. Extensive historic research on what combined rayon fabrics were called and how they were marketed would doubtless reveal insight into fibre combining and blending. A study might be

informed by the examination of how rayon fit within the established economic structure of the textile industry from a material culture point of view. There is still much research to be done on how new fibres changed the fashion system and how they changed the nature of the relationship between people and textiles. For example, did the adoption of man-made fibres follow existing fashion patterns or did the new fibres drive fashion differently than natural fibres had. Also, it would be interesting to explore whether the early manufactured fibre industry was supply driven or demand driven and how the role of industry has changed over time.

The results of this study have demonstrated richness in variety and a complexity in the way rayon was used in the 1920s and the 1930s. The textile picture only becomes more complicated as the twentieth century progresses and many more man-made fibres are introduced. Textile conservators will eventually have to deal with the complexity of twentieth century textile materials as the garments that incorporate them are accessioned, get older and become more fragile. The knowledge and tools used for approaching natural fibres will not be sufficient in this area and further research will be necessary to move the field forward to meet this new challenge.

BIBLIOGRAPHY

Ahern, E. (1941). *The way we wash our clothes*. New York: M. Barrows & Company Inc.

Allen, C. L. (1946). Rayon staple fiber: Its past and its prospects. *Southern Economic Journal, 13*(2), 146-157.

Allen, N. S., & McKellar, J. F. (1980). Photosensitised degradation of polymers by dyes and pigments. In N. S. Allen, & J. F. McKellar (Eds.), *Photochemistry of dyed and pigmented polymers* (pp. 247-278). London: Applied Science Publishers.

American Association of Textile Chemists and Colorists (AATCC). (2008). AATCC Test Method 20-2007 Fiber Analysis: Qualitative. *AATCC Technical Manual.* Research Triangle Park, NC: American Association of Textile Chemists and Colorists.

Block, I. (1982). The effect of an alkaline rinse on the aging of cellulosic textiles, parts I and II. *Journal of the American Institute for Conservation, 22*(1), 25-36.

Bloss, D. F. (1961). *An introduction to the methods of optical crystallography.* New York: Holt, Rinehart and Winston, Inc.

Blum, D. E. (2003). *Shocking! the art and fashion of Elsa Schiaparelli*. New Haven, CT: Yale University Press.

Boulton, J. (1951). The application of direct dyes to viscose rayon yarn and staple. *Journal of the Society of Dyers and Colourists, 67*(12), 522-538.

Brooks Picken, M. (1946). *Practical home mending made easy*. London: Odhams Press Ltd.

Choudhury, A. K. R. (2006). *Textile preparation and dyeing*. Enfield, NH: Science Publishers.

Ciolacu, D., & Popa, V. I. (2006). On the thermal degradation of cellulose allomorphs. *Cellulose Chemistry and Technology, 40*(6), 445-449.

Coleman, D. C. (1969). *Courtaulds an economic and social history*. Oxford: Clarendon Press.

Collard, E. (1981). *Women's dress in the 1920's*. Burlington, Ontario: Eileen Collard.

Cooke, J. G. (1984). *Handbook of textile fibres* (5th ed.). Shildon, Co. Durham, England: Merrow Publishing.

De La Haye, A. (1993). The dissemination of design from haute couture to fashionable ready-to-wear during the 1920's. *Textile History, 24*(1), 39-48.

Egerton, G. S. (1948). Some aspects of the photochemical degradation of nylon, silk, and viscose rayon. *Textile Research Journal, 18*, 659.

Ferreira, L. M. (1999). Manufactured-fiber conservation: A cause for concern? *The Textile Specialty Group Postprints,* Saint Louis, Missouri. *9,* 11-18.

Field, J. (2001). Dyes, chemistry and clothing the influence of World War I on fabrics, fashions and silk. *Dress, 28*, 77-91.

Gaudette, B. D. (1988). The forensic aspects of textile fiber examination. In R. Saferstein (Ed.), *Forensic science handbook* (pp. 209-272). Englewood Cliffs, NJ: Prentice Hall.

Grattan, D. W. (1980). The oxidative degradation of organic materials and its importance in deterioration of artifacts. *Journal of the International Institute for Conservation, Canadian Group, 4*(1), 17-26.

Grieve, M. C. (1990). Fibres and their examination in forensic science. In A. Maehly and R. L.Williams (Ed.), *Forensic science progress* (pp. 41-125). Berlin: Springer-Verlag.

Hague, D. C. (1957). *The economics of man-made fibres*. London: G. Duckworth.

Handley, S. (1999). *Nylon the manmade fashion revolution.* London: Bloomsbury.

Hatch, K. L. (1993). *Textile science.* Minneapolis/St. Paul, MN: West Publishing.

Hearle, J. S. W. (2001). Physical structure and fibre properties. In C. Woodings (Ed.), *Regenerated cellulose fibres* (pp. 199-234). Washington, D.C.: The Textile Institute CRC Press.

Hottenroth, V. (1928). Applications and uses of artificial silk. (E. Fyleman Trans.) *Artificial silk* (pp. 367-375). London: Sir Isaac Pitman & Sons, Ltd.

Houston, M., & Fletcher, H. (1940). The effect of light and heat on the breaking strength, color, and copper number of viscose, cellulose acetate, and cuprammonium rayon fabrics. *Transactions of the Kansas Academy of Science, 43*, 309-311.

Humphries, M. (2004). *Fabric Reference*. Upper Saddle River, N.J.: Pearson Prentice Hall.

Jackman, A., & Rogers, B. (1934). *The principles of domestic and institutional laundrywork*. London: Edward Arnold & Co.

Johnson, G. H. (1927). *Textile fabrics*. New York: Harper & Brothers.

Joseph, M. L. (1981). *Introductory textile science* (5th ed.). New York: Holt, Rinehart and Winston.

Kamide, K., & Kazunari, N. (2001). Cuprammonium processes. In C. Woodings (Ed.), *Regenerated cellulose fibres* (pp. 88-155). Washington, D.C.: The Textile Institute CRC Press.

Kerr, N., Jennings, T., & Méthé, E. (1989). Long-term stability of cellulosic textiles: Effect of alkaline deacidifying agents on naturally aged cellulosic textiles. In S. H. Zeronian, & H. L. Needles (Eds.), *Historic textile and paper materials II: Conservation and characterization.* (pp. 143-158). Washington, D.C.: American Chemical Society.

Kerr, N., Hersh, S. P., & Tucker, P. A. (1884). Physical changes of alkaline-buffered cotton fabric. *ICOM 7th triennial meeting. Copenhagen, 10-14 September 1984. preprints* (pp. 84.9.25-84.9.29). Paris: ICOM.

Knill, C. J., & Kennedy, J. F. (2003). Degradation of cellulose under alkaline conditions. *Carbohydrate Polymers, 51*(3), 281-300.

Kronkright, D. P. (1992). Deterioration of artifacts made from plant materials. In M. E. Florian, D. P. Kronkright & R. E. Norton (Eds.), *The conservation of artifacts made from plant materials* (pp. 139-193) Marian del Rey, CA: Getty Conservation Institute.

Lemiski, S. L. (1996). *Weighted silk: Identification, characterization, and photodegradation.* Unpublished Master of Science in Clothing and Textiles, Department of Human Ecology, University of Alberta,

Lewin, M. (1997). Oxidation and aging of cellulose. *Macromolecular Symposia, 118*, 715-724.

Lewin, M. (2006). *Handbook of fiber chemistry* (3rd ed.). Boca Raton, FL: Taylor & Francis.

Making smart clothes (1930). New York: The Butterick Publishing Company.

Marshall, W. J., & Peters, R. H. (1947). The heats of reaction and affinities of direct cotton dyes for cuprammonium rayon, viscose rayon and cotton. *Journal of the Society of Dyers and Colourists, 63*(12), 446-461.

Mendes, V., & De La Haye, A. (1999). *20th century fashion*. New York: Thames & Hudson.

Michie, R. I. C., Sharples, A., & Walter, A. A. (1961). The nature of acid-sensitive linkages in cellulose *Journal of Polymer Science, 51*, 85-98.

Moncrieff, R. W. (1975). *Man-made fibres* (Sixth ed.). Scarborough, ON: Butterworth & Co. (Canada) Ltd.

Morton, W. E., & Hearle, J. W. S. (1993). *Physical properties of textile fibres* (3rd ed.). Manchester, U.K.: Textile Institute.

Nelson, M. L., & Tripp, V. W. (1953). Determination of the leveling-off degree of polymerization of cotton and rayon. *Journal of Polymer Science, 10*(6), 577-586.

Nevell, T. P. (1985). Degradation of cellulose by acids, alkalis and mechanical means. In T. P. Nevell, & S. H. Zeronian (Eds.), *Cellulose chemistry and its applications* (pp. 223-242). New York: Ellis Horwood Ltd.

Rice, James W. (1972). Principles of fragile textile cleaning. In J. Leene (Ed.), *Textile conservation* (pp. 32-72). Washington, DC: Smithsonian.

Ruggles, M. (1980). The history of conservation in Canada: Developments to the early 1970's. *Journal of the International Institute for Conservation — Canadian Group, 5*(1&2), 5-8.

Schwarz, E. W. K., & Mauersberger, H. R. (1936). *Rayon and synthetic yarn handbook*. New York: Rayon Publishing Corporation.

Scroggie, A.G. (1950). The definition of rayon: Viewpoint of the American textile industry. *Textile Research Journal 20,* 194-198.

Shevchenko, A. S., Nepochatykh, V. I., Bandura, N. A., Vlasyuk, A. T., & Volkova, T. G. (1980). Iron as a factor in the thermal degradation of regenerated cellulose yarn. *Fibre Chemistry, 12*(1), 47-49.

Standing, H. A. (1945). The dyeing of cellulose with direct dyes .1. A review of the literature. *Transactions of the Faraday Society, 41*(7), 410-434.

Stewart, M. L. (2004). Marketing fabrics and femininity in interwar france. *Textile History, 35*(1), 90-111.

Suñol, J. J., Saurina, J., Carrasco, F., Colom, X., & Carillo, F. (2007). Thermal degradation of lyocell, modal and viscose fibers under agressive conditions. *Journal of Thermal Analysis and Calorimetry, 87*(1), 41-44.

Telford, E. (1993). Treating early regenerated cellulose textiles: Two case histories. In D. W. Grattan (Ed.), *Saving the twentieth century: The conservation of modern materials* (pp. 207-212). Ottawa, ON: Canadian Conservation Institute.

Tétreault, J. (2003). *Airborne pollutants in museums, galleries and archives: risk assessment, control strategies, and preservation management.* Ottawa, ON: Canadian Conservation Institute.

Tétreault, J. (1994). Display materials: the good, the bad and the ugly. In *Exhibitions and conservation* (pp. 79-87). Edinbugh, UK: Scottish Society for Conservation & Restoration.

Timár-Balázsy, Á, & Eastop, D. (1998). *Chemical principles of textile conservation*. Oxford England; Boston: Butterworth-Heinemann.

Tortora, P. G., & Merkel, R. S. (2007). *Fairchild's dictionary of textiles* (7th ed.). New York: Fairchild Publications.

Wheeler, E. (1931). *The manufacture of artificial silk (rayon)*. London: Chapman & Hall Ltd.

Wilkes, A. G. (2001). The viscose process. In C. Woodings (Ed.), *Regenerated cellulose fibres* (pp. 37-61). Cambridge, England: Woodhead Publishing Limited.

Woman's Institute of Domestic Arts & Sciences. (1923). *Sewing materials* London: International Educational Publishing Company.

Woodings, C. (2001a). Applications development. In C. Woodings (Ed.), *Regenerated cellulose fibres* (pp. 235-272). Cambridge, England: Woodhead Publishing Limited.

Woodings, C. (2001b). A brief history of regenerated cellulosic fibres. In C. Woodings (Ed.), *Regenerated cellulose fibres* (pp. 1-21). Cambridge, England: Woodhead Publishing Limited.

Zeronian, S. H. (1977). Conservation of textiles manufactured from man-made fibers. In J. C. Williams (Ed.), *Preservation of paper and textiles of historic and artistic value* (pp. 208-227). Washington, D.C.: American Chemical Society.

APPENDIX A: LIST OF ARTIFACTS EXAMINED

Accession #	Database Description	Database Date	Database Fibre ID	Actual Fibre ID
1971.8.8	momie weave crepe dress	1925 - 1928		silk
1971.9.2	dress from ensemble	1930 C		silk
1972.8.4a	dress	1935		viscose/acetate
1973.8.14	satin dress	1920 C - 1929 C		silk
1973.8.15a	dress	1930 C	rayon?	viscose
1975.16.11	dress	1930		silk
1977.5.37	mustard coloured wrap dress	1935 - 1939		viscose
1977.5.49	dove grey evening dress	1930 - 1939	rayon?	acetate/acetate (a) silk (b)
1977.5.96	black chiffon chiton style dress	1920 - 1929		silk
1977.5.101	off-white floral print dress	1930 - 1939		silk
1977.5.102	black crepe dress	1930 - 1939	rayon?	acetate/viscose
1977.9.1	dress	1933 - 1945		acetate
1981.27.32	green crepe dress	1930 - 1939		viscose/acetate
1983.8.4a	sleeveless black lace dress	1930 - 1939		silk / viscose
1983.8.5	navy blue redingote-style dress	1920 - 1924	rayon; silk; cotton	silk
1984.19.02	dress	1925 - 1935		viscose /cuprammonium
1985.8.1	dress	1920 - 1939		silk
1985.57.12	beige floral print Nancy Fraser dress	1930 - 1939		silk
1985.70.6	black dress with semi-attached jacket	1930 - 1939	rayon	viscose
1985.74.55	Marie Klemme dress	1937 - 1939		viscose/acetate (a)/ silk (b)
1985.75.2	dress	1925 - 1935		cotton
1986.31.6a	dress from ensemble	1925 - 1935	nylon	silk / viscose
1986.31.7a	dress from ensemble	1930 - 1939	rayon	viscose
1986.43.7a	dress	1925 - 1935		cuprammonium
1987.25.10	dress by Eleanor Pirie	1920 - 1930		cotton
1987.49.1	dress	1925 - 1935		viscose / silk
1987.80.1b	dress	1930 - 1939	rayon	acetate (a)/ silk (b)
1988.40.3a	dress from ensemble	1930 C	rayon?	acetate / viscose
1988.51.7	dress	1930 - 1939		cotton / viscose
1989.3.28	dress	1935 C	rayon	acetate
1989.32.10	dress	1935 C		viscose/acetate
1993.4.18	dress from ensemble by Elizabeth Vance	1930 C - 1939 C	rayon	viscose / silk
1996.8.4	black satin dress with gold floral trim	1920's		silk
1999.22.10a	navy blue crepe dress	1930 - 1939		silk / acetate
1999.37.4	long black dress	1925 - 1935		silk / viscose
1999.53.49	peach sleeveless dress, 1920s	1920-1929		cuprammonium/mercerized cotton
2002.3.30a	light blue dress	1930s		viscose/acetate
2004.26.1	Betty Barcley dress	1939	rayon	viscose / viscose (a)/ acetate (b)
2006.24.8	black dress and jacket	1920s		viscose
2006.24.9	cream coloured dress	1920s		silk / cotton
2006.24.10	green chiffon dress	1920s		silk
2006.24.17	brown lace dress	1930s		silk / viscose

APPENDIX B: ARTIFACT INFORMATION FORMS

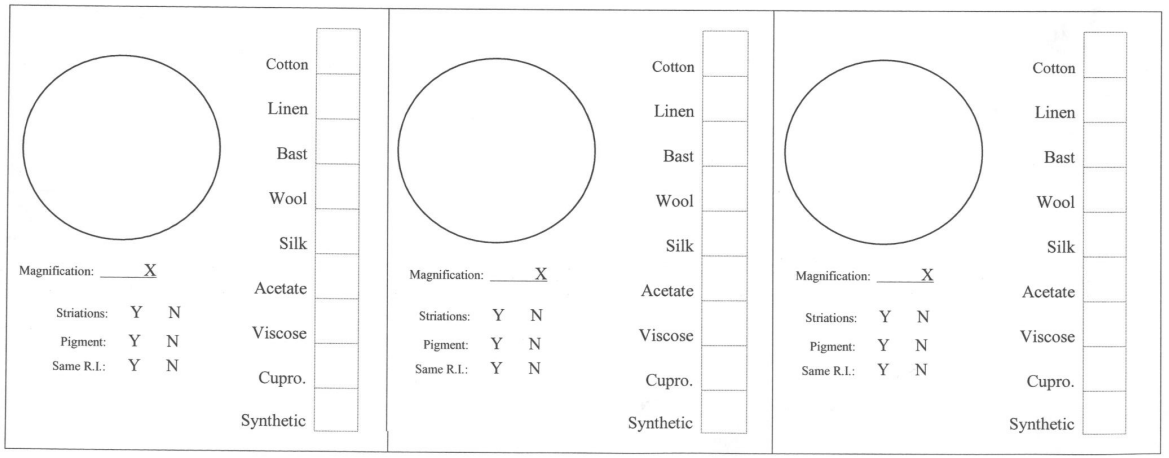
Accession # : _____ Artifact: _____ Date: _____ Database ID: _____

Bright Field Microscopy

Component: _____ Component: _____ Component: _____

Sampled From: _____ Sampled From: _____ Sampled From: _____

Comments:	Comments:	Comments:



Accession # : _____ Artifact: _____ Date: _____

Polarizing Light Microscopy

Component: _____ Component: _____ Component: _____

Comments:	Comments:	Comments:

Calculation: _____ _____ _____ Diameter: _____ Sign of Elongation: +'ve -'ve Order : First Second Third Interference Colour: _____ Birefringence: _____ Cotton Linen Bast Wool Silk Acetate Viscose Cupro. Synthetic	Calculation: _____ _____ _____ Diameter: _____ Sign of Elongation: +'ve -'ve Order: First Second Third Interference Colour: _____ Birefringence: _____ Cotton Linen Bast Wool Silk Acetate Viscose Cupro. Synthetic	Calculation: _____ _____ _____ Diameter: _____ Sign of Elongation: +'ve - 've Order: First Second Third Interference Colour: _____ Birefringence: _____ Cotton Linen Bast Wool Silk Acetate Viscose Cupro. Synthetic

Accession # : _____ Artifact: _____ Date: _____

Acetone Solubility

Component: _____ Component: _____ Component: _____

Comments:	Comments:	Comments:
Soluble: Yes ☐ No ☐	Soluble: Yes ☐ No ☐	Soluble: Yes ☐ No ☐

Accession # : _____ Artifact: _____ Date: _____

Hot Stage Microscopy

Component: _____ Component: _____ Component: _____

Comments:	Comments:	Comments:
Melts: Yes ☐ No ☐ Temperature: _____	Melts: Yes ☐ No ☐ Temperature: _____	Melts: Yes ☐ No ☐ Temperature: _____

Accession # : _____ Artifact: _____ Date: _____

Refractive Index $n_{\parallel}$ (5.480)

Component: _____ Component: _____ Component: _____

Comments:	Comments:	Comments:
Becke Line: In ☐ Out ☐ ☐ Viscose ☐ Cuprammonium	Becke Line: In ☐ Out ☐ ☐ Viscose ☐ Cuprammonium	Becke Line: In ☐ Out ☐ ☐ Viscose ☐ Cuprammonium

Accession # : _____ Artifact: _____ Date: _____

Yarn Characterization

Component: _____ Component: _____ Component: _____

Fibre Content: _____	**Fibre Content:** _____	**Fibre Content:** _____
Fibre Length: STAPLE FILAMENT	**Fibre Length:** STAPLE FILAMENT	**Fibre Length:** STAPLE FILAMENT
Twist: Low Regular Crepe	**Twist:** Low Regular Crepe	**Twist:** Low Regular Crepe
Yarn Structure: Single 2 ply ___ ply	**Yarn Structure:** Single 2 ply ___ ply	**Yarn Structure:** Single 2 ply ___ ply
Other _____	Other _____	Other _____

Accession # : _____ Artifact: _____ Date: _____

Fabric Characterization

Component: _____ Component: _____

Weave Structure:		Plain Weave: _____	**Weave Structure:**		Plain Weave: _____
		Satin Weave			Satin Weave
		Twill			Twill
		Other: _____			Other: _____

Fabric Count:				**Fabric Count:**			
Surface Decoration:	Dyed			**Surface Decoration:**	Dyed		
	Printed				Printed		
	Embroidered				Embroidered		
	Other				Other		
Finish:				**Finish:**			

Accession # : _____ Artifact: _____ Date: _____

Garment Characterization

Garment Description:
Images: **(Photography; Proscope)**
Comments:

Accession # : _____ Artifact: _____ Date: _____

Condition Characterization

Condition	Y	N	Soil w/	Location	Comments
fading					
yellowing/graying					
dye transfer					
stretching/bagging					
evidence of shrinkage					
tears/cuts/broken yarns					
splitting					
holes/losses					
abraision/thinning					
unravelling/fraying					
pilling/snagging					
weakness					
embrittlement					
pest damage					
mould					

APPENDIX C: COMPLETE BRIGHT FIELD MICROSCOPY, ACETONE SOLUBILITY AND HOT-STAGE MICROSCOPY RESULTS

Accession #	Yarn #	Bright-field Microscopy	Hot-stage Microscopy	Acetone Solubility	Confirmed Identification
1971.8.8	1	small, irregular diameter, triangular cross-section visible			silk
1971.8.8	2	small, irregular diameter			silk
1971.9.2	3	small, irregular diameter			silk
1971.9.2	4	small, irregular diameter			silk
1972.8.4a	5	striated	unchanged	insoluble	viscose
1972.8.4a	6	striated, no edge lines, darkly dyed	melted	soluble	acetate
1973.8.14	7	small, irregular diameter			silk
1973.8.14	8	small, irregular diameter			silk
1973.8.15a	9	striated, darkly dyed	unchanged	insoluble	viscose
1973.8.15a	10	striated, darkly dyed	unchanged	insoluble	viscose
1973.8.15a	11	striated, darkly dyed	unchanged	insoluble	viscose
1975.16.11	12	small, irregular diameter			silk
1975.16.11	13	small, irregular diameter			silk
1977.5.37	14	striated, irregular diameter, no edge lines?	charred	insoluble	viscose
1977.5.37	15	striated	charred	insoluble	viscose
1977.5.49	16	delustred, no edge lines	melted	soluble	acetate
1977.5.49	17	delustred (a), small, irregular diameter (b), no edge lines (a)	melted	soluble (a)	acetate (a)/ silk (b)
1977.5.96	18	small, irregular diameter			silk
1977.5.96	19	small, irregular diameter			silk
1977.5.101	20	small, irregular diameter			silk
1977.5.101	21	small, irregular diameter			silk
1977.9.1	22	no edge lines	melted	soluble	acetate
1977.9.1	23	no edge lines	melted	soluble	acetate
1977.5.102	24	delustred, darkly dyedno edge lines	melted	soluble	acetate
1977.5.102	25	striated, darkly dyed	unchanged	insoluble	viscose

Accession #	Yarn #	Bright-field Microscopy	Hot-stage Microscopy	Acetone Solubility	Confirmed Identification
1979.1.8a	26	striated	melted	soluble	acetate
1979.1.8a	27	striated	melted	soluble	acetate
1979.1.10	28	small, irregular diameter			silk
1979.1.10	29	striated	unchanged	insoluble	viscose
1979.1.10	30	small, irregular diameter, triangular cross-section visible			silk
1979.7.2	31	small, irregular diameter			silk
1979.7.2	32	small, irregular diameter			silk
1979.9.6a	33	striated	unchanged	insoluble	viscose
1979.9.6a	34	striated, no edge lines?	unchanged	insoluble	viscose
1981.27.32	35	striated,	unchanged	insoluble	viscose
1981.27.32	36	delustred, striated, no edge lines?	melted	soluble	acetate
1983.8.4a	37	small, irregular diameter			silk
1983.8.4a	38	striated, darkly dyed	unchanged	insoluble	viscose
1983.8.5	39	small, irregular diameter			silk
1983.8.5	40	small, irregular diameter			silk
1984.19.02	41	striated, darkly dyed	charred	insoluble	viscose
1984.19.02	42	delustred, round, regular diameter	unchanged	insoluble	cuprammonium
1984.19.02	43	delustred, round, regular diameter	unchanged	insoluble	cuprammonium
1985.8.1	44	small, irregular diameter			silk
1985.8.1	45	small, irregular diameter			silk
1985.57.12	46	small, irregular diameter			silk
1985.57.12	47	small, irregular diameter			silk
1985.70.6	48	striated, darkly dyed	unchanged	insoluble	viscose
1985.70.6	49	striated	unchanged	insoluble	viscose
1985.70.6	50	striated, darkly dyed	unchanged	insoluble	viscose
1985.74.55	51	striated	unchanged	insoluble	viscose
1985.74.55	52	striated (a, b)	unchanged (a) melted (b)	soluble (a)	viscose (a)/ acetate (b)
1985.75.2	53	lumen, convolutions			cotton

Accession #	Yarn #	Bright-field Microscopy	Hot-stage Microscopy	Acetone Solubility	Confirmed Identification
1985.75.2	54	lumen, convolutions			cotton
1986.31.6a	55	small, irregular diameter			silk
1986.31.6a	56	small, irregular diameter			silk
1986.31.6a	57	striated	unchanged	insoluble	viscose
1986.31.7a	58	striated	unchanged	insoluble	viscose
1986.31.7a	59	striated	charred	insoluble	viscose
1986.31.7a	60	striated	charred	insoluble	viscose
1986.43.7a	61	delustred, round, regular diameter	unchanged	insoluble	cuprammonium
1986.43.7a	62	delustred, round, regular diameter	unchanged	insoluble	cuprammonium
1987.25.10	63	lumen, convolutions			cotton
1987.25.10	64	lumen, convolutions			cotton
1987.25.10	65	lumen, convolutions			cotton
1987.49.1	66	small, irregular diameter			silk
1987.49.1	67	striated			viscose
1987.80.1b	68	darkly dyed (a), small, irregular diameter (b)	melted (a)	soluble (a)	acetate (a)/ silk (b)
1987.80.1b	69	darkly dyed (a), small, irregular diameter (b)	melted (a)	soluble (a)	acetate (a)/ silk (b)
1988.40.3a	70	delustred, no edge lines	melted	soluble	acetate
1988.40.3a	71	striated	unchanged	insoluble	viscose
1988.51.7	72	lumen, convolutions			cotton
1988.51.7	73	striated	unchanged	insoluble	viscose
1989.3.28	74	striated, no edge lines	melted	soluble	acetate
1989.3.28	75	striated, no edge lines	melted	soluble	acetate
1989.32.10	76	striated	unchanged	insoluble	viscose
1989.32.10	77	delustred	melted	soluble	acetate
1993.4.18	78	striated, delustred	unchanged	insoluble	viscose
1993.4.18	79	small, irregular diameter			silk
1996.8.4	80	small, irregular diameter, triangular cross-section visible			silk
1996.8.4	81	small, irregular diameter			silk

Accession #	Yarn #	Bright-field Microscopy	Hot-stage Microscopy	Acetone Solubility	Confirmed Identification
1999.22.10a	82	small, irregular diameter			silk
1999.22.10a	83	delustred, darkly dyed	melted	soluble	acetate
1999.37.4	84	small, irregular diameter			silk
1999.37.4	85	small, irregular diameter			silk
1999.37.4	86	striated, darkly dyed	charred	insoluble	viscose
1999.53.49	87	round, regular diameter	unchanged	insoluble	cuprammonium
1999.53.49	88	swollen convolutions, lumen?			mercerized cotton
2002.3.30a	89	striated	unchanged	insoluble	viscose
2002.3.30a	90	striations, no edge lines	melted	soluble	acetate
2004.26.1	91	striated, delustred	unchanged	insoluble	viscose
2004.26.1	92	striated (a), delustred (a, b)	unchanged (a) melted (b)	soluble (b)	viscose (a)/ acetate (b)
2006.24.8	93	striated	unchanged	insoluble	viscose
2006.24.8	94	striated, darkly dyed	unchanged	insoluble	viscose
2006.24.8	95	striated	unchanged	insoluble	viscose
2006.24.10	96	small, irregular diameter			silk
2006.24.10	97	small, irregular diameter			silk
2006.24.9	98	small, irregular diameter			silk
2006.24.9	99	small, irregular diameter			silk
2006.24.9	100	lumen, convolutions			cotton
2006.24.17	101	small, irregular diameter			silk
2006.24.17	102	striated	unchanged	insoluble	viscose

APPENDIX D: COMPLETE POLARIZING MICROSCOPY RESULTS

Accession #	Yarn #	Yarn	Diameter	Interference Colour	Order	Birefringence	Confirmed Identification
1972.8.4a	5	W	15.68	orange-red	1	0.022	viscose
1972.8.4a	6	F	21.56	red	1	0.022	acetate†
1973.8.15a	9	S1	25.48	DARK	DARK	DARK	viscose * †
1973.8.15a	10	W	15.68	red	1	0.029	viscose
1973.8.15a	11	F	15.68	green-white	1	0.016	viscose†
1977.5.37	14	W	11.76	yellow	1	0.027	viscose
1977.5.37	15	F	11.76	yellow	1	0.027	viscose
1977.5.49	16	W	16.78	grey	1	0.003	acetate
1977.5.49	17 a	F	11.76	grey	1	0.001	acetate
1977.9.1	22	W	19.6	green	1	0.015	acetate†
1977.9.1	23	F	19.6	grey	1	0.007	acetate
1977.5.102	24	W	19.6	grey	1	0.001	acetate
1977.5.102	25	F	15.76	red	1	0.036	viscose†
1979.1.8a	26	W	19.6	grey	1	0.01	acetate
1979.1.8a	27	F	27.44	grey	1	0.01	acetate
1979.1.10	29	S1	15.68	red	1	0.03	viscose
1979.9.6a	33	W	15.68	orange	1	0.023	viscose
1979.9.6a	34	F	19.6	green-white	1	0.021	viscose
1981.27.32	35	W	23.52	blue	1	0.029	viscose
1981.27.32	36	F	39.2	grey-black	1	0.01	acetate
1983.8.4a	38	FIG	29.52	DARK	DARK	DARK	viscose*†
1984.19.02	41	S1	19.6	DARK	DARK	DARK	viscose*†
1984.19.02	42	W	15.68	orange-red	1	0.029	cuprammonium
1984.19.02	43	F	17.64	red	1	0.03	cuprammonium
1985.70.6	48	W	19.6	DARK	DARK	DARK	viscose*†
1985.70.6	49	F	15.68	orange	1	0.025	viscose
1985.70.6	50	S1	19.6	green-white	1	0.017	viscose†
1985.74.55	51	W	11.75	light orange	1	0.029	viscose
1985.74.55	52 a	F	11.76	green-white	1	0.023	acetate
1986.31.6a	57	S1	15.68	orange-red	1	0.023	viscose
1986.31.7a	58	W	19.6	green-yellow	1	0.021	viscose
1986.31.7a	59	F	19.6	blue	2	0.033	viscose†
1986.31.7a	60	S1	19.6	violet-blue	2	0.032	viscose†
1986.43.7a	61	W	11.76	orange-red	1	0.036	cuprammonium
1986.43.7a	62	F	13.72	yellow-orange	1	0.029	cuprammonium
1987.49.1	66	W	27.44	grey	1	0.012	viscose
1987.80.1b	68 a	W	15.68	DARK	DARK	DARK	acetate*†
1987.80.1b	69 a	F	15.68	DARK	DARK	DARK	acetate*†
1988.40.3a	70	W	15.76	grey	1	0.01	acetate
1988.40.3a	71	F	15.76	orange	1	0.024	viscose
1988.51.7	73	F	19.6	grey-black	1	0.01	viscose†
1989.3.28	74	W	17.64	grey	1	0.003	acetate
1989.3.28	75	F	23.52	grey-black	1	0.003	acetate
1989.32.10	76	W	15.68	yellow-orange	1	0.023	viscose
1989.32.10	77	F	19.6	grey	1	0.003	acetate
1993.4.18	78	W	15.68	orange-red	1	0.022	viscose
1999.22.10a	83	F	23.52	DARK	DARK	DARK	acetate*†
1999.37.4	86	LACE	31.36	DARK	DARK	DARK	viscose*†
1999.53.49	87	W	19.6	orange	1	0.023	cuprammonium
2002.3.30a	89	W	23.52	blue	2	0.03	viscose
2002.3.30a	90	F	31.36	grey-black	1	0.003	acetate
2004.26.1	91	W	15.58	no colour showing			viscose†
2004.26.1	92 a	F	33.32	orange	1	0.014	viscose†
2004.26.1	92 b	F	15.68	red	1	0.022	acetate†
2006.24.8	93	LACE	39.2	green-yellow	1	0.021	viscose
2006.24.8	94	W	21.56	DARK	DARK	DARK	viscose*†
2006.24.8	95	F	19.6	yellow-orange	1	0.019	viscose
2006.24.17	102	FIG	29.4	blue	2	0.022	viscose

* Identified based on acetone solubility and hot-stage microscopy

† Incorrectly or inconclusively identified by polarizing microscopy

APPENDIX E: SUMMARY OF ACCESSION NUMBERS, FABRIC LETTERS AND YARN NUMBERS FOR DRESSES CONTAINING RAYON

Accession #	Fabric Letters	Yarn #s
1972.8.4a	A (main fabric)	5 (warp), 6 (weft)
1973.8.15a	B (lace) BB (underdress)	9 (lace), 10 (underdress warp) 11 (underdress weft)
1977.5.37	D (main fabric)	14 (warp), 15 (weft)
1977.5.102	C (main fabric)	24 (warp), 25 (weft)
1979.1.10	E (main fabric)	28 (warp), 29 (pile) 30 (weft)
1979.9.6a	F (main fabric)	33 (warp), 34 (weft)
1981.27.32	G (main fabric)	35 a, b (warp), 36 a, b (weft)
1983.8.4a	H (lace) HH (underdress)	37 (net), 38 (figure) 39 (underdress warp) 40 (underdress weft)
1984.19.2	I (lace) II (underdress)	41 (net), 42 (underdress warp) 43 (underdress weft)
1985.70.6	J (main fabric)	48 (warp), 49 (weft) 50 (supplementary warp & weft)
1985.74.55	K (main fabric)	51 (warp), 52 a, b (weft)
1986.31.6a	L (main fabric)	55 (warp), 56 (weft) 57 (pile)
1986.31.7a	M (main fabric) MM (overdress)	58 (warp), 59 (weft) 60 (overdress net)
1986.43.7a	N (main fabric)	61 (warp), 62 (weft)
1987.45.1	O (main fabric)	66 (warp), 67 (weft)
1988.40.3a	P (main fabric)	70 (warp), 71 (weft)
1988.51.7	Q (main fabric)	72 (warp), 73 (weft)
1989.32.10	R (main fabric)	76 (warp), 77 (weft)
1993.4.18	S (main fabric)	78 (white warp and weft), 79 (pink warp and weft)
1999.37.4	T (main fabric) TT (lace overdress)	84 (warp), 85 (weft) 86 (overdress lace)
1999.53.49	U (main fabric)	87 (warp), 88 (weft)
2002.3.30a	V (net main fabric)	89 (main fabric net)
2004.26.1	W (main fabric)	91 a, b (warp), 92 a, b (weft)
2006.24.8	Y (main fabric) YY (underdress)	93 (lace), 94 (underdress warp) 95 (underdress weft)
2006.24.17	X (main fabric lace)	101 (net), 102 (figure)

APPENDIX F: RAYON DRESS INFORMATION DATABASE

Accession #: **1972.8.4a**

Garment Characterization

Photo:

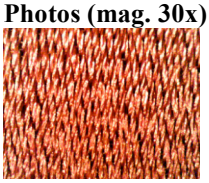
Description:

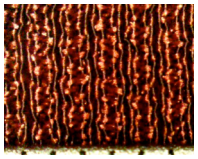
Brown-red ankle-length dress. Volume at the hip area. Front button closure on the bodice. Two patch pockets on the front of the skirt. Vertical pleating in the bodice. Embroidery with gold beading embellishes the front of the collar.

Fabric Characterization

Fabric #: A

Photos (mag. 30x):





Weave Structure: Satin backed crepe

Fabric Count (w x f): 38 x 24

Surface Decoration: Dyed; Embroidered with beading

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
5 (warp)	Viscose Rayon	Filament	Crepe	Simple Single
6 (filling)	Acetate	Filament	Low	Simple Single

Condition Characterization

Description

Fading on the left proper lapel and on the tops of the sleeves. Slight **stretching and bagging** in the elbows.

Accession #: **1973.8.15a**

Garment Characterization

Photo:

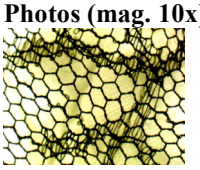
Description:

Long black lace gown. High sweetheart neckline with capped sleeves. Gathered above the waist for volume. Satin covered buttons on back with keyhole opening. Bias-cut chemise style underdress with fagotting around the neck and armholes.

Fabric Characterization

Fabric #: B; BB

Photos (mag. 10x):



Weave Structure: needle run machine made bobbinet lace; satin

Fabric Count (w x f): n/a; 27 x 40

Surface Decoration: dyed black, needle run floral motif; dyed black

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
9 (lace)	viscose	filament	low	simple single
10 (warp)	viscose	filament	crepe	simple single
11 (weft)	viscose	filament	low	simple single

Condition Characterization

Description

Some **pilling and snagging** of the long floats in the lace.

Accession #: **1977.5.102**

Garment Characterization

Photo:

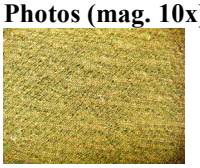
Description:

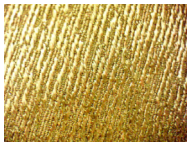
Long, black crepe, bias-cut gown with narrow straps. Dress laces up the sides with pink-violet laces. Horizontal pleats in the bodice.

Fabric Characterization

Fabric #: C

Photos (mag. 10x):





Weave Structure: figured satin back crepe

Fabric Count (w x f): n/a

Surface Decoration: dyed

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
24 (warp)	acetate	filament	low	simple single
25 (weft)	viscose rayon	filament	crepe	simple single

Condition Characterization

Description

Repaired **tear** at back near hem. Allover **small holes**.
Ravelling where straps attach.

Accession #: **1977.5.37**

Garment Characterization

Photo:

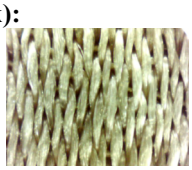
Description:

Calf-length green-yellow dress with a cross-over bodice and short sleeves. Missing belt.

Fabric Characterization

Fabric #: D

Photos (mag. 100x):



Weave Structure: Satin backed crepe

Fabric Count (w x f): 59 x 35

Surface Decoration: Dyed

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
14 (warp)	viscose rayon	filament	crepe	simple single
15 (weft)	viscose rayon	filament	low	simple single

Condition Characterization

Description

Evidence of **stretching and bagging** as hem is not straight. Stitch **holes** left by former alteration.

Accession #: **1979.1.10**

Garment Characterization

Photo:

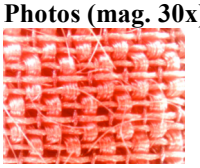
Description:

Long red velvet 1930s gown with a v-neck in the front and a cross-over v-neck in the back. Short sleeved, embellished with horizontally pleated and gathered fabric at the waist. Fabric gathered to create volume for the breasts.

Fabric Characterization

Fabric #: E

Photos (mag. 30x):



Weave Structure: Velvet

Fabric Count (w x f):

Surface Decoration: Dyed red

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
28 (weft)	silk			
29 (pile)	viscose rayon	filament	low	simple single
30 (warp)	silk			

Condition Characterization

Photos:

Description

Splitting at the top of the proper left shoulder seam.
Pilling of one yarn at the centre front of the bodice.

Accession #: **1979.9.6a**

Garment Characterization

Photo:

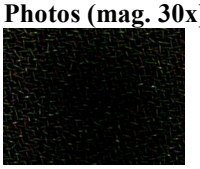
Description:

Black, sleeveless, ankle-length bias-cut shift dress with raised waist. Dress has a rounded v-neck, gathering for volume in the bust. Shawl sleeved, tie-waisted, collared, printed top that accompanies dress.

Fabric Characterization

Fabric #: F

Photos (mag. 30x):



Weave Structure: momie crepe

Fabric Count (w x f): 56 x 36

Surface Decoration: dyed

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
33 (warp)	viscose rayon	filament	crepe	simple single
34 (weft)	viscose rayon	filament	crepe	simple single

Condition Characterization

Description

Embrittlement and **tears** associated with white (deoderant?) residue in the proper left underarm area. Slight **pilling** on the centre front of the bodice. Three small **holes** in the back of the bodice.

Accession #: **1981.27.32**

Garment Characterization

Photo:

Description:

Green-yellow crepe, bias cut, long-sleeved dress with beaded embellishment at the v-waist and below the bust. Pleats create volume in the bust. Buttons along lower 2/3 of the sleeves.

Fabric Characterization

Fabric #: G

Photos (mag. 100x):

Weave Structure: Crepe, momie weave

Fabric Count (w x f): 28 x 28

Surface Decoration: Dyed; beaded embellishment on the bodice

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
35 a, b (warp)	viscose, acetate	filament	crepe, low	2-ply
36 a, b (weft)	viscose, acetate	filament	crepe, low	2-ply

Condition Characterization

Description

Splitting at right proper side seam. Many small **holes** in the skirt at natural waist. Rayon fibres (not acetate) are **snagging** all over the skirt

Accession #: **1983.8.4a**

Garment Characterization

Photo:

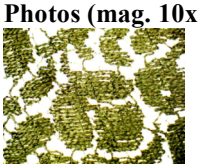
Description:

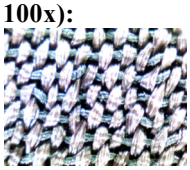
Black raschel knitted, lace, drop-waisted dress. Long sleeves with ruffled just above cuff. Full, calf-length skirt. Tie at collar. Bodice separate from the skirt, though both attached to underdress. Under dress in black plain weave silk fabric and beige chiffon in the decolletage area.

Fabric Characterization

Fabric #: H; HH

Photos (mag. 10x; 100x):





Weave Structure: Raschel knit lace; Plain weave

Fabric Count (w x f): n/a; 50 x 29

Surface Decoration: dyed black

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
37 (net)	silk			
38 (figure)	viscose rayon	filament	low	simple single
39 (warp)	silk			
40 (weft)	silk			

Condition Characterization

Description

Hole in left proper shoulder.

Accession #: **1984.19.2**

Garment Characterization

Photo:

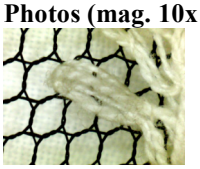
Description:

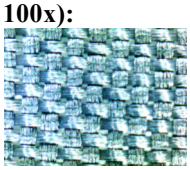
Long, black net overdress with needle-run white floral motif. Short puffed sleeves, small sweet-heart neck-line, ruched bust area. Perple velveteen ribbons at top centre of bodice and on each hip. Underdress is a black, cuprammonium, bias-cut shift.

Fabric Characterization

Fabric #: I; II

Photos (mag. 10x; 100x):





Weave Structure: bobbinet; plain weave

Fabric Count (w x f): n/a; 39 x 29

Surface Decoration: dyed black with white needle run floral motif; dyed black

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
41 (net)	Viscose Rayon	filament	low	simple single
42 (warp)	Cuprammonium Rayon	filament	low	simple single
43 (weft)	Cuprammonium Rayon	filament	low	simple single

Condition Characterization

Description:

Evidence of **shrinkage**, underdress exposed at hem. Net **torn** at left proper shoulder

Photo:

Accession #: **1985.70.6**

Garment Characterization

Photo:

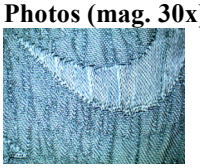
Description:

Black matte lassé dress with attached bolero jacket. Sleveless chiffon bodice. Long voluminous sleeves with red cuffs. Evidence that there once was a red collar also.

Fabric Characterization

Fabric #: J

Photos (mag. 30x):



Weave Structure: matte lassé

Fabric Count (w x f): n/a

Surface Decoration: dyed black

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
48 (warp)	Viscose rayon	Filament	low	simple single
49 (weft)	Viscose rayon	Filament	crepe	simple single
50 (supplementary)	Viscose rayon	Filament	low	simple single

Condition Characterization

Description

Slight **stretching and bagging** of the elbows. Evidence of **shrinkage**, bolero does not cover the untidy stitching at the waist. Several large **holes** along the proper left side seam.

Photos:

Accession #: **1985.74.55**

Garment Characterization

Photo:

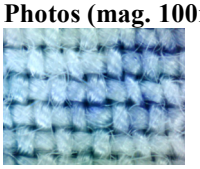
Description:

Short (shortened?), v-neck, blue printed dress with shawl sleeves. Fabric is gattered at the shoulders. Loops indicate there was a belt at one time. Remenants of threads indicate that ther were buttons (?) or bows (?) down the front of the bodice. Embellished with two extant bow on the upper left and right chest area.

Fabric Characterization

Fabric #: K

Photos (mag. 100x):



Weave Structure: plain weave

Fabric Count (w x f): 31 x 21

Surface Decoration: dyed blue, printed with floral motif

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
51 (warp)	Viscose rayon	filament	medium	simple single
52 a, b (weft)	Viscose rayon, acetate	filament	low	simple single

Condition Characterization

Description

Slight all over **fading**. **Splitting** of right proper side and waist seams. **Abrasion and thinning** of the fabric at the hem.

Accession #: **1986.31.6a**

Garment Characterization.

Photo:

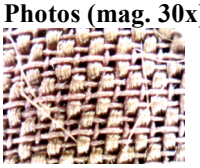
Description:

Brown velvet, long-sleeved, med-calf length dress. Scarf waist. 'Gem stone' and metallic closure. Loops indicate there was once a belt. Shoulder pads.

Fabric Characterization

Fabric #: L

Photos (mag. 30x):



Weave Structure: velvet

Fabric Count (w x f): n/a

Surface Decoration: dyed brown

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
55 (warp)	silk			
56 (weft)	silk			
57 (pile)	viscose rayon	filament	low	simple single

Condition Characterization

Description:

Side seam of scarf waist **splitting. Holes** at left proper neck. Ravelling of the silk ground fabric at the hem.

Accession #: **1986.31.7a**

Garment Characterization

Photo:

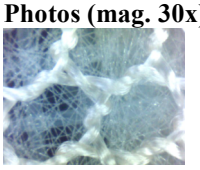
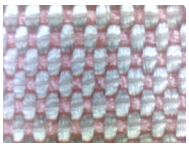

Description:

Underdress is a pink, sleeveless, plain-woven shift dress with a slight sweet-heart neckline and a flounce hem. Overdress consists of a bobbinet lace, sleeveles shift with tuck stitching on the bodice increasing in size to produce ruffles for the lower dress and skirt. Bobbinet is gathered at the top of the shoulders for volume.

Fabric Characterization

Fabric #: M; MM

Photos (mag. 30x):

Weave Structure: bobbinet; plain weave

Fabric Count (w x f): n/a; 50 x 27

Surface Decoration: dyed pink; dyed pink and printed with a floral motif

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
58 (warp)	viscose	filament	low	simple single
59 (weft)	viscose	filament	low	simple single
60 (bobbinet)	viscose	filament	low	simple single

Condition Characterization

Description

Significant **yellowing** in underarms and chest areas of overdress (perspiration?). All over **dye-transfer** of the vibrant pink of the printed pattern, concentrated in the underarms. **Splitting, holes, weakness and embrittlement** associated with yellowing in the armpits and browning along hem. **Seam slippage** of the proper left side seam near the bottom of the dress. Evidence of **shrinkage** of the underdress.

Photos:

Accession #: **1986.43.7a**

Garment Characterization

Photo:

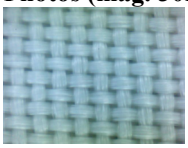

Description:

Long off-white gown with matching gatered bolero. Dress has double spaghetti straps, a ruffle along the edge of the slight sweet-heart neckline and horizontally gathered fabric to create volume for the bust. Bodice waist dips down in a central 'v'. Long full skirt, line of buttons for closure at the back.

Fabric Characterization

Fabric #: N

Photos (mag. 30x):



Weave Structure: plain weave

Fabric Count (w x f): 34 x 34

Surface Decoration: dyed off-white

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
61 (warp)	cuprammonium rayon	filament	medium	simple single
62 (weft)	cuprammonium rayon	filament	medium	simple single

Condition Characterization

Description

Slight **stretching/bagging** in the bist. Evidence of **shrinkage** as lining is exposed below the hem of the dress. **Splitting** of seams at the waist (skirt too heavy?). a 2 cm **hole** in the back hip area.

Photos:

Accession #: **1987.45.1**

Garment Characterization

Photo:

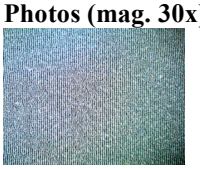
Description:

Long, black, sleeveless gown. Straps gathered at the front of the shoulder. Dress is belted and the skirt consists of three tiers on an angle across the body. Tag indicates the dress was of the 'Queen Dress' brand.

Fabric Characterization

Fabric #: O

Photos (mag. 30x):



Weave Structure: twill

Fabric Count (w x f): n/a

Surface Decoration: dyed black

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
66 (warp)	silk			
67 (weft)	viscose rayon	filament	crepe	2-ply

Condition Characterization

Description

Splitting of side seam near bottom. **Holes/losses** at waist band (where belt was stitched? abraded by belt?).

Accession #: **1988.40.3a**

Garment Characterization

Photo:

Description:

Pink, v-neck dress with wide elbow length sleeves. Belt at waiste and brown printed tie at neck. Skirt flares out slightly below the knee. Stitch holes indicate that this dress has been shortened twice.

Fabric Characterization

Fabric #: P

Photos (mag. 30x):

Weave Structure: true crepe

Fabric Count (w x f): 68 x 26

Surface Decoration: dyed pink

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
70 (warp)	acetate	filament	low	simple single
71 (weft)	viscose	filament	crepe	simple single

Condition Characterization

Description

Holes in skirt associated with brown soiling. **Abrasion** on inner proper right sleeve with associated hole.

Accession #: **1988.51.7**

Garment Characterization

Photo:

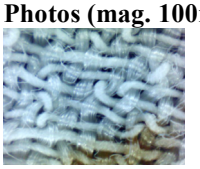
Description:

Mid-calf length, blue, floral dress with short puffed sleeves, a ruffle at the neck and a sash. Skirt is cut on the bias.

Fabric Characterization

Fabric #: Q

Photos (mag. 100x):



Weave Structure: true crepe

Fabric Count (w x f): 38 x 30

Surface Decoration: printed with a floral motif

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
72 (warp)	cotton			
73 (weft)	viscose rayon	filament	crepe	simple single

Condition Characterization

Description

Some **raveling/fraying** at the collar and seam allowances. All over slight **pilling**.

Accession #: **1989.32.10**

Garment Characterization

Photo:

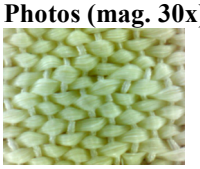
Description:

Yellow, mid-calf length dress with a natural waist. Bodice buttons down the front with a row of white buttons the collar and the edge of the shawl sleaves are cut into crenelated zig-zag patter. Bodice is gathered in the front to create volume for the bust. Skirt flares out slightly just below the knee.

Fabric Characterization

Fabric #: R

Photos (mag. 30x):



Weave Structure: true crepe

Fabric Count (w x f): 35 x 30

Surface Decoration: dyed yellow

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
76 (warp)	viscose rayon	filament	crepe	simple single
77 (weft)	acetate	filament	low	simple single

Condition Characterization

Description

Splitting and **fraying** of right proper side seam.
Embrittlement of the fabric associated with soil on the right proper sleeve.

Accession #: **1993.4.18a**

Garment Characterization

Photo:

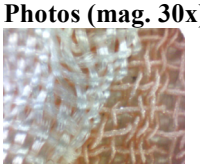
Description:

Long, pink and white, bias-cut, mattelassé gown with a deep v-neck. The dress has a sash that ties in a bow at the back and shoulder pads in the puffed short sleeves made of pink crepe georgette fabric.

Fabric Characterization

Fabric #: S

Photos (mag. 30x):



Weave Structure: mattelassé

Fabric Count (w x f): n/a

Surface Decoration: yarns dyed pink and white

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
78 (white)	viscose rayon	filament	low	simple single
79 (pink)	silk		crepe	

Condition Characterization

Description

Yellowing at the front centre waist.

Accession #: **1999.37.4**

Garment Characterization

Photo:

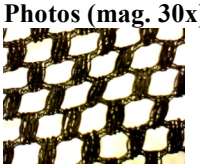
Description:

Sleeveless bias-cut dress with rounded v-neckline and a full skirt. Raschel knit lace at the top of the bodice with beige coloured silk chiffon underneath. Dress hits approximately mid-calf in length. Dress has a matching belt

Fabric Characterization

Fabric #: T, TT

Photos (mag. 30x):



Weave Structure: raschel knit lace; satin weave (silk)

Fabric Count (w x f): n/a

Surface Decoration: dyed black

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
84 (warp)	silk			
85 (weft)	silk			
86 (raschel knit)	viscose rayon	filament	low	simple single

Condition Characterization

Description

Dye transfer from the black raschel knit lace to the beige chiffon. In the underarms. Slight **Abrasion** to the long floats of the raschel knitted lace.

Accession #: **1999.53.49**

Garment Characterization

Photo:

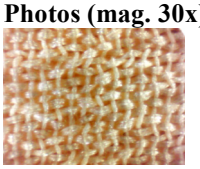
Description:

Short, drop-waisted, orange-pink (peach?) dress with tiny pleats in the skirt. Embroidered decoration at the waist, around neckline and in the centre front of the bodice. Dress has a drawstring tie at the neck. Database indicated that the dress was sewn from a kit.

Fabric Characterization

Fabric #: U

Photos (mag. 30x):



Weave Structure: true crepe

Fabric Count (w x f): 64 x 44

Surface Decoration: dyed peach, embroidered.

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
87 (warp) **88** (weft)	cuprammonium rayon mercerized cotton	filament	low crepe	simple single

Condition Characterization

Description

Fading, **yellowing, splitting and holes** in underarm areas associated with perspiration stains.

Accession #: **2002.3.30a**

Garment Characterization

Photo:

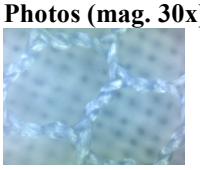
Description:

Long, light blue dress with a high neck, natural waist and elbow length sleeves. Cuffs, neck and courses on the sleeves, bodice and skirt including the hem are finished with a twill woven fabric also in light blue. The main fabric consists of bobbinet lace. There is a bow at the front of the high neck.

Fabric Characterization

Fabric #: V

Photos (mag. 30x):



Weave Structure: bobbinet lace

Fabric Count (w x f): n/a

Surface Decoration: dyed light blue

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
89 (net)	viscose rayon	filament	low	simple single
90 (twill warp and weft)	acetate	filament	low	simple single

Condition Characterization

Description

Yellowing of back bodice and underarms (perspiration?). **Splitting** at the back waist seam. Several **holes** in the right proper underarm associated with perspiration stains. Twill fabric is fraying in some areas.

Accession #: **2004.26.1**

Garment Characterization

Photo:

Description:

Red, long-sleeved, calf-length, heavy crepe dress with vertical pleats on the bodice, a decorative embroidered cotton (?) collar and attached sash that buttons with three buttons at the back. Sleeves are embellished in embroidery with metallic threads and some beading. Zipper closure. Tag reads " Dual Designs Betty Barclay Frocks Junior Half Sizes."

Fabric Characterization

Fabric #: W

Photos (mag. 30x):

Weave Structure: momie weave crepe

Fabric Count (w x f): 30 x 31

Surface Decoration: dyed brown-red, embroidered

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
91 a, b (warp)	viscose rayon, acetate	filament	low, crepe	2-ply corkscrew
92 a, b (weft)	viscose rayon, acetate	filament	low, crepe	2-ply corkscrew

Condition Characterization

Description

Slight **fading** of skirt fabric. **Stretching/bagging** in attached sash/waistband. **Broken construction threads** at back waist. Seam **splitting** in underarm area.

Accession #: **2006.24.8**

Garment Characterization

Photo:

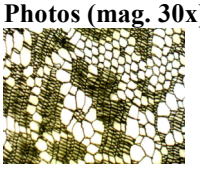
Description:

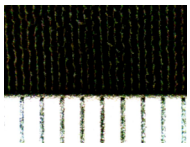
V-neck, drop waisted dress, skirt with a slight flare, sleeveless

Fabric Characterization

Fabric #: Y,YY

Photos (mag. 30x):





Weave Structure: raschel knit lace; plain weave

Fabric Count (w x f): n/a; 40 x 28

Surface Decoration: dyed black

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
93 (lace)	viscose rayon	filament	low	simple single
94 (warp)	viscose rayon	filament	low	simple single
95 (weft)	viscose rayon	filament	crepe	simple single

Condition Characterization

Description

Raveling and **pilling** of long floats in the raschel knit lace.

Accession #: **2006.24.17**

Garment Characterization

Photo:

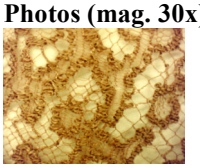
Description:

Long, brown, drop-waisted, raschel knit lace dress with a gathered v-neck and flared sleeves.

Fabric Characterization

Fabric #: X

Photos (mag. 30x):



Weave Structure: raschel knit lace

Fabric Count (w x f): n/a

Surface Decoration: dyed light brown

Yarn Characterization

Yarn #	Fibre Content	Fibre Length	Twist	Yarn Structure
101 (net)	silk			
102 (figure)	viscose rayon	filament	low	simple single

Condition Characterization

Description

Hole in seam at waist. All over slight **pilling.**