to work on and safe for the restored painting to be returned to its future housing conditions which were probably unknown to the reliner. The advantages of this process was that the (re)liner practised a series of specific skills designed to flatten distortions and save any detaching paint while the restorer concentrated on the separate problems of cleaning off the old varnish, filling, retouching any losses, and revarnishing.

However, the expectations placed on a lining increased. Nineteenth-century artists were exploring more expressive techniques of painting in oil on canvas, emphasizing the application of materials, e.g. painting in the style of Velasquez. Thickly applied paint exerts a resilient force on a canvas that can create problems as the painting ages. It is more difficult for a liner to correct such distortions.

The responsibility for any damage is not just the liners' but extends to the restorer, curator, or owner. Continuing insensitivity to lining damage resulted from the arm's length responsibility and the assumption that some damage was acceptable as an inevitable side-effect of the need to save the canvas from falling apart. Nineteenth-century liners, such as Morrill and Buttery, to name but two, caused the same kind of damage over and over again, and this damage was accepted by museums, which were prepared to send more paintings to be lined (Hackney, 1990b).

Some artists, such as William Holman Hunt, Ford Madox Brown, Sir John Everett Millais, and James McNeill Whistler, sent their newly painted canvases to be lined, even during the painting process. They had no concerns about flattening and weave re-enforcement and it may be suspected that they were happy for their canvases to take on the characteristics of the lined old masters that they had seen and copied in museums (Stoner, 1997; Townsend *et al.*, 2005).

The introduction of wax lining in the nineteenth century, using adhesives based on beeswax and colophonium which together melt at about 61 °C and contained no water, was intended to address the damage done by glue liners (Te Marvelde, 2001a, and see Section 25.4, below). The application of heat could be controlled more accurately since the iron was melting wax rather than driving off moisture, and the softening effect of moisture was eliminated. After lining, the wax continued to isolate the painting and canvas from its environment. Similarly, wax was also used to impregnate glue/paste linings to provide a moisture barrier.

25.4 Wax-resin lining, by Mireille te Marvelde

Paintings lined using a mixture of wax and resin 'can even lie under water for a long time without suffering damage'. This claim by Professor Hauser of Berlin, quoted by Eugen Voss in his *Bilderpflege* of 1899 (B. and M. von der Goltz, 1993: 316), illustrates the enormous confidence in wax-resin lining prevalent in the late nineteenth century. Wax-resin lining was developed in the mid-nineteenth century in the Netherlands by the artist and restorer Nicolaas Hopman (1794–1870), possibly together with his son Willem Antonij (1828–1910). The new method, referred to in the literature as 'The Dutch Method', was seen as the solution for the major problems of damp in the Low Countries, which threatened the continued existence of many paintings there (Te Marvelde, 2001a).

From the late nineteenth century onwards, wax-resin was increasingly used by restorers both in the Netherlands and abroad (Te Marvelde, 2001a), while from the 1920s it became an established topic of discussion in the professional literature. Baer and Kunz's survey of the literature from the 1920s to the 1970s (Baer and Kunz, 1977), listed various investigations conducted into the properties of wax-resin mixtures and attempts made to improve those properties by altering the composition of the mixture and by adding various other materials. The disadvantages of the method gradually became clearer; however, wax-resin lining was applied widely as a standard and even 'preventive', method, especially in the twentieth century, until 1974.

25.4.1 Invention of wax-resin lining: the essence of the method

Wax-resin lining was devised as a reaction to aqueous techniques of lining paintings, as discussed above. Moreover, the Dutch climate ensured that aqueous linings did not have a long lifetime; artworks had to be re-treated and were again subjected to the possibility of damage. To solve this problem, Nicolaas Hopman suggested the use of beeswax, inspired by the recent discoveries of many Egyptian objects and paintings that had been immersed in wax or painted with wax-based paint, including the famous Fâyum portraits. These objects were in an exceptionally good state of preservation; Hopman deduced that beeswax must have been a suitable preservative medium (De Hollandsche Revue, 1904: 768; Plenderleith and Cursiter, 1934: 91, etc.).

Beeswax is considered a material that is chemically so inert that it virtually does not age. However, it is a material that is not suitable as a lining adhesive because its adhesive properties are very weak. For this reason, Hopman added colophonium to the beeswax, a resin that in the fresh state is equally insensitive to moisture and which adds considerable adhesive power. Beeswax also impregnated extremely well. Hopman was confronted with a situation in which water-related problems were threatening to destroy many paintings, for both the ground and paint layers had blistered (based on research by the author in the Mauritshuis Archives). In the nineteenth century, there was no central heating or climate control; it seemed best to stabilize the object itself.

The essential advantage of the Hopman wax-resin lining was that in a single treatment both the ground and paint layers could be flattened and consolidated, and the canvas could be 'strengthened'. Consolidation played a much greater role in these considerations than the support of the old canvas with a new one. Examination of lined paintings treated by the younger Hopman (few of the treatments by the father remain) indicated that the lining was carried out because of problems with the ground and paint layers rather than concerns with the original canvas. Wax-resin, as a 'hot melt', usually penetrates readily into the structural openings in canvas, ground, and paint layers.

Characteristics of the technical execution of the prototype: the 'Hopman lining'

Willem Antonij Hopman applied the method widely, and many of his linings have been preserved. Few of Nicolaas Hopman's linings are known, but as of 2011, neither these nor most of the linings of Willem Antonij, the son, have needed to be replaced. Several of these linings can be investigated for the technical aspects of the way they were done, their durability, and the impact of the method on the paint layers. Study of these linings provides information on the original purpose of the wax-resin, and the starting point from which the method was subsequently developed by others.

The Hopman lining has several specific characteristics (see Figures 25.4, 25.5, and 25.6). The lining canvas was woven in a twill weave. The structure of the lining canvas is so fine that it cannot print through on to the front of the painting while, at the same time, the twill weave imparts great strength and contains little flexibility so that it can be stretched well and true. According to H. Heydenrijk (a pupil of Hopman, Jr, active ca. 1900), the canvas was especially woven for this purpose (Raaf, 1905: 451). The newly lined painting was always stretched on to a new, solid stretcher made of broad lathes bevelled on the canvas side and with a roundel at the outer edges on the interior side. It is clear that the Hopmans were aware of the fact that contact of the wooden bars against the canvas would cause stretcher bar marks. Most remarkably, these linings do not show any superfluous wax-resin on the back of the paintings. As a result, Hopman's linings were often misidentified as glue or paste linings because of the absence of excess wax-resin. It was probably as a result of the thinness of the wax-resin that the linings remained relatively supple. Hopman and son must also have been aware of the importance of removing excess wax-resin from the reverse side. The side edges of the lining canvas were cut off against the edges of the stretching frame. If the original tacking edges were unusually wide, these were cut off in the same place identically with the lining canvas. The original tacking edges were never entirely removed, however.

Details regarding Hopman's lining techniques appear in the manuscript, 'Über die Restauration von Gemälden' (1896/97, modified in 1901/02, and published in 1995) by the Rembrandt connoisseur and restorer Prof. Alois Hauser Jr (1857–1919) from Berlin. Hauser had learned the method in 1891 from Hopman Jr when he spent some time in The Hague to restore a number of paintings in the Mauritshuis (Mandt, 1995: 217; letter archives, Mauritshuis 1890–93).

The lining was carried out in two stages. First, the original, faced with silk paper and starch was stretched with strips of thick paper in a frame and laid face down on a soft cushioning material. Any deformations could be removed from the canvas by pre-stretching. The reverse side of the original canvas was rendered smooth and porous using pumice-stone, so that no surface irregularities could impress through to the front side. The open structure thus created also facilitated the process of impregnation. Then the warm, molten mass, 'which should not, however, be too hot' (Mandt, 1995: 222), was poured on to the reverse side of the painting and, using a 'lukewarm' iron (Mandt, 1995: 222), ironed into the structure of the canvas and the ground and

Figure 25.4a Reverse of a painting wax-resin lined by W.A. Hopman 1876/77 (Mauritshuis inv. no. 38) showing Hopman's stretcher and lining canvas. Note also the lack of superfluous wax-resin adhesive. Photograph by the author and permission given by the Mauritshuis

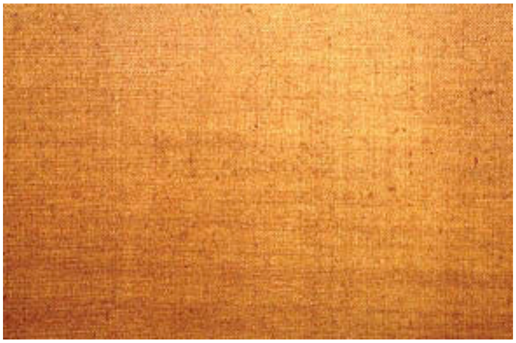

Figure 25.4b Detail of Hopman's twill weave lining canvas (Mauritshuis inv. no. 38). Photograph by the author

Figure 25.4c Same detail of Hopman's twill weave lining canvas, in raking light (Mauritshuis inv. no. 38). Again, no excess wax-resin adhesive is visible. Photograph by the author

paint layers. The quantity of wax-resin must be ample, so that a considerable amount can be moved around with the iron.

In the meantime, the painting was turned over from time to time to see whether the mixture had yet been penetrated through the structure of the painting to the surface. After this, great attention was paid to the removal of the still-warm excess wax-resin, making use of the sides of the iron as though using a wooden spatula. Before the painting had cooled, the facing was then removed. The painting was then newly faced and stretched and the lining canvas, which had similarly been stretched on a frame, was laid on the reverse side of the painting.

The two stretchers fit into one another. The lining adhesive was introduced on to the lining canvas and in the same way as described above, ironed in and the excess material removed. After checking to make sure the canvas was well attached overall, the lining was, if necessary, ironed again, and the painting finally stretched on to the new stretcher (Mandt, 1995: 217, 222–4).

This description indicates that Hopman must have been well aware of the danger of pressure and heat. In a later publication, one of Hopman's successors wrote that the impregnation of wax-resin occurs through capillary action, and that pressure is unnecessary (Cursiter and De Wild, 1937: 171). It is remarkable that this important information is almost never discussed in the literature. In practice, too, it would seem that it has often not been known.

Hauser provided the following recipe for Hopman's lining mixture: three parts colophonium, four parts white wax (probably bleached beeswax), and two parts Venetian turpentine. First the resin was melted in an iron pot over medium heat, to which was then added the wax and finally the Venetian turpentine (Mandt, 1995: 222). Hopman Jr also mentioned this mixture in different sources, although he wrote of 'white resin', possibly mastic (Hopman, 1871: 43). He also recorded that he added one part of copaiva balsam (letter, 23 May 1877, Archives, Mauritshuis). Balsam was added probably in order to enhance the smoothness and flexibility of the mixture. However, analysis has not detected copaiva balsam (Werf *et al.*, 2000). Analysis has shown that the resin mentioned in Hopman's recipe by Hauser is not mastic but colophonium (Van den Berg, 1998: Table 2).

In his manuscript, Hauser noted that every painting is different and requires a different approach. He was aware that the wax-resin lining is not suitable for modern paintings (Mandt, 1995: 222), a realization that has unfortunately only slowly penetrated a wider consciousness; countless modern paintings later suffered enormously from the use of the wax-resin method of lining. Matt, porous paintings painted in light tones could darken radically as a result of such treatment and acquire an oily, shiny appearance.

25.4.2 Dissemination of the wax-resin method and its appearance in the literature

The wax-resin method of lining did not catch on widely after its invention, probably because restoration in the nineteenth century was usually carried out in secluded workshops. Although there were increasingly more publications on restoration and interest in the topic from the press, new developments were more likely to be handled as trade secrets.

By the end of the nineteenth century, there were only a few individuals who had learned the wax-resin lining method directly from Hopman Jr including Alois Hauser and H. Heydenrijk, mentioned above. From handbooks and other publications from the turn of the century it is apparent that these restorers must have introduced the method to other colleagues outside of the Netherlands, who in turn passed in on. From that moment, wax-resin lining appears with increasing frequency in the international literature. Hauser introduced the method in Germany, de Wild in Austria and probably later also in the USA. De Wild's young nephew, Martin de Wild (1899–1969), probably introduced wax-resin lining to his English colleagues in the 1920s (Te Marvelde, 2001: 147). Shortly afterwards, an article by Martin de Wild appeared in French (in a translation from the English) in the newly founded international museums journal *Mouseion* (De Wild, 1931). Martin de Wild wrote a doctoral thesis in 1928 (translated into English in 1929), 'The scientific examination of pictures', which includes a chapter on restoration with a brief account of the wax-resin method of lining. Martin de Wild became an increasingly important figure in the international art and restoration world (Van Duijn, 2003: 27–41, unpublished; Van Duijn, 2005: 33–7) and later published various pieces on wax-resin lining (e.g. Cursiter and de Wild, 1937, 1938a,b, 1939; de Wild, 1959).

The first detailed, step-by-step description in the international literature appeared in 1932 in the 'Technical Notes' of the *Museums Journal*. The 1932 description closely follows Hopman's method, although the proportions of the adhesive mixture were modified in the meantime. Schmidt-Degener cited a mixture of five parts beeswax, three parts resin, and one part Venetian turpentine (Schmidt-Degener, 1932: 87).

Many different wax-resin recipes were developed over the following decades. Alois Hauser devised his own composition for the mixture: '2 parts yellow wax (pure) and 1 part Burgundy resin (white pitch)'. He explained that this mixture is smoother and more elastic (Mandt, 1995: 222). Hauser began the trend towards an increasingly higher wax-to-resin ratio in the mixture. It was the wax that possessed the desired stabilizing properties, while it was probably already known that the resin aged substantially and as a result made the adhesive friable.

25.4.3 Research on wax-resin mixtures: finding the optimal composition

Internationally from the 1930s onwards, there were various investigations into the properties of lining mixtures with different materials in different proportions. An early and extensive investigation was conducted by George Stout and Rutherford Gettens, and published in the second number of the journal *Technical Studies in the Field of Fine Arts* (1933). The article discussed the properties that a lining mixture should possess: (1) give firm adhesion between the layers and have a consistency such that it can penetrate well into all the cracks, (2) be flexible and retain this flexibility, (3) be able to seal the canvas and paint layer from the atmosphere, (4) be soluble in solvents that are harmless, be able to penetrate at a temperature that does no harm to the painting but is high enough not to be affected by room temperature, (5) be non-corrosive and not harbour mould or other agents of decay, and (6) not stain or in any way cause a change of colour or value in the paint film (Stout and Gettens, 1933–34: 83–4).

At the Fogg Museum, different materials were tested on pieces of old paintings and assessed for the properties listed above: glue-paste emulsion, poly(vinyl acetate)-wax, paraffin wax-elemi, pure beeswax, and wax-resin. The authors emphasized the disadvantages of water-sensitive lining adhesives and tested the behaviour of mixtures by exposing them to conditions of extreme damp. The lack of adhesive strength and flexibility were cited as disadvantages of wax and as the reason for the addition of resin and/or balsam. At the same time, the authors recognized that resin oxidizes with age. The argument that wax-resin causes discoloration in the paint layer, which was to become one of the most important criticisms of wax-resin lining later in the century, was not yet discussed fully. The eventual conclusion of Gettens and Stout was that the ideal mixture would never exist, 'but there can be little doubt that the most safe and effective ones . . . are the adhesives of the wax and wax-resin type' (Stout and Gettens, 1933–34: 103).

In the *Manual on the Conservation of Paintings* (1940), published following the first international conference on the conservation of paintings in 1930 (under the aegis of the International Museums Office), the problem of the discolouring of paint layers as a result of wax-resin impregnation was raised but no great weight was attached to it (ICOM, 1940/1997: 216–18). Investigations by the British researchers H.J. Plenderleith and Stanley Cursiter were concerned with wax mixtures as the lining adhesives (Plenderleith and Cursiter, 1934). Attempts were made to find the best mixture by trying out different waxes (bleached and unbleached beeswax and four paraffin waxes of different melting points) and mixtures of beeswax in different combinations with resin, paraffin wax, Venetian turpentine, gum elemi, Canada balsam and/or copaiva balsam. The adhesive properties and the melting point of the mixture were emphasized. Plenderleith and Cursiter had little confidence in synthetic materials. Eventually, colophonium was mostly replaced by the less dramatically ageing dammar.

From the 1950s to the 1970s, in addition to the variants on the traditional mixture, new materials were tested in order to influence the properties of the wax-resin mixture, either to improve them or adapt them to a specific situation. The research and resulting publications by restorers and scientists in this area increased (Baer and Kunz, 1977). A range of plant, mineral, and synthetic waxes and polycyclohexanone resins were tested and used in wax-resin linings. Materials and products regularly cited in the literature in recipes for wax-resin linings included: Carnauba wax, Multiwax ML-445, Mobilwax 2300, Polywax 12000, Polywax 1000, Carbowax, Multiwax 835, MS2A resin and AW2 resin (Baer and Kunz, 1977). These materials were included to influence adhesion, melting point, viscosity, and solubility.

25.4.4 Variations in the execution and equipment used for wax-resin lining

In a series of case studies in the late 1930s, Stanley Cursiter and Martin de Wild demonstrated the 'normal' way of carrying out a wax-resin lining and in what way aspects of the technique could be adapted to the specific situation (Cursiter and de Wild, 1937, 1938a, b, 1939). For example, a painting with an unproblematic, smooth surface could be lined in a single ironing action (1937), whereas the treatment with a painting with marked cupping should be carried out in two stages (Cursiter and de Wild, 1938a, b: vol. VI).

Different canvases were used, from the finely woven twill of Hopman to the very thick canvases woven with double thread, thought to provide extra strength. According to Cursiter and de Wild (1937: 164) the character of the lining canvas would depend on the size and type of the picture under treatment. Further, different materials and adhesives were chosen for applying the facing. The moment at which a facing was introduced could also differ; different facings could be used at different moments within a single treatment. A range of different materials varying in hardness could be chosen for the cushioning during the lining. And in the technique itself, there was a choice of whether or not to stretch the original painting, whether the lining mixture should be applied to the original canvas or to the lining canvas or both, and whether to iron the front or reverse side of the painting. The treatment could be carried out in various stages. In most of the linings investigated by generations

Figure 25.5 Detail of the reverse of a painting wax lined in 1965, in raking light (Mauritshuis inv. no. 166). Excess wax-resin adhesive is visible. Photograph by the author

after Hopman, the wax-resin mixture is usually present in profuse quantities on the reverse side of the paintings (unpublished research, Te Marvelde).

There were also technical innovations that influenced the way the wax-resin lining was carried out. Initially, flat irons were used that had been heated on a stove; subsequently electric irons with better temperature control were adopted. In 1948 the first hot-table, built at the Courtauld Institute, London, was invented, allowing the whole surface to be warmed at the same time and thus obviating problems that previously arose from local differences of temperature. This development was followed in 1955 by the invention of the vacuum hot-table by R.E. Straub and S. Rees Jones, a system that allowed not only for overall heating, but for overall pressure as well (Percival-Prescott, 1974, in Villers, 2003: 12). Uncritical use of vacuum hot-tables led to various changes in paintings, including discoloration and surface deformation such as the so-called 'weave-interference' or 'weave enhancement', the results of using excessive pressure and heating the paintings for too long. These and other optical changes were so obvious that, after decades of positive estimation, the method of wax-resin lining gradually came in for more and more criticism.

25.4.5 The re-evaluation of wax-resin lining after 1974

George Messens demonstrated the 'Dutch Method' at the 'Conference on Comparative Lining Techniques' in 1974 in Greenwich as a reliable method if carried out by experts and only when necessary. This latter qualification was a critical response to earlier recommendations to carry out the treatment as a preventive measure, whether it was necessary or not (Villers, 2003: 70).

At the same conference, Gustav Berger, arguing from a position of long experience of lining practice, gave his views on the fundamental limitations of current wax-resin lining methods and presented an alternative approach to wax-resin lining based on BEVA 371, his own formula synthetic adhesive (Villers, 2003: 25–7, 125–35). A year later, together with H.I. Zeliger, he published a more detailed report of his research in the preprints of ICOM-CC and in the German magazine *Maltechnik-Restauro*. Berger abstracted his conclusions in *AATA* (*Art and Archaeology Technical Abstracts)* (AATA 13–344, 1976); he did not consider the use of wax-resin to be sound conservation practice, questioning its impact on the canvas and paint, the aging of the wax-resin mixture, its removability and added weight. The idea that other types of adhesive could not readily be adhered to a wax-resin lined painting was also proposed as a problem. Berger's views challenged the original intentions of wax-resin lining, questioning that it provided preventive protection of the canvas and paint layers against moisture and ageing, that it was an ideal method for flattening a painting, and that it did not age.

Discussion continued, and various researchers pursued their investigations into the effects of wax-resin lining; publications include: Gerry Hedley (1975/1993) on stress-strain curves of wax-resin-impregnated canvas under tension; S. Rees Jones, A. Cummings, and G. Hedley on current attitudes toward lining practice with replies from 52 conservators to a questionnaire on lining practices (1975); A. Ketnath (1977, 1983) on problems and alternatives using low-pressure tables; S. Hackney and G. Hedley (1981) on the degrading effects of wax-resin on canvas, and D. Bomford and S. Staniforth (1981) on impregnation and colour changes.

Most research was aimed at the development of new lining materials and techniques. There was an increasing concern that wax-resin lining was no longer the best method available for treating paintings and that it was not acceptable to impregnate canvases, grounds, and paint layers. Opinion had evolved and emphasis was now on the integrity of an artwork. The lining of paintings as a preventive measure was succeeded by an attempt to cease lining at all. Attention was increasingly directed to the

the derivatizing agent TMAH). Melting points were tested and analyses of the wax-resin samples conducted by DSC (Differential Scanning Calorimetry) to investigate the physical behaviour of the mixtures, especially with regard to the separation of the wax/resin compounds.

The MolArt research is not yet complete (as of 2011), and remains largely unpublished; however, several observations have emerged. Ageing of the resins in wax-resin mixtures is not affected by the composition of the mixture or the way it is prepared or applied, but purely by time (Te Marvelde, 1998: 88); much of the oxidation occurs during the first 20 years. During impregnation, the beeswax not only penetrates the microscopic openings of the structure of a painting, but also infiltrates the binding medium of the paint itself. The mixture becomes less coherent with age, and, especially when warmed, separation occurs. Even at room temperature, beeswax can migrate from the resin through the entire structure of the painting (Boon, Rainford and Pureveen, 1994: 14). Paint layers of wax-resin lined paintings seem also to be more susceptible to solvents (Sutherland, 2001b: 37). Visual changes mostly depend on the original technique of the painting's execution and on the way the treatment was carried out. In the case of the Oranjezaal paintings there was no colour difference visible between lined and unlined paintings. Discolouration may have been prevented by the fact that the ground layers are lead-white-containing oil grounds (and therefore not so porous) and the fact that no more heat than necessary seemed to have been used during the lining treatments.

These preliminary results can contribute to the design of future treatments for paintings that have previously been wax-resin lined. For example, the application of heat to a wax-resin lined painting further enhances the separation of the mixture in the structure of the painting; the oxidized resin also becomes more polar and less compatible with wax, and the melting point of the resin increases when ageing while the melting point of wax remains the same over time. Extraction of wax-resin from paintings by heat will mainly serve to remove the beeswax which is the component that may have penetrated into the medium. With paintings that have been lined very early on in their existence, there is the possibility that the mixture has so penetrated into the still incompletely oxidized paint that extraction could lead to removal of some of the binding medium along with the lining adhesive. Moreover, one must be aware when using solvents that the paint may have become more sensitive.

25.4.6 Conclusion

The history of wax-resin lining shows how a method devised with the intention of preserving paintings on canvas underwent developments that actually led to their abuse. Its disadvantages have been extensively studied and have formed a case study for challenging interventions and the necessity for lining at all. It has been a cautionary tale from conservation history that this method of conservation was embraced on such a large scale and achieved such high prestige before falling into disrepute. Since so many paintings have been wax-resin lined in the past, research into the effects on a micro-level should be continued to benefit future treatment of those paintings.

Acknowledgements for Section 25.4

This section has been written on the basis of research carried out under the aegis of the Dutch MolArt Project (1995–99) and the Dutch Conservation Project of the Oranjezaal (1998–2001). MolArt (Molecular Aspects of Ageing in Painted Works of Art) was a subsidiary of the Dutch Organisation for Scientific Research (NWO). The Oranjezaal project was commissioned by the State Building Department to the Limburg Conservation Institute.

possibilities of removing wax-resin from paintings (Landgrebe, 1988; Heydenreich, 1994). See Section 25.5 for additional discussion of the history of lining after 1975.

The condition of paintings that had been lined using the wax-resin method was investigated to study the changes that had occurred as a result of the treatments. After observing wax-resin-lined paintings over a number of years, researchers concluded that, even after a relatively brief time, unfortunate changes had occurred that were not related to natural ageing. New patterns of craquelure had formed and deformations had appeared in the canvas. Arthur Ketnath reported in 1977 that even after a few years, paintings which had been wax-resin lined, especially if housed in poor climatic conditions, were manifesting problems where the varnish had been affected along the edges of the craquelure. Ketnath attributed this to moisture penetration from the back to the front of the painting despite the wax-resin (Ketnath, 1977: 99). Consequently, even the properties of wax-resin as a climate buffer were put into question.

In 1992, Schaible and Wülfert expressed surprise that wax-resin had for so long been so uncritically used in the restoration world. They referenced two German publications of 1915 and 1921 in the chemistry and physics literature presenting the results of research on the stability of wax-resin mixtures. This work demonstrated that wax-resin mixtures were not stable and that even at room temperature they could separate out; however, these publications had not come to the attention of the conservation world (Schaible and Wülfert, 1992).

A more recent study within the Dutch MolArt project (Molecular Aspects of Ageing in Painted Works of Art, 1995 to 1999) was concerned specifically with the change and ageing of wax-resin mixtures and their effects on paint layers (Te Marvelde, Van den Berg, Van der Doelen, Boon *et al.*). The idea behind this was that more knowledge was needed about the condition of paintings that had been wax-resin lined in the past. The first requirement was for thorough historical investigation to gain insight into the history of the methods and materials and techniques used, and to find paintings with wax-resin linings for which the date and the name of the person who executed the lining could be identified. These linings dated from the mid-nineteenth century to the late eighties of the twentieth century (Mauritshuis, The Hague, Frans Hals Museum Haarlem, Rijksmuseum Amsterdam, Oranjezaal The Hague: the Netherlands). Further, various paintings could be found that had been lined only once and with wax-resin. The significance of these paintings is that neither the interpretation of visual phenomena nor the results of analysis would in these cases be distorted by earlier linings.

The large-scale seventeenth-century paintings of the ensemble in the Oranjezaal in the Palace Huis ten Bosch in The Hague, which were restored in the period 1998–2001 under the direction of Anne Van Grevenstein of the Limburg Conservation Institute, also provided useful subjects for research. Many of these paintings had never been lined, while a few others had been lined just once with wax-resin (Ekkart, in press/2012). Paintings by the same painter, executed in the same painting technique, unlined and lined, could be compared. The paintings selected for this research were visually analysed and investigated at microscopic and molecular levels. They were investigated for optical differences between lined and unlined paintings, differences in chemical composition of the paint and the composition, and degree of oxidation of the wax-resin mixture. The degree of impregnation of the wax-resin was examined as well as any changes in vulnerability of the paint layer for solvents.

Samples of wax-resin mixtures from well documented paintings could be obtained for each decade from the mid-nineteenth century; these were examined for composition and degree of ageing. Mixtures were made on the basis of several known recipes, and at all stages of the mixing and heating these were analysed to determine whether ageing had already begun during preparation of the mixture or only later in the painting itself. Chemical analyses were carried out with DTMS (Direct Temperature resolved Mass Spectrometry) and Py-TMAH-GCMS (pyrolysis-gas chromatography/mass spectrometry, using

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25.5 The twentieth- and twenty-first-century history of lining, by Stephen Hackney

25.5.1 The hot-table and vacuum lining

In theory, the invention of the hot-table to replace hot irons allowed wax lining to be better controlled (Ruhemann, 1953; Straub, 1965). To adhere the original and the lining canvas together, a sheet of rubber latex with weights around the edges was placed over the front of the painting which was laid face up on the table. Air was evacuated from the system to create a partial vacuum. The two wax-resin impregnated canvases were joined together by heating the table. The vacuum distributed the load across the surface, so impasto did not receive localized pressure, as happened with an iron. This aspect was a great improvement, but unfortunately vacuum pressure can be a surprisingly powerful force and frequently caused the painting's canvas weave texture to collapse, forced down on to the smooth and resisting table surface at the moment when the wax melted (Cummings and Hedley, 2004). A rarer effect was weave interference (Berger, 1966), where the original canvas collapsed into a similar lining canvas when exposed to vacuum pressure and temperature.

Improvements to vacuum lining included attempts to equilibrate pressure at the front and back by using cushioning material on the table, interleaves between the canvases, and independent vacuum envelopes that eliminated the effect of the hard table top. More even pressures were achieved, exploiting improved air-flow. Again, depending on the nature of the canvas painting and the skills and experience of the operator, a range of results could be achieved.

Berger argued against impregnation with wax resin and devised an adhesive BEVA 371 that was as stable but provided a much stronger bond (Berger, 1972). Originally he used it to impregnate canvases but later recognized its value as a non-impregnating adhesive. In combination with vacuum envelopes it enabled better control of the effects of pressure. Others at this time began to experiment with different synthetic adhesives. See also Chapter 23, on adhesives.

25.5.2 Understanding the problems

Since the Greenwich conference of 1974, much progress has been made in understanding how a canvas painting is constructed and how it responds to its environment and to our actions. Paul Ackroyd produced an excellent review of the changes in lining practice (Ackroyd, 2002). In particular, careful measurements of the moisture response of painting materials have been carried out by M. Mecklenburg, G. Hedley, and S. Michalski (Mecklenburg, 1982; Hedley and Odlyha, 1989/1993; Michalski, 1991). The Museum Conservation Institute of the Smithsonian Institution established a long-term research project to systematically measure the stress and strain response of wood, canvas, glue, and oil paints to generate data for finite element analysis.