chapter one | film

> It was meant to be a showcase for Britain's electronic prowess – a computer-based, multimedia version of the Domesday Book. But 16 years after it was created, the £2.5 million BBC Domesday Project has achieved an unexpected and unwelcome status: it is now unreadable.[1]

Fig. 1.1 A 35mm cinema release print. With the exception of the optical soundtrack (left), this photographic film format has been in constant use for recording and reproducing moving images since the early 1890s, making it the longest lasting form of motion picture media by a margin of several decades.

In 1987 the British Broadcasting Corporation (BBC) created a computer-based multimedia resource which was intended to serve as a snapshot of life and work in the UK, consisting of text, still photographs, sound and full-motion video. As *The Observer's* reporter notes, it was supposed to be a reworking of the Domesday Book of 1086; a reworking both terms of its content (the original was basically a glorified asset register and as such was never intended to record any details of England's social, cultural or political life) and more importantly to this discussion, its form. The BBC's 'Domesday Disc' was recorded on 12" laserdiscs, a consumer and semi-professional video format used between the late 1970s and early 1990s. The BBC had adapted laserdiscs to hold digital content by means of a dedicated hardware interface and software designed to work on a non-standard type of computer, one which was only used on any significant scale in British secondary schools. Both the hardware and software are now obsolete, and unlike its Norman predecessor, the 'Domesday Disc' of 1986 has had to undergo 'format migration' (i.e. be copied onto a medium which is supported by current technologies) in order to remain accessible in 2002.

This is an example of a computer-based multimedia format that went from being in common use to unreadable within less than two decades. By contrast, the use of photographic film – that is, a flexible, transparent solid which supports a light-sensitive chemical layer – to record moving images and sound dates from the earliest successful commercial exploitation of this technology in 1889. Furthermore, it is still the most widely used format for feature film production, for television production in cases when image quality is considered important and budgets allow, for the application of special effects, for the mass-duplication of copies and for cinema exhibition. It is therefore the one and only form of moving image media to have remained in continuous, mainstream use for over a century. That fact in itself will not guarantee its long-term future. Many in the industry believe that the technical and economic climates are changing, and that digital technologies will surely supersede film for all of these uses just as soon as the processor speeds and storage capacity in the computers needed to drive them become cheaper than exposing and processing photographic film stock (these issues will be discussed at greater length in chapter eight). There is after all a precedent for this: digital technology replaced the gramophone record for recording sound and distributing it in the commercial music industry with the introduction of compact discs in 1982, just under a century after Emile Berliner produced the first shellac records in 1887. But whether or not this book will turn out to have been written in the closing years of film, the evolution of this technology is of key importance to the development of the moving image history and culture during the period covered here; so much so that it takes the year in which film was first used commercially, 1889, as its starting point.

This longevity is a key reason why film was the most widely used technology for recording moving images during the twentieth century. Assuming that chemical decomposition or physical damage is not an issue (this is covered in chapter seven), a moving image film manufactured in the 1890s could be viewed and copied using equipment in widespread use in 2005, with only minor modifications. Promoters of digital alternatives (notably the producer and director George Lucas) would therefore argue that the industry remains saddled with all the inherent faults of a Victorian technology. Defenders of film believe that it offers the best of both worlds: a tried and tested technology which needs relatively little cascaded expenditure on research and dev-elopment by its users, but one which is also capable of developing and improving the image quality it can deliver:

> Some existing technologies wither and disappear quickly in the face of new technologies. Some make subtle changes and adapt, becoming better. Some reach a stage of development that achieves a kind of stasis. The piano has not altered much since the days of Chopin, 150 years ago.[2]

The history of motion picture film, therefore, is the history of a very subtle industrial and economic combination of continuity, evolution and outright change. The remainder of this chapter will attempt to identify the technological specificities of the earliest and most widely used of all moving image media, and to show how these specificities shaped the industries, institutions and cultures which used it.

Moving images before 1889: establishing the physical properties and performance requirements of motion picture film

There is no such thing as a moving image. No means has ever been devised of continually recording the sequence of changing light over an extended period of time as it is perceived by the human optical and nervous system, and then reproducing it in a way that is perceived identically to the original source. The 'moving image' technologies we have today are all, without exception, based on the discovery during the mid-nineteenth century that a sequence of still images, photographed or created in rapid succession, will, when projected or otherwise mechanically displayed in equally rapid succession, be perceived by the human brain as a continuously moving image. Two processes need to take place in order for this to be achieved. The first is that the camera has to record the sequence of still images, or 'frames', at a fast enough rate that a distinct difference between two individual frames cannot be perceived by the viewer when the sequence is reproduced at a similar speed. The second is that the transition between each photograph in the moving image sequence has to be achieved in a way which is invisible to the viewer, i.e. without a perceptible fluctuation in light level, or 'flicker', when it is reproduced by a displaying device (e.g. a projector or TV monitor). For well over a century both of these processes were thought to have been achieved by a single phenomenon, known as the 'persistence of vision' effect. This held that the human brain continues to 'see' a projected image momentarily even after it has ceased to be projected, thereby enabling a seamless transition from one image to the next to be perceived. But in the second half of the twentieth century researchers identified some serious flaws in this theory. For example why do we perceive motion reproduced by methods which *do not* have a 'black' period between each frame, e.g. an interlaced scanning TV monitor (see chapter 6) or DLP projection (see chapter 8), in the same way as we perceive motion as reproduced by a film projector? One explanation is that of 'visual maksing', a human thought process which 'is said to occur when two visual presentations are made sequentially and one renders the other invisible.'[3] But the bottom line is that we don't know the whole truth of why the illusion of movement is achieved once these two conditions have been fulfilled. For example Stephen Herbert suggests that the periods of darkness in between each frame being displayed by a film projector 'are sufficiently short that they do not register in our brain':[4] yet if that is the case why did early TV engineers have to interlace the scanning sequence in a cathode ray tube display to get rid of the perceived intermittent 'darkness' which resulted from progressive scanning? All we know is that the impression of movement can be created in this way – and has been, on an industrial scale, ever since the discovery was made.

This knowledge was initially exploited several decades before the images could be created photographically in a series of toys which appeared from the mid-1830s onwards. The Phenakistiscope, demonstrated by Joseph Plateau in 1833, was a cardboard disc with sixteen evenly-spaced notches cut out of the edge and sixteen sequential drawings or paintings placed between each notch. The viewer held the painted side of the disc facing a mirror and rotated it while looking through the notches at the reflection. This gave the effect of a moving image. The Zoetrope, described by the Englishman William Horner in 1834 but not built or mass-marketed until the 1860s, consisted of a perforated drum mounted horizontally on a spindle. A paper strip containing a sequence of drawings or paintings was placed around the inner edge of the drum, and by looking through the perforations as the drum was rotated, the appearance of movement could be perceived. It could be argued that the Zoetrope was one of the earliest forms of moving image mass-media: the 'software', in the form of printed paper strips, sold for less than the price of a newspaper and remained popular throughout the late nineteenth century. A whole genre of optical toys based on the idea proliferated during this period, a process which culminated in Émile Reynaud's *Théâtre O ptique* of 1892, which projected a linear sequence of hand-painted lantern slides onto a large screen in front of a theatrical audience. Embodying principles both of the Victorian optical toys and the modern cinema projector, the *Théâtre Optique* consisted of slides mounted horizontally on a linear band, with each joint perforated. The complete sequence of between 500 and 700 images was fed between spools and passed in front of a light source. However, the system of rotating mirrors which enabled the transition from each slide to appear seamless and the mechanical tolerances of the mechanism could not even approach the speed needed to project a perceived moving image to the quality achieved when the first public demonstration of moving image film projection took place a little over three years later.[5]

In the half-century before 1889, therefore, the optical toy industry established that the perception of continuous movement could be induced mechanically. Two other technologies were also developed during this period which, when combined with the illusion of continuous movement, resulted in the film stock first sold by George Eastman in 1889. These were photography and the film base itself (i.e. the physical support on which a photographic image is held).

Photography – the creation of a permanent record of the existence of light in a given place and at a given moment in time – also had its origins in the early nineteenth century. A photographic image is created through the use of substances in which chemical change is induced by exposure to light, and in which that change can be permanently recorded and perceived by the human eye. In order to create a photograph two technologies are needed: the photosensitive medium, and the device used to achieve the exposure, i.e. a camera. The mechanical and optical properties of cameras are discussed at length in chapter two. As far as photographic technology is concerned, this chapter will concentrate on the chemical processes needed to create a photographic image.

Like the mechanical processes which exploited the persistence of vision effect, photochemical technology also has its origins in the nineteenth century. In its crudest form a photographic image is created by exposing a silver-based halide (a compound of halogen with a metal or radical, such as bromide) to light. This causes a chemical reaction to take place which is initially invisible (known as the *latent image*), but which can be made visible and permanent by a two-stage chemical process. This procedure, known as *processing*, consists firstly of *development* – immersing the photochemical substance in a chemical which converts the exposed halide into a pure metallic silver, which is visible. The developed image is then *fixed* by making the undeveloped (i.e. still photosensitive) silver halide soluble in water by sodium thiosulphate and then washing it away. This leaves only the metallic silver dye in place, and this is visible to the naked eye as a black-and-white photograph.

As well as the photochemical layer itself, a surface is needed to support it during exposure, processing and subsequent viewing of the processed image. When referring to motion picture film the flexible, transparent support is known as the *base* whilst the photochemical layer is termed the *emulsion*. The earliest bases, however, were not flexible or transparent, and were quite unsuitable for use in any motion picture process. Experiments took place involving paper, leather, canvas, glass and copper since Thomas Wedgwood saturated a leather canvas with a solution of silver salts in the early 1800s.

The very early photographic emulsions were only used successfully for producing images of silhouettes (for example leaves, which were used in Wedgwood's canvas images) or of existing images on a transparent base such as stained-glass windows. They were unusable for creating photographs of real-life subjects due to their very low *speed*. The speed of a photographic emulsion measures the intensity of light and length of exposure needed to produce the latent image. Nowadays the speed of film is generally specified using the *exposure index* (EI) scale. The film used in 35mm still cameras today usually has an EI rating between 100 and 400. Film rated at EI100, for example, would require an exposure of 1/125 second to photograph a typical street scene in bright sunlight.[6] By comparison, Wedgwood's sensitised canvas would have needed several tens of hours. Given that the perception of continuous movement requires an effective minimum of 16 images per second, it is clear that the creation of moving images photographically was at that stage a long way off. Emulsion speeds gradually improved during the Victorian period as techniques were increased to improve the concentration and grain structure of the silver halide. Two important breakthroughs happened in the 1830s: the discovery by Louis Daguerre that the sensitivity of silver halides could be increased by exposure to iodine, and the announcement in 1839 by Henry Fox-Talbot that he had successfully invented a means of copying photographic images. This would, of course, be of crucial importance to the application of photography for moving images, and for two reasons.

Fig. 1.2 Negetive (above) and positive photographic images

When initially exposed and developed, the silver-based photographic emulsion yields an image which is known as a *negative*. That is to say, the greater the intensity of light in the original subject, the more opaque the developed area of the photographic image is, and vice-versa. The negative photograph thus looks like an inverse of the actual scene in real life. In order to produce a *positive* image – a photograph which actually resembles the original subject – it is necessary to create a *print*. This is done by passing light through the negative image onto a second layer of photosensitive emulsion. When developed, this second photograph yields a negative image of the original negative, thus making a positive print. It is possible to make multiple prints from the same negative, which, when photography began to be used for moving images, was the means by which many hundreds of prints could be made of a single film for distribution to cinemas. The *reversal* process, originally described in 1899 by the Italian chemist Rodolfo Namias,[7] was a process for developing a photographic image directly to a positive which consisted, in effect, of processing the image twice in one procedure. The image is developed in the same way as a negative, after which the converted halides are bleached away leaving the unexposed silver halides to form a positive image of the original negative latent image. This residue is then exposed to light (or treated with a chemical which achieves the same effect) and the second latent image is redeveloped and fixed, thus creating a negative of the negative – in other words, a positive image of the original subject. The reversal process was eventually used in two significant areas of moving image technology: amateur filmmaking, in which the original camera negative could be used for projection, thus avoiding the expense of making additional copies, and films intended for television use, where speed of processing is crucial but the need to make multiple film copies is not.

By the late nineteenth century the sensitivity of photographic emulsions had improved to reduce exposure times to significantly under a second and the techniques for coating them onto various different bases had evolved into an efficient mass-production process. Crucial to the latter was the invention of the gelatine bromide process in 1871.[8] Gelatine is a transparent semi-liquid adhesive derived from albumin. By suspending particles of cadmium bromide and silver nitrate in gelatine, it was found possible to produce an emulsion which was many times faster than any of its predecessors (exposures of 1/1000 second were now possible) and which could easily be coated onto any surface – initially paper and glass plates, but eventually film. Though the gelatine bromide chemistry was originally demonstrated by the British chemist Richard Leach Maddox, a patent for the automated process of coating it onto paper was applied for by George Eastman (the founder of Eastman Kodak) in 1884, and eventually granted in 1890.[9] Eastman photographic paper rolls went on sale to the public in 1885.

By the mid-1880s it was possible to change the perception of continuous movement mechanically and to create photographic images at the quality and frequency needed for use in a moving image device. The only remaining issue was the production of a physical support – the base – that would allow photographs to be exposed and projected as moving images. It was established relatively early on that the most suitable method for passing large numbers of still photographs through a mechanism at high speed was to place them consecutively on a continuous strip of material.

Working from a rented workshop in a suburb of Leeds, the French inventor Louis Augustin Le Prince built a working camera in which paper roll film was exposed and advanced intermittently in 1888.[10] But because paper was opaque it could not be used for projection. Projected still photographs on a glass base were by then an accepted and growing part of magic lantern performances, and the *Théâtre Optique* would later establish the technique of feeding multiple frames through a projection mechanism in roll form. For the new photography/moving image hybrid, projection on a screen before a theatrical audience was the goal, but for that a transparent base was essential. In the (as yet) absence of film, Le Prince attempted to build a projector which advanced individually-mounted glass slides using a mechanism that worked on similar principles to that of a modern Carousel slide projector. It achieved a speed of approximately seven frames per second – less than half the rate that would be needed to display a flicker-free image with fluent motion.[11] Meanwhile the use of paper-base photographic material in optical toys began to be established. In 1876 the Englishman Wordsworth Donisthorpe patented the Kinesigraph,[12] a single-lens camera similar to Le Prince's projector, which exposed glass-plate negatives at eight frames per second. It was used to produce photographic images which were then printed on paper and viewed in a Phenakistiscope.[13] But projected moving images remained stubbornly out of reach.

The research which would eventually lead to the production of a flexible, transparent film base began slightly later than the development of persistence of vision devices and photography. Cellulose nitrate – a liquid formed by dissolving cellulose (a wood derivative) in nitric acid, is believed to have been discovered in Germany around 1845–46.[14] During the following three decades processes were invented for refining this substance into a flexible, transparent solid.[15] The end result was a patent granted to the Eastman Kodak company on 10 December 1889, for transparent sheets of celluloid: 'a mixture of methyl alcohol, camphor, nitrocellulose, amyl acetate and fusel oil, dried on a polished support, then taken off and coated with the photographic emulsion'.[16] It was widely reported that the first cellulose nitrate film supplied for motion picture research was received by William Kennedy Laurie Dickson on 2 September 1889. It would seem that the Edison company (Dickson's employers) was the first to successfully use the new material as a moving image film base, though many of the inventors who had previously worked in the field, including Le Prince and William Friese-Greene, experimented with celluloid but failed, initially, to make it work in a camera or projector.[17] But by 1889 the three essential ingredients of the first mass-produced form of moving image technology were in place: the ability to induce the perception of continuous movement effect mechanically, photographic emulsions which were fast enough to produce the images needed for these devices and a strong, flexible and transparent film base to support them on.

The remainder of this chapter divides the history of photographic film in moving image technology into two sections: the period when cellulose nitrate was used as the principal film base within the moving image industry, which lasted almost exactly the first half of the twentieth century, and the period following its replacement in 1948– 50 by acetate and polyester bases. In doing this I will argue that the use of

nitrate and its eventual obsolescence was a fundamental influence in the industrial evolution of moving image technology in general and of film in particular. The simplicity, reliability and low cost of manufacturing nitrate film coupled with its high tensile strength made it an almost ideal medium for originating, distributing and projecting moving images. Almost, because another characteristic of the medium – its high volatility and inflammability – necessitated extensive health and safety precautions wherever it was used or transported. A further attribute of nitrate is that it is prone to long-term chemical decomposition which, while not an issue when the base was in everyday industrial use, most certainly is an issue for archivists attempting to preserve it decades later, one which is covered in chapter seven. The development and evolution of monochrome (black-and-white), silver-based emulsions will also be considered here alongside film bases, though colour film technologies are covered separately in chapter three.

Film technology during the nitrate period: 1889–1950

In the decade following 1889 film-based moving image technology developed quickly into a mass-medium. Historians have identified a number of economic, cultural and political reasons for the unusually rapid growth in the film industry, from the experiments of a small number of engineers and scientists to the provider of a popular and expanding leisure activity. These were helped and influenced by the evolution of the technology underpinning it – the film itself. The production and exhibition of films was at first very closely linked to that of magic lantern slides. During the mid-Victorian period these had started to be produced photographically as distinct from images drawn or painted onto slides. The glass slides used for the still images in magic lanterns were an ideal base for photographic emulsions for almost thirty years before a flexible equivalent was available for moving image projection, and so the companies and individuals which produced lantern slides were already used to working with one of the key technologies used in moving image film. In fact, many early motion picture projectors were supplied in the form of mechanisms which used the same light source as a magic lantern, thus enabling exhibitors to use both still and moving images interchangeably. The relatively short length of most early films ensured that they could easily be assimilated into the existing leisure industries of the period, notably Music Hall performances and fairground attractions. And the economic climate in which the motion picture pioneers operated, one in which the service sector economy underwent rapid expansion on both sides of the Atlantic, also worked in the new technology's favour.

The characteristics of film itself and the ability of that technology to be adapted for compatibility with existing cultural practices were also important factors in the rapid growth in its use. But initial progress was slow. In the period between 1889 and 1895 the equipment and processes began to be developed which enabled and then extended the activities of moving image photography and film duplication. Among the improvements made during these years were variations to the nitrate base formulation which made it easier to perforate and more resistant to tearing when stressed by sprocket teeth engaging the perforations, a slower emulsion designed specifically for printing and the emergence of methods for cutting and joining together separate pieces of film.[18] But projection remained a problem, and without the means of showing a moving image on a large screen in front of a paying audience, the economic potential of film remained severely limited, not least because it was incompatible with most pre-existing forms of leisure activity. The only commercially marketed means of viewing moving image film between 1889 and 1895 was the Edison Kinetoscope, a device hastily designed by Dickson in 1891 to exploit the Edison company's film, which at that stage represented a major research and development expenditure without any means of exploiting it. The Kinetoscope was a wooden cabinet housing an endless loop of 35mm film transported continuously through a series of rollers under a rotating shutter illuminated by an incandescent filament bulb. A magnifying glass built into the top of the cabinet enabled the viewer to observe, through the shutter, a moving image sequence lasting about twenty seconds. 'Kinetoscope parlours' featuring a number of the coin-operated machines sprung up in New York and America's major cities in the early 1890s, but the Kinetoscope turned out to be a purely transitional form of film exhibition. When the mass-audience problem was finally overcome, which is generally accepted to have happened when Louis and Auguste Lumière demonstrated a working projector in Paris on 28 December 1895, the stage was set for moving image film to become second only to paper as the software medium on which the mass-communication industry was based.

Crucial to the growth of the medium was the means of editing and duplication. Editing, or the technique of cutting lengths of film supplied by manufacturers and joining them together in different configurations after exposure and processing, was possible almost as soon as moving image film started to be used. The method which Dickson recalled using during his early film experiments with Edison involved 'a clamp with steady pins to fit the punch holes, to use in joining the films with a thin paste of the base dissolved in amyl acetate which, I suppose, is still [in 1933] commonly used'.[19] This is now known as cement splicing, and involves the use of a chemical compound which dissolves a thin layer of film base on two facing surfaces, which are then pressed together under considerable pressure to form an adhesive seal. It remained the sole method of joining film until the late 1960s. In fact Dickson's clamp was relatively sophisticated even compared to common practice two decades later: as late as the 1920s, the routine method of producing splices in studios, laboratories and projection rooms was still by hand using a razor blade, without any form of mechanisation.[20] It was not until 1918 that the Bell and Howell company marketed an automatic splicer in which the film perforations were held by registration pins as the emulsion was scraped off, in order to produce a splice of a pre-set width and which was guaranteed not to be visible in projection. The 1918 version was only suitable for use with original camera negatives, as the splices it made were strong enough for printing but not for projection. In 1922 Bell and Howell introduced a modified version suitable for use on release prints.[21] Before the introduction of mechanised splicing, however, film editing was a slow and laborious process. It is interesting to note that genres and individual filmmakers whose work relies on the use of complex editing

techniques, for example the Hollywood continuity system or Soviet montage, did not become firmly established until the mid-1920s, after the widespread introduction of automated splicing. Another labour-saving innovation from Bell and Howell was the introduction of automatic film perforators in 1908; before then stock was generally supplied by the manufacturer unperforated, leaving the customer to perforate the stock for use in the sprockets of a camera, printer and/or projector.[22] Bell and Howell's perforators were subsequently used by Eastman Kodak to perforate their raw stock before coating, thus automating another aspect of the manufacture and use of moving image film. Laboratory technology – the ability to duplicate film, manipulate the visual qualities of the photographic image in the course of so doing and produce large numbers of release prints for showing in cinemas – improved and expanded rapidly in the years following the discovery and early use of nitrate film as a photographic base in 1889. Methods of film printing fall into two categories. In *continuous* printing, the processed original containing the image to be copied and the unexposed film stock which is receiving the copy are transported over a light source at a constant speed. This technique can be further subdivided into continuous contact printing, in which the emulsion surfaces of the source and destination film elements are placed in physical contact with each other as they pass the light source, and continuous optical printing, in which the light source is used to 'project' an image of the moving source film through a lens onto the surface of the receiving film. In *step* printing, each individual frame is held stationary for the duration of an exposure and the film is then advanced intermittently as in a camera or projector. Nowadays both step contact and step optical printing are used, though continuous contact printing was used exclusively in the period between 1889 (the invention of film) and 1895 (the first successful demonstration of an intermittent mechanism). Optical printing was not used on any significant scale until the 1910s, though the early British film pioneer Cecil Hepworth used a modified projector and camera to produce trick special effects around the turn of the century. As optical printing produces a higher contrast, less sharp duplicate than contact printing (because the lens introduces imperfections in the way it refracts the flow of light), it is only used for film duplication which cannot be achieved by contact printing. The three main uses of ~~contact~~ optical printing are enlargement and reduction between gauges (e.g. making a 35mm print from a 16mm negative), copying damaged originals, usually for archival preservation, and introducing special visual effects. During the first two decades in which moving image film was used as a mass-medium there was only one format in widespread use (35mm), and all the film in existence was relatively new and undamaged. Special effects were generally produced in front of the camera rather than by manipulating the image during the process of duplication.

The basic technology needed to carry out continuous and step contact printing was developed in the early 1890s. W. K. L. Dickson designed a continuous printer which he used for striking release prints for the Kinetoscope parlours.[23] Step printing began with the Cinématographe used by the Lumière brothers for their public film show in December 1895. It was in fact an integrated device which performed all three of the mechanical and optical functions needed to use photographic film as a mass-medium: it was a combined camera, printer and projector. Its printing functions were carried out by the same film transport mechanism used for projection, which advanced the film intermittently. Purpose-built step printers started appearing in 1896, and were thereafter the most widely used method of film duplication for the next two decades. The fact that both the source and destination film stocks were held stationary during exposure ensured more accurate registration, thus producing a sharper copy than any of the continuous printers available at the time could achieve: as Barry Salt notes, 'it was realised almost immediately [in 1895] that the only type of mechanism that gave good registration between the positive and negative was that with an intermittent claw pull-down'.[24]

Together with the basic chemistry of black-and-white film processing, the technique of step contact printing represented the effective limit of what could be achieved in a moving image film laboratory until World War One. Film stock and laboratory technology were refined slightly during the 1900s. With the introduction by the French Gaumont company of continuous processing machines in 1907, the first viable alternative was available to the method devised by Dickson in 1899, in which lengths of exposed film were wound on a cylindrical wooden frame which was transferred manually between chemical baths. The Gaumont system, the basic principle of which is used in processing machines today, transported the exposed film stock through a sequence of steel tubes which directed it through immersion in developer and fixer sequentially. In modern processing machines non-abrasive recessed rollers have replaced the tubes in order to minimise the risk of introducing dirt or scratching while the film is being processed, of which a typical unit contains several hundred. In 1911 Bell and Howell introduced a continuous contact printer that offered vastly superior film registration and consistency of exposure than could be obtained from any previous design. Continuous contact printing would eventually become the mainstay of release print production, because it offers the image quality advantage of step contact printing but can run at much higher speeds than a step printer (modern continuous printers are capable of running at speeds up to 1,000 feet per minute). The need to produce many hundreds of release prints of a given title did not become systematic until the vertical integration of the global film industry, which began to take shape in the aftermath of World War One. This economic model, in which the same company owned studios (the means of production), distribution infrastructure and cinemas, required individual films to be shown in vast numbers of cinemas. This in turn necessitated the technology to produce hundreds, and sometimes thousands, of release prints from a single original camera negative. Continuous printing and developing was one of the ways in which this was accomplished, but it was soon found to be impossible to strike more than a few tens of prints by contact printing from a camera negative. An early demonstration of this came with Cecil Hepworth's 1905 film *Rescued by Rover*. This was a five-minute chase narrative in which a baby is kidnapped and then rescued by her family's dog. It proved so popular that the cut and spliced camera negative was, in Hepworth's words, 'worn out' through repeated continuous step printing to the point at which it was no longer possible to strike further prints. Hepworth's solution was simple: he

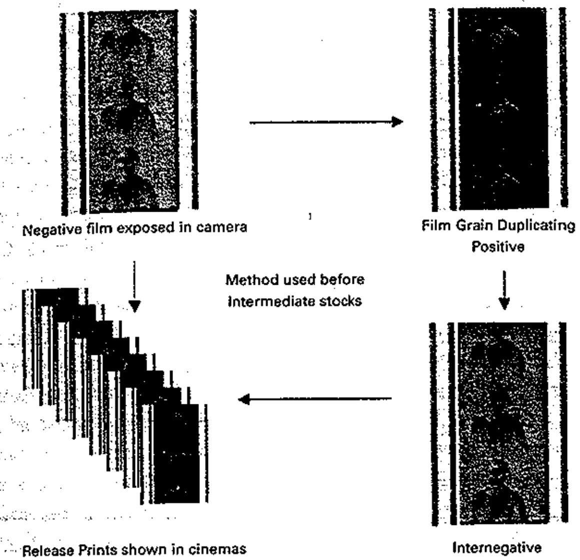


Fig. 1.3 The basic stages in film duplications

reassembled the actors and reshot the film – twice. In the final version, the 'baby' has quite clearly outgrown the pram from which she is kidnapped![25] For the mass copying of films, therefore, Hepworth had discovered that cellulose nitrate would only withstand repeated mechanical pressure up to a given point before perforation damage and contamination of the film surface made it unprintable. The solution was the introduction of intermediate elements.

Like optical printing, widespread use of intermediate elements, or as it was called at the time, 'duplicating stock', did not take place until the 1920s, although it is likely that intermediate printing using standard negative and print stocks took place much earlier for films where large numbers of release prints were required. Separate emulsions intended for negative and positive printing were marketed by Eastman Kodak and the Blair company in the UK from 1895; the positive stocks were extremely fine-grain, low-speed (unlike with camera stocks, speed did not matter in film intended for step printing, which could simply be exposed for as long as was needed) and with a slightly higher contrast and density under uniform exposure than most negative stocks available. This was in order to minimise the duplication of grain from the original. The principle was further improved with the introduction of Eastman Cine-Positive stock in 1916, which with minor modification remained the standard release print stock used by Western film industries for over two decades. Eastman Kodak introduced the first purpose-designed duplicating film in 1926. This was a very slow, fine-grain emulsion which was used to produce a contact duplicate from an original camera negative with very little loss of quality. A further duplicate negative would be made from the fine grain positive (the positive was sometimes called a 'lavender print', due to the blue-tinted base used to reduce contrast), and it was from this second negative that release prints were struck. This method offered several advantages over simply contact-printing release prints straight from the cut camera negative. Firstly, the original camera negative only had to be passed through a printer once in order to yield large numbers of release prints. Secondly, optical effects such as dissolves, fades and superimposition could be introduced by optical printing between the intermediate generations. And when optical sound-on-film started to be introduced in the late 1920s, the soundtracks could be synchronised with the picture during the duplication process.

The other key technological advance in black-and-white photochemistry which took place during the nitrate period was the introduction of panchromatic emulsions. The earliest film emulsions to be used for moving image photography were only sensitive to blue light (orthochromatic emulsions, which were sensitive to both blue and green, were introduced in the mid-1910s). In other words, areas of a photograph which appear red or green to the naked eye (or shades which have a red and/or green component) would not cause any chemical changes to the emulsion during exposure, and thus would not register in the latent image or be visible in the developed photograph. Blue-only and orthochromatic film tends therefore to have a higher contrast and less subtle shades of shadow and contrast than the black-and-white photographic images we are used to nowadays. Two particular problems which cinematographers in the 1900s and 1910s frequently raised were that clouds were usually invisible – skies tended to reproduce as uniform shades of grey – and the hair of blonde actresses appeared a lot darker than in real life. The latter became a particular problem during the early 1920s due to the fashion of using hydrogen peroxide (bleach) to lighten the appearance of women's hair, as the hair of a 'peroxide blonde' film star would frequently turn out to be less than flattering in the final print! The reproduction of light by a blue-only emulsion can be seen to the naked eye by looking through a blue-tinted piece of transparent material, a practice that was frequently used by cinematographers on location.

As is becoming increasingly apparent, a pattern emerges whereby a siginificant technological advance, be it optical printing, continuous developing, or as we shall see in subsequent chapters sound, colour and widescreen, tends to happen in two stages: the research and development which makes the process technically viable, and the changes to economic and industrial practice which enables its widespread commercial use. The introduction of panchromatic emulsions – ones which are uniformly sensitive to the entire red, blue and green areas of the colour spectrum – is another example of this, one which happened gradually over a 15-year time scale. C. A. Kenneth Mees notes that there was 'no great difficulty' in sensitising emulsion panchromatically right from the outset, but that difficulties in its manufacture and use initially inhibited the technology.[26] Unprocessed panchromatic stock has to be handled in total darkness, whereas blue-only and orthochromatic can be handled by cinematographers and laboratory technicians under a red 'safelight' to which the emulsion is insensitive. The earliest known use of panchromatic emulsions for moving image use was by Léon Gaumont in France, in the short-lived additive three-strip 'Chronochrome' colour process (see chapter 3) first marketed in 1908. Eastman Kodak supplied panchromatic film on an experimental basis from 1913, and following the successful production of what is believed to be the first panchromatic feature, the Will Rogers horror spoof *The Headless Horseman* (1922, dir. Edward D. Venturini), introduced it as a regular product the following year.[27]

The widespread introduction of panchromatic film into industry use did not happen for a further five years. The stock itself was much more expensive than orthochromatic and laboratories, which had to process it in total darkness, also charged more. Intermediate and release prints could continue to be made (and black-and-white prints still are made) on blue-only stock, as the image on a panchromatic negative is of course black-and-white (i.e. it does not contain any red or green which a blue-only monochromatic stock could not reproduce) and the light source used in the printer is of a uniform colour temperature, with the only adjustment being to its intensity. The eventual catalyst was the launch of a much cheaper panchromatic stock by Eastman Kodak in 1926, another panchromatic stock by Kodak's main US rival, Du Pont, in 1928, and a systematic, planned change in the lighting technology and practices used by the major Hollywood studios. The method of lighting used in film studios at the time was either carbon-arc or mercury vapour discharge lamps. In carbon-arc lighting, illumination is produced by burning carbon by passing a low-volt-age, high-current electrical signal across a gap between two carbon rods. Carbon-arc illumination was also used extensively in cinema projectors, and as such is discussed further in chapter 5. Mercury vapour discharge lighting ignited a gas to similar effect, and required the use of two highly inflammable substances. Both were especially suited to orthochromatic film, as the colour temperature of the light they produced was concentrated in those areas of the visible spectrum to which orthochromatic emulsions were most sensitive. Exposed under artificial light, however, panchromatic film required a form of illumination that gave a more even output across the entire range of colour temperatures in the visible spectrum to produce an even exposure. The solution came in the form of tungsten incandescent lighting. This consists of a conductive filament encased in an airtight glass bulb filled with a gas (tungsten at first, later halogen) which emits light at a high temperature. A high-voltage, low-current charge is passed through the filament in order to illuminate the gas. The resulting light output was far more even across the visible spectrum than either arc or mercury discharge lighting, and also offered several further advantages. It was powered by a conventional mains supply, whereas arc and discharge lighting needed rectifiers to produce the type of current required. Running costs were cheaper and studios lit by incandescent bulbs needed far fewer technicians to operate them. A series of organised tests took place at the Warner studios early in 1928 in order to determine the incandescent lighting requirements of panchromatic stock, its sensitivity and exposure characteristics and the likely cost implications of a wholesale conversion. It was found that the savings achieved with the new lighting technology more than offset the increased cost of panchromatic film stock, so much so that nine major studios expressed the belief that incandescent lighting had reduced their maintenance and electricity costs by half.[28]

Thus panchromatic film, tungsten lighting and synchronised sound all converged in 1928–32 to become key technologies in studio production practice. By the end of the decade Kodak, Du Pont and the German Aktien-Gelleschaft für Analin Fabrikation (Agfa) company were all marketing panchromatic film, which became the standard for studio and location use. Thereafter orthochromatic emulsions gradually dropped out of use for motion picture imaging. There were few significant developments in nitrate film base and black-and-white emulsions apart from the introduction of stocks intended specifically for optical sound recording (see chapter four) and for Technicolor separations (chapter three), though 1938 saw the introduction by Kodak of a faster camera negative stock. The next major technology which would bring about significant industrial change was the introduction of cellulose triacetate 'safety' film base in 1948.

As has been noted above, one major problem with cellulose nitrate was its inflammability. Once ignited nitrate film burns fiercely, generates highly toxic fumes and cannot be extinguished. This is because the combustion process itself generates oxygen, which makes the process autocatalytic. Even a roll of nitrate film immersed in water will continue to burn, and the only effective safety procedure with a nitrate fire is to contain it and evacuate everyone from the immediate vicinity. This unfortunate property of the film base necessitated elaborate health and safety precautions wherever it was used, ones which had a wide-ranging impact on virtually every aspect of film industry activity during the 1889–1948 period. In the US, a series of highly publicised nitrate fires during the 1900s and 1910s led to the gradual introduction of state legislation which determined the necessary fire precautions in studios, cinemas, labs and distributors' depots (or 'exchanges'). In Britain a similar process took place about five years earlier, although the dangers of nitrate had been well known ever since a fire at a charity bazaar in a temporarily constructed venue in Paris had killed 121 theatre-goers on 4 May 1897.[29] As most early film exhibition took place in music halls, fairgrounds and later in halls hastily converted from other premises such as shops which were known as 'penny gaffs', the projector was usually positioned in the middle of the auditorium rather than in a projection box separated by a partition wall, as it is today. This meant, of course, that if the film did ignite the consequences were likely to be serious. After a number of fires which resulted in deaths and serious injuries, mainly from smoke inhalation, the 1909 Cinematograph Act was passed. It stated that nitrate films could only be shown to the paying public on premises which had been licensed by the local authority as fit for the purpose. One interesting footnote to this legislation is that it established, almost by accident, the legal basis for film censorship in the UK which persists to this day. Though it was primarily intended to protect the public against nitrate fires, the 1909 act did not explicitly limit the grounds for refusing a licence to the sole criterion of health and safety. Councils immediately started imposing other, unrelated conditions on their cinema licences, including restrictions on the content of films that were shown. As a result of hundreds of different authorities making separate censorship decisions, the industry established the British Board of Film Censors (BBFC) in 1912 in an attempt at standardisation, which now effectively makes decisions on the authorities' behalf. Even now the BBFC's classification decisions carry no legal weight in themselves, but are advisory for the local authorities who issue individual licences to cinemas.

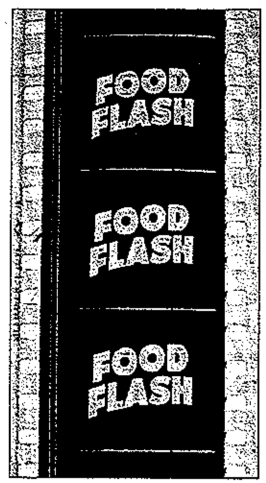


Fig. 1.4 A nitrate release print (in this case from a government propaganda film made during the Second World War). The words 'nitrate film' can be seen in inverse on the left-hand edge, thus identifying the film as inflammable to anyone who is handling it.

However, although these precautions and film-handling techniques gradually reduced and managed the risks posed by nitrate, they never entirely disappeared. Britain's worst film fire (defined as numbers killed) happened as late as 31 December 1929, when 69 people, almost all children, were killed and over 150 injured when a reel of nitrate caught fire during a children's matinee at the Glen Cinema, Paisley, Scotland.[30]

An obvious way of circumventing the need for the costly and restrictive health and safety requirements of nitrate would be to develop a non-inflammable base. As with panchromatic film and so many other moving image technologies, these were actually available decades before their widespread introduction. The reasons why nitrate remained in use for so long will also have a ring of familiarity, too. Early 'safety film', i.e. bases which do not have the uniquely dangerous combustion characteristics of nitrate, took two forms: those in which the nitrate base itself was modified to inhibit its combustibility, and bases in which acetic acid as distinct from nitric acid was used to dissolve the cellulose used to produce an inherently less combustible base material. Of the former category, W. C. Parkin in France developed a method of inhibiting the flammability of nitrate by adding a metallic sodium compound to the base during casting, which he patented in 1904. Various methods were invented along these lines of making nitrate more difficult to ignite, though if it did ignite it burnt just as fiercely as untreated stock. None of these techniques was ever reliable enough to convince any authorities to allow the treated stocks to be used in an unregulated way. The first mass-manufactured cellulose acetate base was marketed by Kodak in 1909, with Agfa following suit in November of that year.[31] It was intended for amateur use in the 28mm format, but there were significant difficulties in using the stock professionally. Early generations of acetate stock were far more fragile and dimensionally unstable than nitrate, because they retained a higher proportion of solvent in the base than nitrate. This tended to evaporate quite quickly in the weeks and months following manufacture, resulting in the base shrinking and becoming brittle. Acetate was more likely to tear and suffer perforation damage in the sprocket teeth of a camera or projector than nitrate, and the base was also a lot more prone to scratching. As with panchromatic emulsions, early acetate bases were also a lot more expensive to manufacture than nitrate and it took several decades for the film stock manufacturers to convince their customers that the additional costs of acetate offset the health and safety costs associated with nitrate. Brian Winston even goes as far as to suggest a conspiracy theory to explain the continued use of nitrate:

> It seems to me reasonable to suggest that the industry basically clung to an extremely dangerous substance long after an alternative was available as much as a protection against competition as an earnest of its commitment to top-quality images. After all, only professionals could handle real films; only professionals could be, quite literally, licensed as projectionists and cinema managers, creating thereby at the most potentially dispersed end of the industry, exhibition, a coherent, identifiable and controllable element. The business protection that this provided was worth the odd projection booth conflagration.[32]

Though elegant, this suggestion fails to account for why safety film was adopted by the industry following the introduction of an acetate base which offered comparable mechanical qualities to nitrate in 1948. On a more general level, the introduction of safety film followed the familiar industry pattern of separating the research and development and economic infrastructure phases of each major technological development.

During the period between 1909 and 1948 acetate bases were used mainly for applications in which nitrate fire precautions were not available. The largest by far was amateur film. George Eastman himself expressed the belief that nitrate should never be used in amateur technologies: on 4 June 1912 he wrote to Edison stating that he would only supply acetate base for use in the latter's 'Home Kinetoscope' projector, as, 'in our opinion, the furnishing of cellulose nitrate for such a purpose would be wholly indefensible and reprehensible'.[33] Thus when Kodak launched the first cameras, projectors and reversal stock in the 16mm format in 1923, the base was exclusively acetate. There were other, limited moving image uses for safety film before 1948. These included short cinema prints (such as advertisements and trailers) which did not need to withstand heavy-duty projection and which, unlike nitrate, could be sent through the normal post; prints for showing in temporary venues which did not have a separate projection room; and negative stocks for cinematography in situations where the risk of a nitrate fire was deemed unacceptable, e.g. medical photography and on board an aircraft. In Britain, prints of politically controversial films made on safety base were sometimes used in attempts to circumvent censorship (the 1909 act only applied to nitrate), and acetate bases were also used extensively for still photography. The mechanical properties of acetate gradually improved during the 1920s and 1930s, culminating with the introduction of cellulose acetate propionate in 1938, which was described as being 'midway between cellulose nitrate and the former acetate' in terms of its strength characteristics.[34] Even as late as World War Two, however, users of safety film still considered its fragility to be a major problem. By this stage 16mm had grown from a home-movie format to a professional medium that was used extensively for location actuality footage where the size and weight

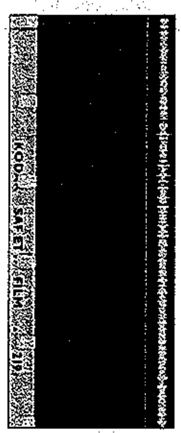
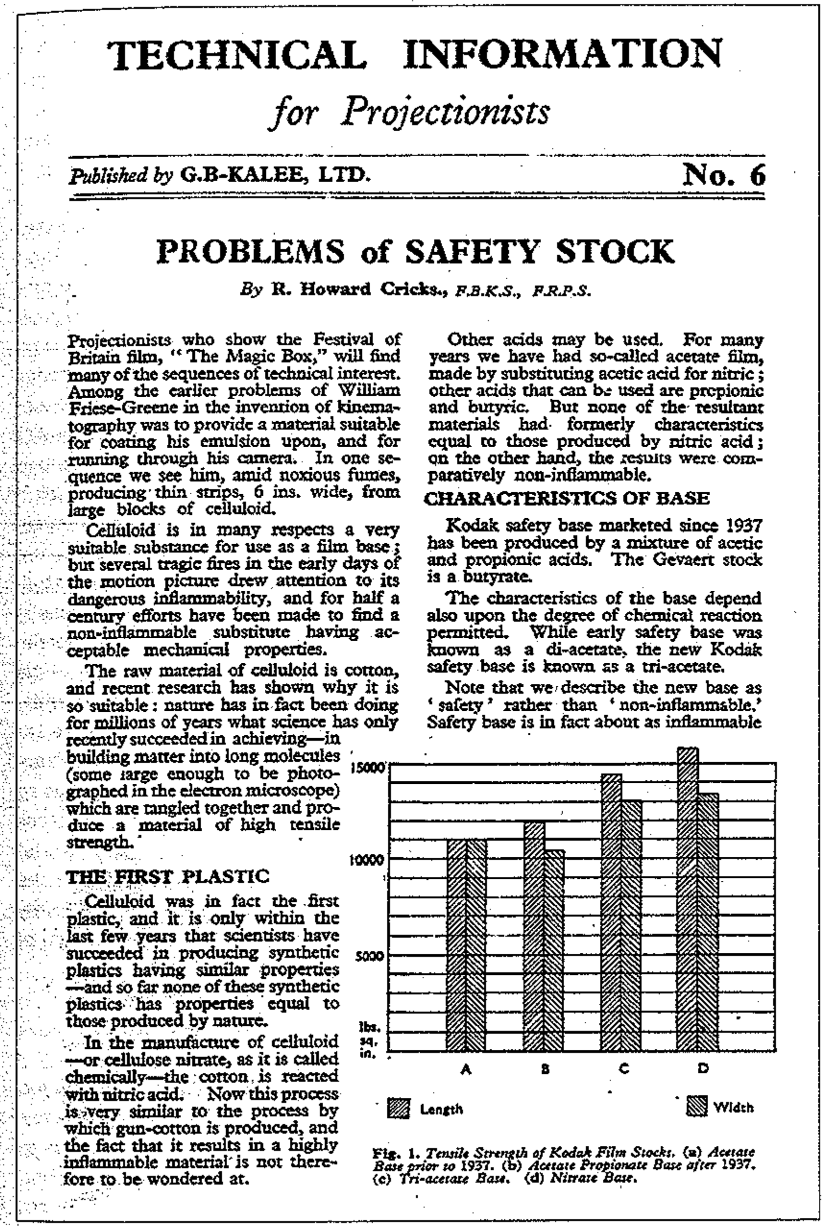


Fig. 1.5 A 16mm triacetate release print. As with the nitrate example shown in 1.4, this element also contains an edge marking, only this time to indicate that it is not nitrate.



TECHNICAL INFORMATION

for Projectionists

Published by G.B-KALEE, LTD. No. 6

PROBLEMS of SAFETY STOCK

By R. Howard Cricks., *F.B.K.S., F.R.P.S.*

Projectionists who show the Festival of Britain film, "The Magic Box," will find many of the sequences of technical interest. Among the earlier problems of William Friese-Greene in the invention of kinematography was to provide a material suitable for coating his emulsion upon, and for running through his camera. In one sequence we see him, amid noxious fumes, producing thin strips, 6 ins. wide, from large blocks of celluloid.

Celluloid is in many respects a very suitable substance for use as a film base; but several tragic fires in the early days of the motion picture drew attention to its dangerous inflammability, and for half a century efforts have been made to find a non-inflammable substitute having acceptable mechanical properties.

The raw material of celluloid is cotton, and recent research has shown why it is so suitable: nature has in fact been doing for millions of years what science has only recently succeeded in achieving—in building matter into long molecules (some large enough to be photographed in the electron microscope) which are tangled together and produce a material of high tensile strength.

THE FIRST PLASTIC

Celluloid was in fact the first plastic, and it is only within the last few years that scientists have succeeded in producing synthetic plastics having similar properties—and so far none of these synthetic plastics has properties equal to those produced by nature.

In the manufacture of celluloid—or cellulose nitrate, as it is called chemically—the cotton is reacted with nitric acid. Now this process is very similar to the process by which gun-cotton is produced, and the fact that it results in a highly inflammable material is not therefore to be wondered at.

Other acids may be used. For many years we have had so-called acetate film, made by substituting acetic acid for nitric; other acids that can be used are propionic and butyric. But none of the resultant materials had formerly characteristics equal to those produced by nitric acid; on the other hand, the results were comparatively non-inflammable.

CHARACTERISTICS OF BASE

Kodak safety base marketed since 1937 has been produced by a mixture of acetic and propionic acids. The Gevaert stock is a butyrate.

The characteristics of the base depend also upon the degree of chemical reaction permitted. While early safety base was known as a di-acetate, the new Kodak safety base is known as a tri-acetate.

Note that we describe the new base as 'safety' rather than 'non-inflammable.' Safety base is in fact about as inflammable

Fig. 1. *Tensile Strength of Kodak Film Stocks.* (a) *Acetate Base prior to* 1937. (b) *Acetate Propionate Base after* 1937. (c) *Tri-acetate Base.* (d) *Nitrate Base.*

Fig. 1.6 Technical information leaflet issued to projectionists in 1951. It warned cinema staff not to relax the health and safety precautions associated with nitrate while any of this highly inflammable film base remained in circulation.

of 35mm equipment was prohibitive, and there were frequent complaints about the unreliability of the exclusively acetate 16mm stock. Writing in April 1945, an armed forces cameraman argued that 'professionals have long been hampered by the shortcomings of this slow-burning base', noting shrinking, brittleness, jamming in camera mechanisms and extreme sensitivity to temperature and humidity extremes among the problems. 'There is only one possible solution', he believed, 'and that is the use of nitrate base.'[35]

The eventual catalyst for a wholesale conversion came when Kodak announced at the 1948 SMPE conference on 17 May 1948 that it had developed a new 'high acetyl' cellulose triacetate base which was significantly stronger than acetate propionate and almost as strong as nitrate. There is evidence to suggest that the new base was at least in part the result of work done on equipment and research findings captured from the Agfa laboratories in Germany and Czechoslovakia following the fall of the Nazi regime in 1945, because immediately before Kodak announced their two-year research programme which led to the launch of 'high acetyl' triacetate the US authorities had systematically blocked the British government's attempt to remove film base casting plant from Germany, apparently at the behest of Eastman Kodak.[36] The Nazi film industry certainly used acetate base 35mm stock far more extensively than was the case in Allied countries towards the end of the war, due mainly to the difficulties of transporting nitrate using a road and railway system under constant Allied attack, and also to facilitate the large number of screenings for armed forces in temporary locations that were ordered by the Propaganda Ministry to boost morale. Kodak started manufacturing the new acetate base in place of nitrate negative in the autumn of 1948 and ceased manufacturing nitrate in February 1950. Du Pont continued to produce nitrate for a further year and small quantities of nitrate remained in circulation for several years afterwards. Outside the West the production of nitrate went on a lot longer: the Soviets and Chinese are believed to have continued using it (including 16mm nitrate) until well into the 1960s, while Japan's main film stock manufacturer, Fuji, did not cease producing nitrate until 1958.[37] The relaxation of nitrate health and safety precautions was not as straightforward as some in the industry had hoped, and the exhibition sector in particular had to maintain fire safety equipment on cinemas long after nitrate film ceased being produced on account of back catalogue titles which remained in circulation.

Film technology in the safety period: 1948–2000

The main developments in film base technology during this period were gradual refinements of the triacetate base to improve mechanical strength and stability, and the introduction of polyester base stock. Polyester – polyethylene teraphalate – is an inorganic polymer, which, unlike all cellulose film bases, is not liable to dimensional change according to its varying moisture content. It is also far stronger then any other material used to produce film base and will not break, even under extreme pressure. The first polyester base was announced by Du Pont under the trade name Mylar in 1955,[38] though, as with acetate, it was not used on any significant scale

as a base for moving image products for over three decades afterwards. Polyester offered significant advantages over nitrate and acetate: like acetate it was no more inflammable than paper, it had a far higher tensile strength and the surface was less prone to scratching. There were also two significant disadvantages. The strength of the new stock turned out to be as much of a curse as a blessing, since the fact that polyester is significantly thinner than acetate and prone to holding a static charge led to instances of it jamming in the mechanisms of cameras, printers and projectors. Whereas acetate film would simply break in these circumstances, the pressure on a jammed section of polyester can be transmitted to components in the film path and cause serious damage to equipment. Polyester also cannot be joined using cement (which works by breaking down the organic solvents used in nitrate and acetate), and can only be spliced using adhesive tape or ultrasonically. Heat-resistant adhesive tape, which is usually applied using a small machine that automatically cuts and perforates it during application, is used mainly on release prints in cinemas, where the momentary appearance of the tape splice on the screen is not considered a major issue. This is not considered suitable for use in production and post-produc-tion, where film is joined using an ultrasonic splicer, a device which softens the base by applying localised, intense heat and then fusing the two surfaces by means of ultrasonic energy. Ultrasonic splicers are a lot more expensive than tape or cement splicers, which is why they are usually only found in laboratories, archives or in the post-production departments of major studios.

Again, as with acetate, the amateur film market was used as a test-bed for the introduction of polyester. The earliest widespread use of polyester base stock was probably in a variant of the Super 8 home movie format (see chapter 2) which was known as Single 8 and marketed by Fuji from the late 1960s. Additional tensile strength was deemed necessary because the film was supplied in the form of self-loading cartridges (to make it easier for amateur filmmakers to load and unload film stock), which increased the mechanical stresses of film transport. Furthermore the perforations were extremely small, and thus needed extra strength and dimensional stability to withstand repeated engagement by the sprocket teeth of a projector. It was anticipated that, being an amateur medium, most consumers would be unlikely to want to edit their footage, whereas the added resistance of polyester to dirt and scratching would prove a major selling point for a medium that was likely to be subjected to repeated projection by untrained amateurs. Following these initial trials, polyester was also used in the Super 8 and 16mm prints of feature films shown on airliners, the rationale being similar (ability to withstand repeated handling by untrained operators). Polyester did not come into mainstream use for cinema exhibition until the 1990s. Apart from these applications its only widespread uses before that point were for X-ray plates and document microfilming. A survey of US cinema operators sponsored by Agfa-Gevaert in 1979 revealed widespread objection to its introduction as a release print medium, and that fear of equipment damage was 'the main source of resistance to polyester'.[39] During the mid- to late 1980s Agfa began an aggressive marketing campaign for its 35mm polyester release print stocks. In 1992 the National Association of Theatre Owners' (NATO) technology committee recommended that release prints be made on polyester film, in response to which Kodak announced on 9 May 1996 that it was investing $200 million in a new polyester film manufacturing plant at its New York headquarters.[40] This marked the start of the post-production and exhibition sector's conversion to polyester: in 1998 the new facility came on-stream and started producing the new Kodak 'Vision' print film (using the trade name 'Estar' to describe the base), type 2383. By 2000 almost all intermediate elements and release prints were being made on polyester. Camera stocks remain on triacetate, however, due to the potential for costly damage and lost production time (for example, if only one camera is available at a remote location) in the event of a polyester film jam.

The Eastman Kodak company has been cited extensively throughout this chapter. George Eastman was almost certainly the first to sell flexible, transparent film base sensitised with photographic emulsion for moving image use, and the company he founded has maintained the world's largest market share in this product throughout the history of its use covered by this book. By 1992 it was estimated that Kodak accounted for 75 per cent of film stock sales in the US domestic market.[41] Other significant film base manufacturers include the US chemical giant Du Pont, founded by the French scientist Eleuthère Iréneé du Pont in 1802 to manufacture gunpowder. In February 1925 it started producing nitrate film base at a factory in Parlin, New Jersey, and quickly established itself as the second largest supplier of stock in the US. In the 1950s Du Pont turned its attention to polyester film bases and became the market leader in this sector until Kodak's entry in the 1990s.

In the UK the firm of Ilford Ltd. (named after the east London suburb in which its main factory was located), was founded by Alfred Hugh Harman in 1879 and originally manufactured dry plates for still photography. Following the acquisition of a smaller company which operated a cellulose casting plant in 1895 it began manufacturing film, and sold its first length of 35mm for moving image use – 291 feet – to Birt Acres in the following year. Production-line manufacturing of 35mm negative and release print stock began in 1912 under the trade name 'Selo', but temporarily stopped during World War One because the operation was being run by two German expatriate engineers who were taken prisoners of war. Film manufacture at Ilford recommenced in 1920, but in 1923 the company abandoned its base-casting operation and thereafter imported 'raw' (i.e. unsensitised) cellulose nitrate base from the US. During the 1930s Ilford invested in the Dufaycolor additive process (see chapter three), which became one of the UK's leading colour film stocks for amateur use until 1951, and in 1943 launched the product for which it was best known in the post-war years: the HP3 moving image negative stock. This had a speed equivalent to EI250 in today's terms, which made it one of the fastest black-and-white stocks available and had a significant impact on newsreel and documentary production.[42] Ilford gradually concentrated more on the still photography market during the second half of the twentieth century, and in 2004 became the first major film manufacturer to go bust. The company went into receivership on 24 August, blaming the growth of digital imaging for an unsustainable decline in sales of film stock.

In Europe the pioneering firms of Pathé and Gaumont phased out their film stock manufacturing operations as other sources emerged during the 1900s and 10s, notably imported stock from Kodak in the US. The Gevaert Company in Belgium and Agfa in Germany (which had began production of nitrate in 1913) emerged during the 1920s as the major European suppliers. An Agfa factory at Wolfen in East Germany was taken over by the Soviets at the end of World War Two, and after two decades producing film stock under the name of VEB Filmfabrik AGFA, was renamed under East German ownership as OrWo (Original Wolfen) in 1964. OrWo became one of the main suppliers of black-and-white stock to the Soviet Union and Eastern Bloc countries until the collapse of communism. Due to the low cost of OrWo stock compared to Western equivalents, its output has traditionally sold well in India and elsewhere in Asia, and continues to do so under private ownership since 1998. In Japan, the Fuji company was founded in 1934 sensitising imported film base, but became the first Asian manufacturer of raw stock in 1936 and has been the main supplier to the Japanese market ever since. It started selling colour negative and print stock in the US in 1973, and since then Fuji's products have sold to a small but consistent niche market in the West.

Film technology in the digital period: 1992–2005 and beyond

Without doubt, film has proven to be the longest-lasting and most adaptable of any medium yet devised for storing and reproducing a series of photographs as a moving image sequence. The example of format obsolescence given at the start of this chapter describes the opposite extreme: an electronic medium consisting of a complex and unique combination of hardware and software, which became obsolete within 15 years of going on the market. Despite ever-increasing speculation that film will imminently be succeeded by computer-based alternatives it is still, at the start of the twenty-first century, the carrier used almost exclusively for projection in cinemas and for the production of feature films intended primarily for exhibition in cinemas. Furthermore it is still used extensively in television production. Digital processes have started to make inroads in the areas of intermediate duplication and special effects, but for the vast majority of theatrical features, initial cinematography and final output is still accomplished using a medium based on the three areas of technical knowledge which were converged by W. K. L. Dickson in 1889.

The key reason film has survived so long lies in the interface between the software and hardware used to create and reproduce film-based moving images. The essential functions of a camera, printer and projector remain unchanged from those of the 1890s. The optical precision of photographic lenses available has been developed and improved, as has the accuracy of film transport mechanisms and the mechanical stress exerted on the film in motion. The designs of shutters have improved to maximise the amount of light exposure during photography and projection, as has the quality and versatility of the film duplication process. But the essential mechanical properties and functions of film-based equipment have not; leaving aside the issues of nitrate inflammability (see above) and chemical decomposition (which will be discussed in chapter eight), unexposed film stock produced by the Lumières could be used in a modern 35mm studio camera and a finished Lumière film could easily be shown using the projector in a modern multiplex with only minor modifications. But that is not to say that the capabilities of film imaging have not changed, or as the advocates of digital imaging would argue, that we remain stuck in a time warp, saddled by the constraints of what is essentially a Victorian technology. The wheel is a stone-age technology, but it continues to be used extensively in the twenty-first century, because with minor modifications and additions to the basic principle (such as the addition of pneumatic tyres) it can easily be adapted for use in modern vehicles which are reliable, simple, cheap to maintain and easy to operate. The airship, on the other hand, was abandoned after barely thirty years as a form of public transport. This was because it was quickly discovered that airships could only fly in almost perfect weather, were very slow, depended on complex and unreliable control systems, needed almost as many highly-paid crew members as they could carry passengers and had an unfortunate habit of crashing and blowing up.

The same analogy can be used to compare film to the computer-based alternatives which are vying to replace it. The optical and mechanical devices that record on and reproduce from film are simple, effective, reliable and, to their users, a long-term capital investment. The research and development which led to improved image quality, versatility and economy of use are delivered through the medium itself – the film base and emulsion. A Lumière film and a modern Hollywood blockbuster can both be shown using the same projector, but that does not mean that the picture quality of the latter will be no better than the former. The polyester film base used in 2005 is still compatible with equipment made during the nitrate period, and even with such equipment will deliver a more stable picture, is less susceptible to visual defects such as dirt and scratching, is less likely to break and will withstand more intensive use than either acetate or nitrate. The emulsion in a 2005 release print will yield a finer grain structure, be more uniformly sensitised across the visible light spectrum and will enable much larger pictures to be projected from it, while its equivalent camera and duplicating stocks will be faster and able to withstand more printing across a greater number of generations than its predecessors. Successive generations of film technology have had inherent defects: the extreme flammability of nitrate, the fragility of acetate and the tensile strength of polyester risking equipment damage are but three examples. But the industry has consistently found that the cost of managing the use of film in order to minimise the impact of these defects has been more than offset by the long-term reliability and versatility of the medium, and improvements which address specific defects are introduced as and when it is economically viable to do so. This is not always at the point of invention, as the conversion from nitrate to acetate base illustrates.

This unique combination of the highest-quality, most reliable moving image medium yet invented and the fact that so much of the technological advance is delivered through the software rather than the hardware has also meant that film is, by a long way, the most expensive moving image medium yet invented. But the up-front costs of film stock and processing have proven to be small for those who

require a high-quality, long-lasting carrier, in comparison to the equipment costs and rapid obsolescence of any of the alternatives. I have thus far been using the adjective 'digital' quite indiscriminately, and will seek to define its application to moving image technology more precisely in chapter eight. Since the launch by Sony of the first mass-marketed digital video format (i.e. a system which represents televisual images as digital data stored on magnetic tape), Digital Betacam, in 1992, speculation has been rife that 'digital' will signal the end of film. All digital imaging (and sound recording) uses computer technology to translate images which are visible to the naked eye into digital data and back again; therefore, the definition and quality of moving images produced digitally is essentially a function of the speed at which a computer can carry out this processing function relative to the volume of data it can store. The speed with which computers can crunch numbers and the volume of numbers they can store and manipulate is, and throughout the history of computer technology always has been, constantly expanding. Applying this principle to moving images, this means that a personal computer bought this year is capable of reproducing a sharper and more detailed moving image than one bought last year, just as a modern camera negative stock improves on the emulsion formulation it replaced. But a new generation of film stock can deliver improved performance when exposed in the same camera as its predecessor. A new PC is just that – a whole new computer, which requires the user to write off the capital investment in its predecessor. The guts of digital imaging lie in its hardware, whereas with film the technology is contained within the medium itself. £300 for a ten-minute roll of unexposed film stock (which can be expected to last for hundreds of years after processing when stored in appropriate conditions) might seem expensive compared to £30 for a one-hour broadcast standard videotape (which will probably be unplayable within two decades), but when the machine needed to record on and play the tape costs £40,000 and has a useful working life of three years, it becomes clear that the economies of scale with film are fundamentally different. A studio camera or cinema projector costs a similar amount and will last for decades, needing only minimal maintenance. Furthermore as film is an analogue, human-readable format there is little danger of it becoming obsolete as the Domesday Disc did. A producer making a substantial investment in originating a theatrical feature or major television programme on film can be reasonably confident that he will still have access to the footage in years to come. Like our airship, the hardware needed to read digital data from a magnetic or optical carrier is mechanically and electronically complex and intricate, is specific to an individual format, requires additional, specific hardware and software to drive it and most data storage formats become obsolete in less than a decade.

In 2000 computer technology was just about fast enough to enable the capture, manipulation and output of moving image content to a definition approaching that of lower-resolution film stocks. By 'just about', I mean that these functions represented the absolute limit of what the technology was capable of delivering, and that using it was hugely expensive because the commercial costs of this technology reflected the desire of the companies which produced it to recoup the enormous research and development costs. At the time of writing, digital video photography is used extensively for television, but in the cinema industry its use is confined mainly to the processing of special effects. It may well be that as processor speeds increase and the capital costs of film reduce, digital imaging technologies will become more cost effective overall than film. But even that cautious speculation also assumes that film technology will cease to improve (whereas in fact new generations of film stock have consistently outperformed their video and digital imaging equivalents in image quality, versatility, compatibility and longevity), and that sectors of the industry which currently operate on low capital equipment and high media costs (most notably cinema exhibition) will be able to find substantial additional funding to finance the conversion. It is likely, therefore, that film will continue to play a key role in the development and use of moving image technologies well into the twenty-first century.

chapter two | cinematography and film formats

Cinematography

'You know what wouldn't be bad? Ghosts. They come through the screen, fly over the heads of the audience ... ghosts that drip blood. I can see it all now: Bloodoscope ... Bleedorama!' – John Goodman in *Matinee* (1993, dir. Joe Dante)

Chapter one examined how the physical and chemical properties of the world's earliest and longest-lived moving image medium – photographic film – shaped the growth of an industry and culture which evolved around it. This chapter will expand on that overview to explore two specific areas of technology which are needed to produce moving image content on film. Cinematography, which can broadly be defined as the technology needed to expose photographic images (or 'frames') onto film which are intended to be reproduced as a moving image sequence, consists primarily of the cameras themselves and the peripheral technologies designed to facilitate their use (such as studio lighting). Film formats relate to the practice of standardisation, one which has proved to be a crucially important reason why film became the longest-lived and most successful moving image medium. When Henry Ford famously declared that he would supply the Model 'T' 'in any colour, as long as it's black', he was pointing out that the private car could only be successful as a mass-produced consumer product if the cost of producing it was kept as low as possible relative to the disposable income of Ford's intended customers. The only way to achieve that was to develop a single design which could be manufactured many times over on a production line.

By the same logic, when a chief projectionist I once worked for expressed his complete disinterest in any of the cultural or artistic issues related to the films he was showing by declaring that 'as far as I'm concerned, it's this wide [holding up his right thumb and forefinger roughly 35 millimetres apart] and it goes through a projector', he unwittingly identified the key aspect of film technology which has made it so successful. The film he was referring to is 35 millimetres wide, has four evenly-spaced perforations alongside each frame and the dimensions and position