chapter three | colour

'I wonder if he'd like to have me bring my magic lantern over some evening?' Alexandra turned her face toward him. 'Oh, Carl! Have you got it?' 'Yes. It's back there in the straw. Didn't you notice the box I was carrying? I tried it all morning in the drug-store cellar, and it worked ever so well, makes fine big pictures.' 'What are they about?' 'Oh, hunting pictures in Germany, and Robinson Crusoe and funny pictures about cannibals. I'm going to paint some slides for it on glass, out of the Hans Andersen book.' Alexandra seemed actually cheered. There is often a good deal left of the child in people who have to grow up too soon. 'Do bring it over, Carl. I can hardly wait to see it, and I'm sure it will please Father. Are the pictures colored? Then I know he'll like them.' – Willa Cather, *O Pioneers!*

A processed photographic image in its most basic form consists of an emulsion formed of pure metallic silver of varying density. This is often referred to – incorrectly – as 'black-and-white'. The correct term for such an image is 'monochrome' (from the Greek: 'mono' – one, 'chrome' – colour). The metallic silver appears to the human eye as a single colour, but its shade, or intensity, varies according to the volume of the chemical present on a given surface area of the film. In an analogue photographic image the number of shades is theoretically infinite, so perhaps a more accurate term for such an image would be 'black *to* white'. In the digitally processed image opposite, there are 256 shades of the printing ink used to produce this book between the darkest and the lightest. A genuinely black-and-white image is comprised of only two shades: either you see the colour of this paper with ink on it (black) or without (white). The photographic and moving image research scientists of the nineteenth century had, by 1889, arrived at a combination of technologies which enabled the recording and reproduction of (seemingly) moving images using one colour. It was not long before they started work on adding the rest of them.

Fig. 3.1 A genuinely black-and-white (top) and monochrome (bottom) photographic image (showing a reel of 35mm monochrome release print stock).

From 1889 until the introduction of optical sound in the early 1930s, moving image film reproducing more than one colour did so in one of two ways, which I will classify as artificial colour and photographic colour. Artificial colour refers to processes which introduced coloured dye to the film independently of the recorded monochrome image, while photographic colour systems attempt to record a greater range of the visible colour spectrum than is possible with silver halide alone at the point of photography, and then to reproduce that recording accurately in projection.

Artificial colour (1889–c.1930)

The earliest form of artificial colour was the method Carl intended using for his lantern slides – hand colouring. Carl's slides were not, of course, photographic: they were images produced by making a small oil or watercolour painting on a transparent base (i.e. glass) which was then displayed by projection. Needless to say hand colouring of 35mm moving image film was a far more difficult and time-consuming process. Not only were the frames a lot smaller than in opaque-base paintings or even lantern slides, but the volume of images was far greater: approximately 960 per minute of screen time. During the nineteenth century the pioneers of still photography had identified a number of chemical compounds which could be used to dye the metallic silver emulsion, such as hydrogen sulphide for brown or copper ferrocyanide for red. They were applied to nitrate film by being mixed with alcohol and then placed on the emulsion surface with a very small brush. The dye was absorbed by the gelatine layer which binds the emulsion to the base, and after the alcohol had evaporated the gelatine was dyed. Colours were applied as the film passed a bench-mounted machine similar to the gate assembly in a camera or projector which was lit from below and in which each frame was held stationary while being painted.

Brian Coe cites the earliest instance of a hand-coloured film being publicly shown in the UK as that of an 'Eastern dance' by R. W. Paul at the Alhambra Theatre (later the Odeon Leicester Square) in London on 8 April 1896,[1] and it seems that by the turn of the century the technique was in regular, though limited, use. The longest surviving films to be hand coloured were made by the fantasy director Georges Méliès; by 1899 he was selling 'some' release prints of fictional narrative films up to 10 minutes in length with hand colouring.[2] Hand-coloured prints of two of his best-known productions, the science fiction drama *Le Voyage dans la lune* (*The Journey to the Moon*, 1902) and the sci-fi spoof *Le Voyage à travers l'impossible* (*The Voyage Across the Impossible*, 1904), in which explorers from the 'Institute for Incoherent Geography' travel to the sun by train, survive in the UK's National Film and Television Archive and have been preserved on modern colour negative stock. They reveal an astonishing accuracy of colour registration between the different parts of the image, given that the original element would have been coloured by individually painting onto almost 10,000 separate images, each of which was about the size of a postage stamp. By the middle of the 1900s it became apparent that hand colouring was just too labour intensive to be economically viable for significant numbers of release prints, and ways were introduced of automating the process.

But that was not quite the end of this technology. In the 1930s the avant-garde animator Len Lye revived it for some sequences in a series of short films commissioned to advertise the Post Office: *A Colour Box* (1935), *Trade Tattoo* (1936) and *Rainbow Dance* (1936). *A Colour Box* was an experimental film intended to highlight and distort the effect of the 'induction of continuous movement phenomenon' as described in chapter one. No camera at all was used to create the film, which was made entirely by painting directly on to strips of unsensitised, raw film stock. The abstract painted shapes in some sections disregarded the positioning of frame lines, and so a continuous, flowing shape on the film itself appears in projection as disjointed, four-perf sections. These scenes were intercut with repeated drawings occupying four-perf sections, thus creating the familiar image of movement. Lye explored these ideas further in *Trade Tattoo* and *Rainbow Dance*, superimposing hand painting on live photography, just as Méliès and the early colourists had done. These films were duplicated and distributed using photographic colour systems (Dufaycolor, Technicolor and Gasparcolor respectively) which had become available during the intervening three decades and which are discussed below. Lye's ideas were adopted on a limited scale by other experimental animators, most famously by the Canadian Norman McLaren, whose short *Begone Dull Care* (1949) set hand-painted animation to jazz music and in doing so launched the career of the pianist Oscar Peterson, and by the American avant-garde pioneer Stan Brakhage.

Reverting to the mid-1900s, Méliès and his colleagues quickly discovered that hand-coloured films were enormously popular with audiences. But as the nascent film industry grew to require ever larger quantities of release prints for each title, the labour-intensivity of this process quickly made it impossible in its original form: Barry Salt suggests that a hand-coloured release print would cost an exhibitor 'three or four times' a monochrome one (this being before the days of distributors when prints were purchased outright by exhibitors).[3] In 1905 the Pathé company devised a means of mechanising it. Branded as Pathécolor this system originally involved cutting stencils from a release print by hand, but in 1907 was modified by the introduction of a device which involved back-projecting each frame onto a screen approximately the size of a modern portable television set. The colourist traced the outline of the area of the frame to receive the colour dye using a pointer, which was linked by a pantograph mechanism to a stylus which cut away the corresponding area on a frame of raw film stock. The process was repeated for each frame and the resulting reel of cut film became a stencil. Separate stencils were produced for each colour to be used in dyeing the release print. To dye the film itself, a machine was used which laid a stencil on top of a release print and applied a dye to the surface. The dye passed through those areas of the stencil which had been cut away, thus dyeing the print itself in the areas selected by the colourist. The print was then rewound and the process repeated with the next stencil and colour dye. The dyeing process could be repeated for as many prints as were required, effectively meaning that the hand colouring only had to be done once. As Roderick T. Ryan has noted, the principle behind this system was very similar to the dye transfer process developed by Technicolor (see below), the crucial difference being that the Technicolor dye process was intended to reproduce colour which had been recorded photographically rather than added later.[4] Nevertheless, stencil colouring remained a labour-intensive process requiring highly skilled colourists: a manual from 1915 estimated that a typical Pathécolor colourist was capable of cutting three feet of stencil (or 48 frames) per hour.[5]

Pathécolor and variants thereof were used on a limited scale until the mid-1930s. In 1916 Max Handschiegl devised a means of mechanising the application of each colour dye and increasing the accuracy of registration, and his system was used by a number of Hollywood studios for high-budget features during the late 1910s and 1920s. However, in the last analysis, stencil colouring was also too time-consuming and expensive to be a viable means of adding colour to feaure-length narrative films. In the early to mid-1910s feature films of several reels duration started to be shown, notably *Cabiria* (1914, dir. Giovanni Pastrone) and *The Birth of a Nation* (1915, dir. D. W. Griffith), the first European and American features to significantly exceed 10,000 feet in length respectively. At the rate of three feet per colour per hour, these features would literally have required several man-years to prepare a full set of Pathécolor stencils (assuming the average of three to six colours). A very small number of prestige, highly-budgeted feature-length films were coloured in this way, for which artificial, individual colouring systems were used during the 1920s. But this approach was clearly no longer viable for the mainstream, given the industrial-scale production of feature-length release prints which was now taking place. By the end of the 1910s there were still no photographic colour systems available which matched even the aesthetic impression of reality achieved by artificial, individual colouring systems at the time. Another means of artificial colouring was needed which was quicker and cheaper. The 1910s and 1920s, therefore, became the decade of tinting and toning.

In terms of the image on the screen, it would be fair to say that tinting and toning was actually a step backwards from Pathécolor or Handschiegl. Unlike these systems a maximum of two colours could be applied to each frame, and furthermore there was no way of applying the dye to selected areas of the film – the whole surface had to be dyed uniformly. *Tinting* is the application of a layer of dye that is absorbed by the gelatine 'subbing layer' which binds the emulsion to the base, resulting in the light or clear areas of the picture taking on the colour of the tinting dye. Examples include Amaranth for red, Quinoline for yellow and Naphthol for blue. *Toning* is the application of a dye that reacts with the metallic silver which forms the emulsion, resulting in dark or opaque areas of the picture taking on the colour of the toning dye. Examples include Prussian Blue, Chrysoidine for brown, Safranine for red and even Uranium Sulphate for brown! Put in crude terms, toning colours the black and tinting the white. A combination of two colours could be used for the tint and tone (such as Prussian Blue and Croceine Scarlet for a red tint with blue tone), and in some rare cases stencil colouring was also applied to a print after tinting and/or toning.

Because toning dyed the developed silver image, it could only be done to a release print after processing. Tinting, however, was carried out in one of two ways. Tints could also be applied after processing in the same way as tones, which was done in a laboratory by simply winding reels of processed release print through a set of rollers immersed in a bath containing the dye. Because the gelatine layer which receives the tinting dye does not undergo chemical change during processing, release print stock could also be tinted *before* exposure. The first reels of pre-tinted stock were sold by the Belgian Gevaert company in 1912, and within a few years they were marketed by all the major film manufacturers. According to Ryan, by the early 1920s pre-tinted film accounted for 80–90 per cent of commercial release printing.[6] In 1921 the range of pre-tinted stocks sold by Eastman Kodak included red, green, blue, light amber, dark amber, pink, yellow and orange.[7] In order to colour different scenes using different dyes, the negative being used to strike the release print (which, until the use of intermediate elements became widespread in the late 1920s, was usually the cut camera negative) would be made up into reels of sections, not necessarily in their order of appearance in the finished film, but with each reel of negative to be either tinted and/or toned with the same dye or printed onto the same colour of pre-tinted stock. Each section was identified with a reference number identifying its place in the finished film. After processing, the sections of coloured positive were cut together in order of their reference numbers and intertitles added to form each complete print. By today's standards this method was also very labour-intensive, though nowhere near as much as with stencil colouring.

The practice of tinting and toning came to an abrupt and almost total end with the introduction of sound in 1926–32. This was because the optical, or photographic recording and reproduction of a soundtrack depended on a consistent amount of light illuminating the photoelectric cell which 'read' the soundtrack in a projector for accurate modulation. As the presence of a uniformly applied colour dye which changed from scene to scene varied the density of the emulsion, it affected the signal level being fed to a cinema's amplifiers, and thus the volume of the sound being played in the auditorium. To address this issue Eastman Kodak introduced a range of stock which was pre-tinted in the picture area but not the soundtrack, known as 'Sonochrome': however, it was considerably more expensive, the dyes had a habit of leaking and it was only ever purchased in small quantities. A few sound feaures were nevertheless released (either in their entirety or with selected sequences) on Sonochrome print stock, or in a combination of Sonochrome and two-colour Technicolor scenes, *Hell's Angels* (US 1930, dir. Howard Hughes) being a notable example. Pre-tinted stock continued to be sold during the 1930s for amateur use in the (silent) 8mm and 16mm formats, but would never again be used on any significant scale for release printing for cinema projection. For a few years the majority of cinema release printing reverted to monochrome for the first time since the 1900s. In the early 1930s cinema audiences may have gained sound, but in doing so they (temporarily at least) lost colour. As the managing director of British International Pictures noted on his return from a trip to the US in the autumn of 1932, 'there is practically no colour in America now. Colour has virtually collapsed and there is no hope of it becoming a commercial possibility again.'[8] He was right in that due to the incompatibilities between the colour technology in widespread use during the 1920s and sound-on-film, the latter had pushed the former out of the market. But by this stage, however, truly photographic colour systems were almost at the point of being mass-marketed. By

the end of the decade they were a firmly established technology, and colour as a 'commercial possibility' was back; this time, for good.

The theory of colour photography

Colour photography – including its use in moving image technology – differs fundamentally from the artificial colour systems described above. With hand colouring, stencil colouring, tinting or toning, colour dyes are added to a photographic image according to the perception or personal taste of the individual doing the colouring. No colour information is recorded at the point of photography. True colour photography consists of two processes: making a recording of the colour perceived by the naked eye at the point of photography (i.e. more than just the 'monochrome' of a silver halide latent image), and then reproducing that information in projection.

Colour photography as we know it today has its origins in an experiment which the scientist James Clerk Maxwell demonstrated in a lecture to the Royal Institution in 1861. This showed that every shade of colour which can be perceived by the naked eye (the 'visible colour spectrum') can be reproduced with light or dyes on a solid base by mixing varying proportions of what he termed the three *primary* colours: red, green and blue. For his experiment Maxwell photographed a piece of tartan ribbon three times with a red, green and blue filter in front of the lens. Filtration is a crucial technique in colour photography, which involves the use of a semi-transparent solid that will allow some areas of the visible light spectrum to pass through it but not others. For example, a piece of glass coated with a blue dye will only allow blue light to pass. A more sophisticated form of refractive device known as a *prism* has triangular surfaces facing a parallel axis. When light is shone through one surface it will project through the reciprocating one at a specific point in the visible spectrum, depending on the angle of projection.

In the lecture theatre Maxwell projected his photographs using three magic lanterns (i.e. slide projectors) fitted with the same filters he had attached in succession to the camera. The resulting image on the screen showed the tartan pattern in roughly its original colours. The colour reproduction was not entirely accurate as the emulsion used to form the original photographs was not only mono*chrome* (i.e. the processed image only displayed one colour) but mono*chromatic*, meaning that the unexposed silver halides were only sensitive to blue light. But Maxwell's experiment worked well enough to prove the principle.

The process of mixing the primary colours can be achieved in two ways, known as additive and subtractive. *Additive* colour involves adding to black the red, green and blue light needed to produce a given shade. For example, by shining a red light onto a screen and then a blue one, the screen will become purple. By projecting equal proportions of red, green and blue the screen will be white. This is the way in which colour is produced in television. *Subtractive* colour involves the use of filters to take away from white the proportions of red, green and blue light needed to produce a given shade. Because the three primary colours have reciprocating negatives (thus enabling duplication in a negative-positive system), all film colour today is subtractive. These three colours are cyan, magenta and yellow, and are produced by removing (i.e. filtering out) their reciprocating primary colour from white light. They are sometimes described as the *secondary* or *complementary* colours, but here will be termed the *subtractive negatives*. For example, the subtractive negative of red is the colour you would see if all the red area of the colour spectrum was filtered out of a white light source, i.e. cyan. By the same token the subtractive negative of green is magenta, and of blue is yellow.

Additive colour systems (1899–1952)

The earliest forms of photographic colour used in moving images were all additive, and worked either by a refinement of Maxwell's system – filtering the light used to expose and project the photographic image – or by incorporating colour dyes within the film itself. By the 1880s ways had been discovered of extending the photosensivity of the silver halide solution used in monochrome photography to include green, thus producing *orthochromatic* film.[9] As noted in chapter one, *panchromatic* film, which is uniformly sensitive to all three primary colours,[10] was not introduced on any significant scale for monochrome moving image cinematography until the 1920s, though it was used in additive colour systems a lot earlier.

The first generation of additive systems were restricted to two colours, usually red and green, due to the mechanical limitations of the cameras and projectors used. Colour systems which incorporated filters or dyes into the film itself did not become reliable or commonplace until the mid-1920s; all the systems developed before then used an arrangement of colour light filters in the camera and projector, some being more successful than others. The earliest known systematic research and development in this area was undertaken by the so-called 'Brighton School' of film pioneers based in the seaside town in southern England. As Luke McKernan has argued, it embraced 'a wider group, all active in the Brighton and Hove area in the early 1900s' who achieved the first demonstrable results in the process which ultimately led to the truly photographic systems for recording and reproducing colour we know today.[11]

The first step was an attempt at a full, three-clour system by the photographer Edward Turner and the entrepreneur Frederick Marshall Lee in 1899. This involved fitting an additional shutter disc to a conventional camera, which consisted of three filtered 'blades' for the primary colours. Thus, red green and blue records would be registered on three successive frames of exposed film. In projection, the frames were projected their reciprocating filters. The Lee and Turner system had a fundamental flaw. Because the camera used the 'successive frame' method but the projector displayed all three colour images simultaneously, parallax errors (see chapter 2) would have been visible as a 'fringing' effect, blurring the image on the screen. Interestingly, an account of a demonstration of Lee and Turner system written by George Albert Smith, who a few years later would develop the rather more successful Kinemacolor process, does not seem to recognise this fundamental mechanical flaw: that the projected image would inevitably be distorted because the three colour records were not exposed simultaneously. He suggested that: '...the difficulty is due to the fact that cinematograph pictures are too small to begin with', and that it was the scale of magnification in projection which caused the fuzzy picture.[12] What had worked for Maxwell did not for Lee and Turner because Maxwell's three-colour experiment was with a still photograph of a stationary subject. So it did not matter how much time elapsed between the exposure of the three colour records, and those records could be shown using three separate projectors focused on the same screen without any need for synchronisation. As film-based moving image technology depends on rapid successive exposure and projection, this obviously creates problems when each individual picture occupies more than one frame of film.

However that was by no means the end of mechanical, additive colour. George Albert Smith, in collaboration with another figure associated with the Brighton film industry, Charles Urban, continued to develop Lee and Turner's idea, and specifically to work on the problem of registration. Smith realised that the time gap between exposure of the colour records was a problem, though it would seem from his account of the Lee and Turner experiments that it did not occur to him to try and devise a means of simultaneous exposure. Instead he reduced the number of colour records from three to two, doubled the film speed, to 32fps,[13] and developed a panchromatic emulsion – a key element in the advance his system represented relative to Lee and Turner's. The result was Kinemacolor, first demonstrated publicly in London on 1 May 1908.[14] The camera used was a standard Moy and Bastie with a filter wheel mounted behind the existing shutter, timed to hold alternating filters in front of the lens while the shutter blades were open. Different filter combinations were used in the camera to suit the scene being shot (red and cyan being the most usual combination), while in projection the filters were red and green or blue/green. The combination of the slow film emulsions in use at the time, the limited exposure time available at a rate of 32fps and light absorption by the filters meant that to all intents and purposes, only exteriors in bright sunlight could be shot.

As Nicola Mazzanti discovered when printing preservation masters of Kinemacolor original release prints, the issue of 'time parallax' (or 'motion fringing' as Barry Salt termed it) is still there: Smith's improvements vastly reduced the visible flicker and colour smearing, but could not entirely get rid of them.[15] There was a gap of one 32nd of a second between the exposure of the two colour records, meaning that a fast-moving subject could move during the time taken by the film pulldown, resulting in a visible visible lack of registration in projection. Nevertheless, contemporary reviews agreed that, even with this limitation and the fact that Kinemacolor could only reproduce two of the three primary colours, the impression of colour reproduction on the screen seemed surprisingly life-like. During the early 1910s Kinemacolor was used with notable commercial success on a number of short subjects and finally for the World War One propaganda film *Britain Prepared* (1916, dir. Charles Urban), before patent litigation by Urban and Smith's commercial rivals forced them out of business.

At around this time there were several other two-colour systems based on successive frame exposure through mechanically operated filters, but eventually the researchers began to realise that truly accurate colour registration could only be obtained if the colour records were exposed and projected simultaneously. A number of two-colour systems emerged during the late 1910s and early 1920s which managed to achieve this, for example Colcin in the UK and the Busch process in Germany. Out of the research being undertaken all over Europe into mechanical additive colour systems eventually came the first successfully demonstrated three-colour additive system: Léon Gaumont's Chronochrome, developed as a rival system to Pathécolor (with the added advantage of being truly photographic) and first publicly demonstrated in Paris on 15 November 1912. The Chronochrome camera had three separate filtered lenses to simultaneously expose the red, green and blue records onto successive frames of panchromatic stock, and an enlarged aperture and triple lens assembly in the projector to reproduce them, again simultaneously. Coe notes that 'at the cost of introducing some mechanical complication, Chronochrome achieved good quality by using three almost full-size component images'.[16] In doing so it also established the principle (of using three, simultaneously created colour records) which would be incorporated in the world's first successfully mass-marketed three-colour subtractive system, Technicolor (see below).

The development of mechanical, additive colour systems during the 1900s and 1910s, first using successive frame exposure and projection, then later simultaneous, proved that Maxwell's findings could be successfully applied to moving images as well as still ones. However, these systems never made it into mass production and the mainstream cinema industry, largely because of the issues of technical standardisation discussed in chapter two in relation to film formats. To borrow Coe's phrase, the cost of introducing some mechanical complication was not one which the rapidly globalising film industry was willing to pay. All of these technologies, from Kinemacolor to Chronochrome, required specially designed cameras and projectors which could only be used in conjunction with the colour system for which they were marketed. Some, for example Kinemacolor, also required special film stock. As with Cinerama, VistaVision, Vitaphone, CDS and countless other examples, these colour processes all fell by the wayside due to their cost, complexity, unreliability and incompatibility with pre-existing technologies. By the end of the 1910s they probably accounted for 2–3 per cent of the total film footage shown in the world's cinemas at most, while the vast majority of audiences were seeing tinted and/or toned prints, and would continue to do so for a further decade. What was needed was a means of photographing and reproducing colour in a way that was compatible with the 35mm, four-perf standard as it had been enshrined by the SMPE in 1917. To achieve this, successive or simultaneous multiple-frame systems were out of the question and the use of moving filters attached to the camera and/or projector was at best undesirable. A way was needed of incorporating all three colour records on a single frame of 35mm, and ideally they had to be represented in the form of colour dyes on the release print itself, meaning that colour projection would be possible without any modification whatsoever to the equipment already installed in cinemas.

No full, three-colour system achieving the latter was available which supported the production of multiple release prints in significant quantities until the introduction

of three-strip Technicolor in 1935 (see below). There were, however, two notable transitional stages between the mechanical additive systems of the 1900s and 1910s and the dye-based colour processes which emerged during the 1930s and which are still with us today. They also represented the final stage in the development of additive colour for film before this approach was largely abandoned and the subtractive method took its place.

These technologies were both attempts to record and reproduce all three primary colour records from a single frame of film, thus eliminating the 'mechanical complication' which ultimately killed off Kinemacolor and Chronochrome. The first was *lenticular* colour (sometimes referred to as *mosaic* or *dry-screen* colour). The earliest description of this process is variously attributed to Robert Berthon or Gabriel Lippmann in 1908 or 1909 respectively. It involved embossing a series of vertical indentations or lenticules into the film base, and exposing the film through a colour filter with three 'bands', for red, green and blue. They were so focused that the indentations would act as miniature 'lenses', recording an image through each separate filter onto the appropriate section of the panchromatic emulsion. After developing to a reversal positive the film was projected through a reciprocating filter. This time the indentations acted as projection lenses, directing light through the appropriate filter band in front of the projector's objective lens, thus producing a full-colour picture on the screen. This technique was first successfully demonstrated by Berthon in Paris on 17 December 1923. The patent rights were subsequently bought by Eastman Kodak, and after further development it was marketed as the first colour system intended specifically for amateur use, known as Kodacolor, in 1928.[17]

Kodacolor achieved moderate success as a home-movie medium between 1928 and its withdrawal from the market in 1938 following the launch of Kodachrome (see below). It, and the small number of rival lenticular systems developed around the same time, represented a move in the direction the industry required: all three-colour records were on a single strip of film and furthermore did not require the mechanical complication of a successive frame system. But there were crucial drawbacks. As with the mechanical systems, the amount of light needed for exposure was very high. In this case, not only was the film exposed through a light-absorbing filter fitted to the camera, but as the lenticular embossing was on the base of the film, it had to be exposed with the base side facing the lens, meaning that the base absorbed yet more light before it struck the photosensitive emulsion. As with Kinemacolor, Kodacolor could only be used successfully in bright sunlight. Furthermore, each different coating of panchromatic emulsion varied slightly in its relative sensitivity to the three primary colours, which without any compensation would upset the overall colour balance in projection. A special paper stencil had to be supplied with each roll of Kodacolor which the customer fitted in front of the filter to ensure that exposure was compatible with the colour balance of each batch of film. Failure to use it frequently resulted in poor colour rendition on the screen.[18] And finally, despite intensive research by Eastman Kodak in the early 1930s, lenticular colour could not be made to work in a negative-positive process, only reversal. This prevented its use within the professional film industry, for which large numbers of release prints were needed.

The Kodacolor lenticular process was briefly revived when, in November 1951, the 35mm Eastman Embossed Print Film, type 5306, was first demonstrated. This was the result of collaborative research between Eastman Kodak and Twentieth Century Fox's head of research, Earl Sponable. The idea was to produce a way of striking large numbers of single-strip colour release prints which was cheaper and more flexible than the Technicolor dye transfer process which at the time represented the only colour system capable of yielding multiple prints of consistent quality (see below). Kodacolor mk. II involved optically printing colour separation internegatives produced using the Technicolor beam-splitting prism, through the lenticular filter bands onto 5306. Although TCF decided in 1953 to use it as a release printing format, they quickly abandoned the idea because by this stage tripack stocks, which did not need a filter attachment on the projector and did not absorb as much light as a lenticular print (see below), were rapidly being adopted industry-wide. This rendered the need for a lenticular release printing system obsolete.

One other additive colour process in use during the 1920s and 1930s deserves a mention here, because it represented another small step on the road to a fully stand-alone, single-strip colour system which could also be used to produce large numbers of prints. In 1908 the Paris photographer Louis Dufay started marketing 'Diopticolor' reversal glass plates for still photography, and over the following two decades worked on making his process suitable for cinematography. The process itself consisted of a film base onto which was printed a matrix of embossed lines, coated with alternating patterns of red, green and blue dye; termed the 'réseau' (network) by Dufay. Underneath the réseau was a layer of conventional panchromatic emulsion. In exposure the réseau acted as a filter, registering a latent image or not depending on whether light of the appropriate colour passed through it. After processing the silver halides were washed away in the exposed areas, allowing light from the projector to pass through the coloured réseau and illuminate the screen. In unexposed areas the halides were fixed to a metallic silver, preventing light from passing through the colour dye and showing on the screen as opaque.[19] Because the colour filters were in the form of dyes built into the film itself, no modification was needed to a camera or projector designed for use with conventional monochrome stock in order to make it compatible with Dufaycolor. The issue of mechanical complication had thus been overcome, but two problems remained. Like Kodacolor, Dufay film had to be exposed through the base, and again, this was a reversal system and the production of multiple prints was difficult, expensive and involved considerable loss of image quality. Dufaycolor was therefore used predominately by amateurs, and from 1935 was sold in the Kodak 8mm and 16mm formats. It was also available in the Pathé 9.5mm gauge, and was thus the only colour film available to European home-movie makers using this format in the 1930s.

The British film manufacturer Ilford had entered into an agreement in 1932 to market and promote Dufaycolor, initially in small gauge reversal form; but it also undertook to invest in research and development aimed at adapting it for 35mm negative-positive use in the professional film industry. There were a number of complications. Because the Dufay system was additive – the three colours had to be evenly balanced so that together and in equal intensity they would form white – the colour temperature of tungsten (incandescent) or carbon arc studio lighting frequently caused problems. And although a negative-positive variant of Dufay was eventually developed, the production of mass print runs was complex, expensive and had a high wastage rate. The end result was that for professional cinema film use Dufaycolor represented a substantial extra cost per print: around 3½ pence per foot, which Simon Brown's research suggests was around six times the cost of monochrome.[20]

Dufay had undoubtedly cracked the nut of photographically recording all three primary colours and reproducing them additively without the 'mechanical complication' of specially modified equipment which had dogged all the mechanical systems from Lee and Turner to Kodacolor. But as with all non-mechanical additive systems, the fatal flaw was that it was a reversal process. Thus the production of multiple prints was difficult, expensive and the result was of poor quality. Unlike Technicolor, Dufaycolor did not cost a lot more *to shoot* than conventional monochrome: that extra 3½ pence per foot was for release printing. Another problem was that the dense Dufaycolor réseau absorbed a lot of light in projection. The carbon arc projector lamphouses installed in the 'picture palace' cinemas built during the 1920s and 1930s often struggled to produce an acceptable level of illumination on the screen due to the long throws which were necessary. Dufaycolor exacerbated this, yielding an even dimmer picture. The only Dufaycolor films printed in any great quantity for cinema release were a newsreel of King George V's silver jubilee in 1935, a short sequence in the musical revue *Radio Parade of 1935* (1935, dir. Arthur Woods) and the only full-length Dufaycolor feature: a 'simple minded, naïve' (to quote Halliwell's Film Guide) propaganda film made to drum up recruitment for the Royal Navy shortly before the outbreak of World War Two, *Sons of the Sea* (1939, dir. Maurice Elvey). It was shot mainly at Dartmouth Naval College and took advantage of the intense natural light found in south-west England during the height of summer. Dufaycolor made a brief revival as an amateur medium between the end of the war and Dufay-Chromex (the company to which Ilford had sold out in 1937) going into liquidation in 1952, and for a small number of short travelogues and documentaries. And that was pretty much that for additive colour in commercial moving image technology.

Subtractive colour I: Technicolor

The inventor of the Technicolor process, Herbert Kalmus, argued that the successful marketing of colour film technology depended on addressing two issues in relation to standard industrial practice:

> 'How far will it [the film industry] permit departure from standard equipment and materials, and how will it attempt to divide the additional requisites of recording and reproducing colour between the emulsion maker, the photographic and laboratory procedure and the exhibitor's projection machine?'[21]

The inventors and promoters of additive colour discovered the hard way that the answer to Kalmus' first question was 'as little as possible', and that the answer to the second was to concentrate non-standard equipment and procedures in areas of the process where its economic impact was lowest, i.e. at the production end, where the effect of the economies of scale invoked by mass-production (Henry Ford's 'any colour, as long as it's black') was minimised. All the additive colour processes developed up to and including Dufaycolor were ultimately a commercial failure because they fell foul of one or both of these criteria. The successive frame method was fundamentally flawed, because it could not record or reproduce more than one colour record simulataneously (though Kinemacolor managed to keep the visible impact of this down to a minimum). Both the successive frame and the simultaneous mechanical systems required modification to both the cameras and the projectors in cinemas. Only the film processing chemistry was largely unaltered, and even then the use of panchromatic stock was not common and required special procedures (e.g. handling in total darkness). And while lenticular systems could be used in almost standard and Dufaycolor in totally standard cameras and projectors, the manufacture of lenticular raw stock was non-standard and expensive. Furthermore, being essentially reversal systems, the mass duplication of both was very difficult and very expensive, meaning that these processes were effectively useless as mass media.

Just as W. K. L. Dickson realised in 1889 that cinema film technology had to be standardised along a 'one size fits all' philosophy in order to make it commercially viable, Kalmus realised that colour had to be made to fit that economic model, too. Furthermore he realised that exhibition was the sector of the industry where standardisation was most important and where introducing any standard which violated that technology would seriously jeopardise its chances of success. This meant that whatever happened in the studio or laboratory, his colour film had to be showable via the hundreds of thousands of 35mm projectors operating worldwide, without any faffing about with mechanical filter wheels, multiple strips of film, special lenses, non-standard pulldowns or anything that would increase costs or reduce reliability at the exhibition end. The result was a combination of two technologies which together comprised the original Technicolor system and which were developed in the two decades between the formation of the Technicolor company in 1915 and the release of the first three-colour Technicolor feature, *Becky Sharp* (1935, dir. Rouben Mamoulian). The Technicolor camera combined the principle of mechanical, additive colour (i.e. optically filtering light to record the three primary colours separately) with the technique upon which tripack colour coupler processes would later depend: exposing each colour record individually, simultaneously and initially as a negative (i.e. not reversal) in order to permit mass-duplication. The final version departed from all previous systems in that the three colour records were exposed onto three separate elements of monochrome stock running in synchronisation: it was termed the 'three-strip' Technicolor camera, in order to distinguish it from earlier 'two colour' (red and green only) versions used on a limited scale for shorts and a small number of Hollywood features during the 1920s.[22]

Though Barry Salt suggests that the camera was 'to a certain degree modelled on the Mitchell',[23] it was essentially a design unique to Technicolor. Cinematographers appreciated several refinements which were not to be found in any studio camera formerly in use, notably a viewfinder which virtually eliminated parallax errors and focusing that could be remotely controlled.[24] The mechanism consisted essentially of a magazine which held three 1,000-foot rolls of 35mm stock and two gates mounted at right angles to each other. Between them was a 45° beam-splitting prism, mounted behind a single prime lens. Directly behind the prism was a gate holding a single strip of panchromatic stock, which recorded the green image. At a 90° angle to it was a second gate, through which passed two strips of film in contact with each other, emulsion to emulsion. The strip nearest the prism was sensitised to blue light only, and had a red/orange dye which blocked green and blue light, with a layer of panchromatic stock behind that which therefore recorded the red image. However, these stocks were all monochrome negative stocks, i.e. not reversal, so unlike any previous photographic colour system which had used successive frames or multiple strips of monochrome film to record separate additive colour records, the colours actually recorded on the Technicolor films were the subtractive negatives of the primary colours, i.e. cyan, yellow and magenta.

The three camera negatives were then developed in the same way as normal monochrome stock, and cut to produce three edited negatives holding the three colour records for the final film. Release prints were made using an extraordinarily complex method of physically transferring three organic dyes onto the surface of the release print stock. Each strip of negative was printed to produce a *matrix* element, in which a gelatine layer varied in thickness in proportion to the silver density on the original negative. These matrices were then immersed in a dye of the subtractive negative colour to the element used to print the matrix (e.g. the red matrix is immersed in a cyan dye). The gelatine absorbed a quantity of the dye in proportion to its thickness, and thus to the density on its source negative. It is for this reason that the Technicolor printing process is known as the *imbibition* process (from the Latin verb *bibere* – to drink or absorb).

The raw release print stock carried a black-and-white emulsion to receive the soundtrack and a uniform gelatine coating to absorb the dyes. Each dyed matrix was placed in contact with the print stock in three separate passes, using the 'pin belt' mechanism developed by Technicolor to ensure that the two elements remained in precise registration. While in contact with each other, dye passed from the matrix element to the print in proportion to its density in the matrix (hence the reason imbibition prints are also sometimes referred to as 'dye transfer' prints). When all three matrices had been printed, the result was a full, three-colour image on the print stock. The remaining dye was then washed out of the matrices, which were then re-dyed and used to make the next print. Because this was not a photochemical process, Technicolor printing could be done in full daylight. However, there is anecdotal evidence to suggest that there were initial problems with ensuring the accuracy of registration (alignment) between the three colour dyes, resulting in blurred edges and colour fringing on the prints. A distributor's print manager who worked in London during World War Two told me that due to wartime film stock shortages, Technicolor prints which ordinarily would have been junked at the quality control stage had to be put into circulation. Such copies became known as 'north of Watford' prints,[25] the implication being that the good ones were reserved for prestigious central London cinemas while the slightly misregistered prints were sent to the provinces.

These teething troubles apart, the original Technicolor process was, in terms of its technical performance, a phenomenal success. It represented the culmination of two decades of research and development by Kalmus and his staff, and was truly the first three-colour system which enabled large quantities of high-quality release prints to be made according to the same economies of scale as monochrome, and which did not require any modification to equipment or practices in cinemas. The extent to which it was accepted by the public as the first genuinely mass-producible system for recording and reproducing full, three-colour moving images is summed up by the 'glorious Technicolor' marketing campaign: the phrase has subsequently entered the English language as a colloquial expression denoting high quality, glossy production values (not to mention the phrase 'Technicolor yawn', meaning to vomit). But Technicolor was phenomenally expensive at the production end. The historian Rachael Low estimates that immediately following its launch, the use of three-strip Technicolor on an average studio feature added between £20,000 and £25,000 to the production budget (around 20–30 per cent).[26] The increased production costs included hiring the cameras themselves, three times the negative stock cost of a monochrome production, more complicated and expensive studio lighting (even by 1939 the three-strip negative stock only had a speed equivalent to EI40, requiring far more intense studio lighting than a monochrome production) and of course the production of matrices and prints. As Panavision was to do two decades later, the three-strip cameras were never sold outright to studios. Furthermore (and unlike Panavision equipment), they were not even available on a 'dry hire' basis.

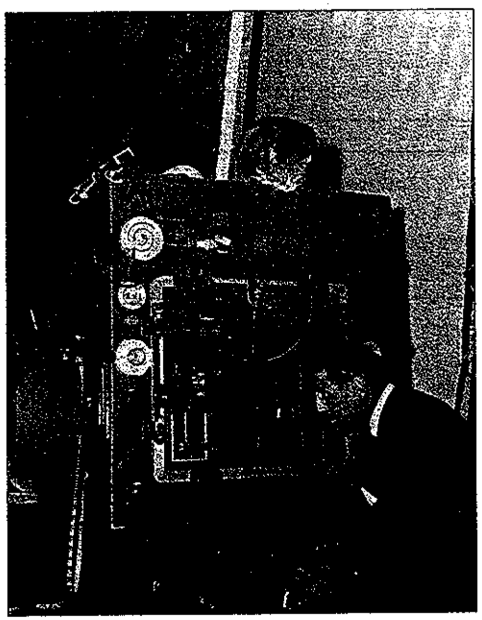

Fig. 3.2 The three-strip Technicolor camera mounted in a soundproof blimp with operator Jeff Seaholme and 'colour consultant' at Pinewood Studios, near London, circa late 1940s. Picture courtesy of BFI Stills, Posters and Designs.

Technicolor did a lot more than just supply cameras and lab services. They marketed a complete package which impacted on virtually every stage of the production and distribution process. In Technicolor UK's standard contract with a production company from 1943, the provisions included: all raw camera stock to be supplied

exclusively by Technicolor, all cameras to be hired exclusively from Technicolor, all photography to be undertaken under the supervision of a technician supplied by Technicolor (who could override the director of photography's creative decisions), all the lab stages from processing of the camera negatives to the production of release prints to be done exclusively by Technicolor (with a minimum order of 100 prints). In addition, clause 15 of the contract stated that 'the Producer shall use the services of and consult with a Colour Consultant to be supplied by Technicolor'.[27] There have been many documented instances of these consultants exerting considerable influence on set and costume design and much else besides. For example, when directing his first Technicolor production, *Rope* (1948), Alfred Hitchcock noted that following differences of opinion between the director of photography (Joseph Valentine) and Technicolor's appointed consultant (William V. Skall), the former became 'sick' and the latter shot most of the film.[28]

The late 1930s and 1940s were the heyday of the integrated beam-splitting camera and imbibition printing Technicolor process. After the war the cameras were largely superseded by dye coupler stocks (see below). The last Hollywood feature to be shot using the three-strip camera was *Foxfire* (1955, dir. Joseph Pevney). In the UK (which operated the only IB printing facility outside the US), it was last used on *The Ladykillers* (1955, dir. Alexander Mackendrick). Imbibition printing from coupler negatives (see below) continued into the 1970s, with the matrices being made from separation intermediates derived from dye coupler camera negatives. More recently, an updated version of the imbibition printing system was introduced at Technicolor's Hollywood plant on a limited scale in 1998. It was subsequently used to produce small print runs of major Hollywood features and high-profile rereleases, most notably Robert Harris' 2000 restoration of *Rear Window* (1953, dir. Alfred Hitchcock). The new generation of imbibition prints were clearly sharper and more saturated then even the most modern generation of coupler prints. But sadly the updated dye transfer process was abandoned after only a couple of years. Despite the higher image quality the industry was not willing to absorb the increased cost, with the result that Technicolor was not able to find enough of a market to make the system commercially viable.

The combination of technologies and services which constituted the original Technicolor 'package', therefore, marked a significant step forward in that it proved that the technique of recording and reproducing colour subtractively successfully enabled the production of full, three-colour cinema release prints on the scale needed to support a mainstream release and (eventually) of consistent quality. But with echoes of additive systems like Dufaycolor which almost made it into mainstream use but not quite, there was one aspect of Technicolor that did not quite comply with established industry standardisations, and thereby ensured that the 'glorious Technicolor' package would usually be restricted to high-budget, 'A' movie features (a bit like 65mm/70mm would a generation later). This was because it was just that – a package. Studios could not simply buy the hardware outright and then go away and do what they liked with it: they had to allow Technicolor a considerable degree of involvement and decision-making power on a film produced and released using their system. The technological success together with the associated restrictive practices of Technicolor resulted in the American film industry starting to look for the form of colour film technology which eventually superseded it, the one which is primarily with us today: 'tripack' or dye-coupler film stock.

Subtractive colour II: dye-coupler stocks

What this managed to achieve which Technicolor could not was to provide a single roll of unexposed film that could be used in the same camera, without any modifications whatsoever, as monochrome film. Thereafter it could be duplicated through intermediate stages to yield mass-produced release prints, just as monochrome could. In fact the only differences as far as production was concerned were in the studio lighting and processing chemistry. It is in the latter that the guts of this technology lies, as we shall see shortly.

It is somewhat ironic that, though this technology would eventually crack the nut of making full, three-colour photography usable in mass-produced moving images, its first significant commercial application was in a reversal system marketed primarily to 35mm still photographers and amateur filmmakers.[29] Kodachrome, as it was eventually marketed, was the brainchild of two professional musicians and amateur photographic chemists, Leopold Mannes and Leopold Godowsky. Since the early 1920s they had been attempting to create a form of photographic emulsion which is now known as the 'dye coupler' or 'chromogenic' process. In very simple terms, the single strip film emulsion contains three layers which are sensitised to the primary colours. When it is developed, a chemical reaction converts each layer of photosensitive emulsion into a visible dye of the corresponding colour. The technique was initially described by the German chemist Rudolf Fischer in the early 1910s, but its first successful commercial implementation was with the launch of Kodachrome, first in 16mm movie form in 1935, and for 35mm still cameras a year later. The fact that Kodachrome was a reversal stock which could not be adapted to a negative-positive process meant that for moving images, its use was largely confined to the amateur domain. However, its comparatively slow speed and very fine grain ensured that it rapidly gained a commercial foothold for still photography, especially in the glossy magazine market: as the photo editor of *National Geographic* remarked, 'we knew the millennium was here for magazine colour reproduction. It [Kodachrome] had the possibility of almost infinite enlargement.'[30] At the time of writing (March 2005), 35mm Kodachrome stock is still being produced for still photography in the EI64 and EI200 variants, and for moving image use in Super 8 EI40 stock. The very fine grain EI25 emulsion was discontinued in 2003 due to rapidly falling sales.

The film industry did use Kodachrome on a very limited scale in conjunction with the Technicolor dye transfer printing system, as a cheaper and more versatile substitute for the three-strip camera. 'Technicolor monopack', as this hybrid was termed, was first marketed in the US in the autumn of 1942. 35mm Kodachrome reversal film was exposed in a conventional studio camera, the only difference in production technique being the need for more studio light (or bright natural sunlight on location) relative to black-and-white: by the early 1940s monochrome film emulsions were available with speeds of up to an equivalent of EI200, while Kodachrome had speeds of EI10 for the daylight-balanced stock and EI16 for the artificial light variant respectively. After exposure and processing, Technicolor produced three black-and-white separation negatives from the Kodachrome original, which were then dye-transfer printed in exactly the same way as if they had been exposed in the three-strip camera. Technicolor monopack was used for a number of productions between 1942 and the end of the decade, when it was superseded by negative-positive coupler stocks (see below). These were mainly features in which the three-strip camera was unsuitable, either for reasons of portability or lighting requirements. Arguably the best known feature to include Monopack footage was the war propaganda film *Western Approaches* (1944, dir. Pat Jackson), much of which was filmed in a lifeboat in the North Atlantic using natural light only.[31]

From the film industry's point of view, its economic requirements dictated that for colour to achieve mass-market saturation, a form of coupler technology which would work in a negative-positive process was needed. This eventually materialised in the West in the late 1940s, almost certainly as the result of Allied forces having helped themselves to the infrastructure which remained of the Nazi film industry following the end of World War Two.

Since the mid-1930s the Nazis had been anxious to develop a colour film system to rival Technicolor. Hitler's propaganda minister, Joseph Goebbels, was a well-known admirer of Hollywood genre cinema, and specifically its potential to communicate political or ideological messages under cover of 'entertainment'. He understood that if audiences realised that they were being fed propaganda, they would reject its message. This was demonstrated by a string of high-profile box-office flops commissioned by the Nazi government shortly after it came to power in 1933. Goebbels had noted the commercial success of Technicolor in high-budget, prestige features – in particular he praised the 'magnificent artistic achievement' of *Snow White and the Seven Dwarfs* (1937, dir. David Hand)[32] – and was determined that the Third Reich should have something similar. But the form of technology they used to deliver it was dramatically different from that of Technicolor; it would also prove to be cheaper and far more versatile.

The first colour film produced by the German Agfa company was a reversal stock for still photography, 'Agfacolor Neu'. It was launched in 1936, the year after Kodachrome went on sale in the US.[33] However, there was a crucial difference in the way its chemistry worked, one which would enable its conversion to a negative-positive process shortly afterwards. With Kodachrome, the coupler elements (i.e. the chemicals which converted the exposed film into three visible dyes) themselves were not present in the emulsion as exposed, but introduced during processing. This made both the chemistry of the film emulsion (five layers, each one to three microns thick) and the processing of it enormously complex. With the first generation of Kodachrome, this consisted of 28 separate procedures, 'all of which had to be carried out with the utmost precision.'[34] The Agfa system incorporated the coupler elements into the film emulsion during manufacture, which were 'activated' during processing, i.e. the developing chemical simply induced the change from an emulsion to a dye. This reduced the number of processing steps to four, and any existing black-and-white lab could easily adapt its equipment to process the new stock.

In 1939 Agfa launched a negative-positive version of the system, which was used to produce a number of feature films throughout the remaining life of the Nazi regime. Two notable examples were *Münchhausen* (1943, dir. Josef von Baky) and *Kolberg* (1945, dir. Veit Harlan).

As I have argued elsewhere, the Allied plundering of captured Nazi film technology infrastructure may well have hastened the global film industry's conversion from nitrate to safety stocks,[35] not to mention the Nazis' role in developing magnetic sound technology (see chapter four). With colour there is even less speculation implicit in such an argument. As the Agfa plant which manufactured and processed the bulk of its colour stock was in Prague, the equipment and chemicals remaining there were quickly removed by the Russians after the end of the war, and some years later a cloned version of the system emerged, dubbed 'Sovcolor'. The first major Soviet feature to be produced after the war, *Ivan Groznyi* (*Ivan the Terrible*, 1946, dir. Sergei Eisenstein), induced scenes that were shot and printed on leftover Agfacolor stock abandoned by the Nazis. Meanwhile the Americans sent federal investigators to interrogate Agfa scientists being held by the Allies as prisoners of war. With them went representatives from Agfa's US subsidiary (which by that stage was wholly American-owned), the General Aniline and Film Company of Santa Monica, California (Ansco). Ansco lost no time in obtaining both the physical and intellectual property associated with Agfacolor, and in 1948 the first Anscocolor stocks – initially reversal – went on sale to the industry.[36]

Although a two-strip only (red and blue) system known as Cinecolor had been used on a limited scale in the US for B-movies and documentaries during the mid-1940s, the introduction by Ansco of a tripack stock which eliminated most of the complexity and expense associated with Technicolor marked the start of a conversion process. Within two decades, black-and-white film stock would have virtually disappeared from Hollywood studios and mainstream cinemas. The launch of Anscocolor was quickly followed by a number of other manufacturers starting to produce tripack stocks including Gevaert in Belgium and Ferrania in Italy. In Japan, Fuji non-substantive reversal coupler stock was used to shoot *Carmen Comes Home* in 1949 and in October 1955 the company launched a negative-positive process suitable for moving image use.[37] The most significant development in this period was the launch of Eastmancolor in 1950. In this stock the Kodak company introduced a number of refinements, most notably the use of coloured couplers. The couplers are coloured in two of the layers to provide masking, which improves the clour reproduction of the duplicate elements by correcting for dye deficiencies in the negative stock. The coloured couplers are what give modern colour pre-print elements (including 35mm still negatives) their characteristic orange tint, even though this is not visible on the finished print.

Eastmancolor and the range of masked coupler emulsions which followed were a phenomenal success. It was a technology which fulfilled the industry's needs for

the mass-rollout of colour. Although early versions of Eastmancolor were significantly slower than their monochrome equivalents (EI16 at first, increasing to EI24 in 1953 and EI50 with the launch of type 5250 in 1959),the additional cost (and difficulty) of using this process relative to black-and-white and where a large run of release prints was needed was negligible compared to those of any other colour process which had ever been available. Although Eastman Kodak was (and remains to this day) the market leader in masked colour emulsions, the distribution of patents and the commercial realities of the day ensured that the restrictive practices which had applied to earlier colour systems – most notably Technicolor – no longer applied. Eastmancolor stock could be purchased by a studio off the shelf, shot by its own cinematographers using its own cameras, be processed in a lab of its choosing (as a matter of policy Eastman Kodak did not own, operate or franchise processing labs for motion picture film – they just sold the raw stock) and the cut negative used to produce multiple release prints using the same sequence of intermediate elements as black-and-white. The fact that masked coupler emulsions were also being rolled out across the still photography sector (both amateur and professional) helped also to tip the economies of scale in this technology's favour.

This form of colour film technology has effectively remained the industry standard for the last five decades, although the colour saturation, grain and definition available from tripack colour emulsions has continued to evolve and improve throughout that time. As F. P. Gloyns puts it:

> The story of the laboratories from those days up to the present is a record of gradual improvement of technique leading to improved consistency and quality rather than of any fundamentally new innovation. In principle, the products of 1950 are those which we use today, but they have all been vastly improved in detail.[38]

Another issue was the need for quality control across the mass print runs which, given the quantities involved, had never been a significant issue with any previous system. The use of chemical analysis to maintain, or 'replenish' the developer solutions used in film processing to a consistent strength became routine in the 1960s (it was desirable to do this with black-and-white developers too, but many labs did not). The Bell and Howell model 'C' printer introduced a system of dichroic mirrors (not unlike the beam-splitting prisms in the three-strip Technicolor camera), and 'light valves', which allowed precise control over the colour temperature of the light used for exposure in the printer. In the 1980s the huge increase in the volume of release printing necessitated by the advent of multiplex cinemas lead to the development of high-volume, high-speed printing and processing which today is largely computer-controlled. This will be discussed in greater depth in chapter five. With the benefit of hindsight, we now know that the early generations of masked coupler tripack emulsions had one very serious flaw: their chemistry was highly volatile, making them susceptible to serious colour dye fading over time. It was a flaw which went undetected until the 1960s, and is now one of the main problems which archivists and restoration experts have been grappling with in recent years. Colour dye fading and the techniques which have been developed to reverse it will be covered in chapter seven, but are beyond the scope of this discussion.

By the mid-1970s, black-and-white had become an exception which proved the rule. The conversion process was accelerated as American network television increasingly moved to full colour broadcasting in the late 1960s, with the result that broadcasters were increasingly reluctant to license black-and-white films for transmission from the Hollywood studios. *Who's Afraid of Virginia Woolf?* (US 1966, dir. Mike Nichols) was probably the last major first-run studio feature in black-and-white to be licensed by the US networks.[39] Thereafter, films as diverse as *Alice in den Städten* (*Alice in the Cities*, 1992, dir. Wim Wenders), *Manhattan* (1976, dir. Woody Allen) and *The Elephant Man* (1984, dir. David Lynch) used black-and-white in order to make an artistic statement, just as colour features in the 1930s and 1940s – such as *Becky Sharp*, *Gone With the Wind* (1939, dir. Victor Fleming) and *Münchhausen* – had used this technology to make a commercial or political statement.

Conclusion

The story of colour film processes, and specifically the reasons for different forms of this technology being developed, appearing and disappearing as and when they did, lies as much in the cultural and economic domains as it does in the purely technological. Since Maxwell's experiments in 1861 had shown that photographically recording and reproducing colour variations as perceived by the naked eye was theoretically possible, a large number of scientists and engineers tried to apply the principles involved to both still and moving image photography. As with television, there is no 'great man' theory or individual process or technique which can explain the push towards full colour as a standard: Eastmancolor would not have become that standard if the earlier, flawed systems had not demonstrated the existence of a market which that product eventually serviced.

This had, of course, been what generations of scientists and engineers had been working to achieve from Frederick Lee and Edward Turner onwards. Most of them thusfar were ultimately thwarted: the results of their research were either technically flawed, incompatible with the economic realities of the film industry, or both. Non-photographic colour was always perceived to be 'second best' to colour information recorded at the moment of photographic exposure. In any case, even state-of-the-art non photographic colour (Pathécolor, Handschiegl), which attempted to retrospectively 'add' scene-specific colour information to different areas of the frame, proved to be so labour-intensive as to be uneconomic for entire features. While tinting and toning was able to be applied to large print runs at minimal cost, it proved incompatible with sound-on-film, which in the late 1920s was a more economically attractive proposition. By that stage full 'three strip' photographic colour was on the verge of becoming a technical and economic reality.

The very first generation of truly photographic colour systems used the successive frame method. It was a combination of technologies which, as a package, quite simply did not work. The combination of panchromatic emulsions with filtered lenses enabled multiple colour records to be recorded and reproduced, but the successive frame method could not enable these records to be exposed or projected simultaneously. The visible colour 'fringing' in Lee and Turner's system was so bad as to preclude its use for three-colour reproduction altogether. Kinemacolor used a number of devices to minimise the shortcomings of successive frame, notably a reduction in the number of colour records from three to two, an abnormally high film transport speed (32fps) and only photographing static or slow-moving subjects. While this mitigated the complete failure experienced by Lee and Turner, Kinemacolor also proved that a means of photographing the three colour records simultaneously was needed for any further progress to take place. While the short-lived Gaumont Chronochrome process proved that this could be done mechanically and additively, by the early 1920s it, like tinting and toning, was about to be eclipsed by the next stage of development.

The early single-film systems of the late 1920s and early 1930s cover the transition from additive to subtractive colour. In different ways they focused the industry's mind on the idea of a colour film process which would meet its own economic needs, i.e. the Henry Ford model of reliability and mass production according to increasing economies of scale. Lenticular Kodacolor, Dufaycolor and Kodachrome all succeeded in enabling the full visible colour spectrum to be exposed and projected from a single strip of film. But, being reversal processes, none were capable of mass-duplication without significant extra cost and loss of image quality. This was where Technicolor stepped in, applying the principle of subtractive colour recording to enable large-scale printing, albeit using the horrendously complex dye-transfer process. But cost still remained a problem, one which restricted Technicolor's use to big-budget feature films in which colour was used as an explicit selling point.

One interesting side-effect of this is that most colour cinematography which did take place before the Eastmancolor revolution of the 1950s was by amateurs, for whom the inability to produce large numbers of prints was not an issue. The resulting wealth of colour 'home movie' material made during the 1930s and 1940s has come to the attention of television documentary producers in recent years, helped by the public sector film archive movement (which has always believed that amateur footage is as culturally valuable and worth preserving as much as commercially made films) and the fact that many of these systems (and in particular post-1938 Kodachrome) seem virtually immune to the dye fading which affected early generations of Eastmancolor. Television series including *The Third Reich in Colour* (Spiegel TV, 1999) and *The British Empire in Colour* (TWI, 2002) have done much to increase awareness both of a hitherto ignored aspect of our moving image heritage and (although to a lesser extent) the early colour film technologies themselves.

Ironically the origins of the colour process which would ultimately dominate moving image film technology throughout the latter half of the twentieth century have their origins not in the economic domain, but in the political. In the mid-1930s Technicolor had come to be seen as a symbol of Hollywood's global domination of world film culture, in response to which Goebbels decided that the Nazis had to have an alternative. There is certainly no evidence to suggest that Agfa sought to develop dye coupler emulsions into a viable technology in order to offer a cheaper and more flexible alternative to Technicolor, even though this was the eventual result. In 1950 Eastman Kodak released the first masked coupler emulsions to the global market, and the rest is really a side issue to the history recounted in this chapter.

If a more convincing demonstration were needed of the economic prerogatives which drive and have always driven technological evolution in the global film industry, it can be found in the fact that the use of black-and-white is now more expensive than colour, despite the chemistry being so much simpler. Demand for stock and processing has decreased to the point at which the former is only manufactured by Eastman Kodak to special order, and the latter is offered only by specialist labs which primarily serve the archive market.

An ironic illustration of the extent to which colour made the transition from an embryonic series of research and development projects to an industry norm, both in film and television (for more on the latter see chapter six), was the thankfully short-lived phenomenon of 'colourisation'. This emerged in the 1980s and involved a variety of techniques: they ranged from what were in effect electronic versions of hand colouring and stencil colouring to computerised attempts to automate the process of adding colour information selectively to black-and-white originals. It was driven by the television industry, which perceived that black-and-white footage was in some way inferior and would be rejected by consumers. Adding colour would therefore be making classic movies 'better'. This assumption reached its zenith (or nadir, depending on your point of view) with the establishment of a company called American Film Technologies (AFT) in 1988, the idea being to offer a colourisation service to film studios and broadcasters which were sitting on the rights to large collections of black-and-white archive material. AFT started by colourising *Meet John Doe* (1941, dir. Frank Capra), *The Scarlet Pimpernel* (1934, dir. Harold Young) and *They Made Me a Criminal* (1939, dir. Busby Berkeley) for television broadcast. A trade paper report made their reasoning brutally clear in predicting that 'if these succeed in the ratings, hundreds of currently unsyndicatable black-and-white series could rise from the dead to funnel streams of new revenues into the coffers of their distributors'.[40] A sarcastic response to the colourising phenonenon is offered in the film *Gremlins 2: The New Batch* (1990, dir. Joe Dante) in which a thinly-disguised caricature of the cable TV impresario Donald Trump offers his subscribers '*Casablanca* ... now restored in full colour and with a happy ending!'

Towards the late 1980s the colourisation bandwagon gathered steam, with the Hollywood-based Color Systems Technology signing a deal with the TV magnate Ted Turner to colourise much of the MGM archive, the rights to which he had bought in March 1986. This led to a classic 'industry vs. artistry' debate: as with panning and scanning (see chapter six) Turner and his supporters regarded the issue purely as a business decision, while those for whom film was an object of cultural integrity condemned what they saw as the 'vulgarisation' of historically important footage.[41] There were even calls for legislation to ban the practice, though, unsurprisingly, none ever materialised.[42]

By the mid-1990s colourising had all but disappeared, one suspects because it never found much of a market in the first place. However, it should be born in mind that – technically, at least – the process of adding colour information to a photographic image which had never captured it in the first place was nothing new. In the commercial film industry it had been widespread – in the form of tinting, toning and the various forms of selective non-photographic colour – in the three decades before the transition to sound. But, when revived in the late 1980s, it had failed because more effective ways of recording and reproducing colour photographically had become an industry standard, the technical quality of which consumers expected as a bare minimum and which was cost-effective to deliver as part of the production process.

The case-study in the next chapter follows a very similar pattern. The idea of synchronised sound had existed throughout the development of moving image technology. Indeed Thomas Edison was only interested in developing the latter in the first place because he thought it would add commercial value to his audio technologies. Yet the mass-integration of picture with sound did not take place until the late 1920s, just as the mass-integration of colour with moving image photography did not take place until the early 1950s. Again, with sound, we will see that a comparatively rapid series of events precipitated the commercial rollout of technologies which has been in active development for several decades previously; really the last instance of this happening before we move into the 'post-film' era of technologies centred around television, video recording and digital imaging.