FIAF

the preservation and restauration of colour and sound in films

FIAF

the preservation and restauration of colour and sound in films

D 4266

International Federation of Film Archives
Commission for the preservation
of audiovisual material

The Preservation and Restoration of Colour and Sound in Films

Collective of authors

Dumitru Moruzan - Roumania
Hubertus Pietrzok - GDR
Anatoli Polischko - USSR
Herbert Volkmann - GDR

Chairman and editor
Herbert Volkmann - GDR

1977

The Authors

Preservation of Colour in Films

Dr. Hubertus P i e t r z o k — Chapter 1
formerly Research Department of ORWO
Wolfen (GDR)

Herbert V o l k m a n n — Chapter 2
President of the International
Commission for the Preservation of
moving images of FIAF; former Director
of the State Film Archive of GDR,
Honorary Member of FIAF
Berlin (GDR)

Dipl.Chem. Dumitru M o r u z a n — Chapter 3 and 4
Director of the State Film Laboratory
Buftea (Roumania)

Preservation of Sound in Films

Dipl.Ing. Anatoli P o l i s c h k o — Chapter 5, 6 and 7.
Head of the Sound Department of
Gosfilmofond - Moscow

Table of contents

The Authors

Preface

The Preservation of Colour in Films

Chapter One — Historical development and properties of the colour photographic materials used in cinematography — 1

Chapter Two — The preservation of original colours in developed colour films — 52

Chapter Three — Preservation of the colour film picture by means of colour records on black-and-white film — 69

Chapter Four — Possibilities of restoring the colour in films — 87

The Preservation of Sound in Films

Chapter Five — Sound recording methods in Cinefilms — 105

Chapter Six — Types of sound recordings — 114

Chapter Seven — Preservation and restoration of sound recordings — 124

Preface

The present paper on "The Preservation and Restoration of Colour and Sound in Films" is the partial publication of a more extensive publication. It is made available to the member Archives of F.I.A.F. now in advance to that, in view of the rapidly increasing stock of colour films, the knowledge required will be propagated as soon as possible.

It would have been wrong if we had advocated a system of cheap but, in the long run, ineffective measures for the purpose of preservation of colour in films. That is of no use to anybody, least of all to the lovers of film arts and historians. If we want to preserve colour films until such time as it becomes possible to transfer them to a more durable medium of information, we must rely on scientific findings and practical experience and they show us the complication of the matter. The problem of preserving colour films cannot be solved by means of tricks and short cuts.

In the first chapter we discuss the historical development of cinema colour film materials as far as necessary to meet the needs of film Archives, particularly as to the identification of old films and decisions on measures of restoration. We have to take for granted a basic knowledge of physics and chemistry at least to the level taught in secondary schools. Chapter 4 necessarily involves chemists and technicians because, due to its sophistication, the restoration of colour films can only possibly be carried out by highly qualified personnel. Any attempt made by unqualified people will almost inevitably result in the loss of the original material.

Complicated chemical processes such as diffusion or masking cannot be explained without the pre-requisite of fundamental knowledge of physics and chemistry. To facilitate under-

standing, the technical terms used in the text will be explained by definitions in the supplement of the final version of the complete publication.

The paper is a collective work. Apart from the authors listed above, contributions were made by the following people:

Harold B r o w n
Film Preservation Officer,
National Film Archive, London (England)

Dipl.Chem. Desiré D e w a l s
Research department of Agfa-Gevaert,
Antwerp (Belgium)

Dipl.Ing. Harry E n e q u i s t
Svenska Film Institutet, Stockholm (Sweden)

Dr. I.M. F r i d m a n
Research Laboratories of the N.I.K.F.I.,
Moscow (U.S.S.R.)

Nils-Hugo G e b e r
former Head of the technical department,
Cinemateket Svenska Film Institutet,
Stockholm (Sweden)

Helmut K r ö n e r t
Filmtechnician in Staatliches Filmarchiv,
Babelsberg (G.D.R.)

Dr. G.I.P. L e v e n s o n
Research Department,
Kodak Ltd., Harrow (England)

Henk de S m i d t
Head of the technical department,
Nederlands Filmmuseum, Amsterdam (Netherland)

Dipl.Chem. T a m m
Research Department of Orwo, Wolfen (G.D.R.)

Dipl.Ing. Viorel T u d o r i c a
Head of the technical department,
Arhiva Nationala de Filme, Bucharest (Roumania)

Dipl.Ing. Jean V i v i é †
Service des Archives du Film,
Centre National de la Cinématographie,
Bois d'Arcy (France)

at conferences in

Leipzig	(G.D.R.)
Stockholm	(Sweden)
Copenhagen	(Denmark)
Kleinmachnow	(G.D.R.)
Moscow	(U.S.S.R.)
London	(England)
Bucharest	(Roumania)

over a period of 4 years, and in each case a remarkable number of experts from host countries in which we held meetings.

Many thanks to all of them. In particular I would like to thank those Archives which, by their generous hospitality, enabled us to carry out this work:

Staatliches Filmarchiv of the G.D.R., Berlin
Svenska Film Institutet, Stockholm, Sweden
Det Danske Filmmuseum, Copenhagen, Denmark
Gosfilmofond, Moscow, U.S.S.R.
The National Film Archive, London, England
Arhiva Nationala de Filme, Bucharest, Roumania

and the Fédération Internationale des Archives du Film (F.I.A.F.)

The authors wrote their various chapters in three different languages. We owe this english version to Harold Brown, National Film Archive in London, Member of the commission. Many thanks to him.

As stated in the beginning this is a partial publication. It will be united with the paper "Film Preservation" for black-and-white film (revised and brought up to the date), supplemented by a further paper on the preservation of magnetic recordings, of video-electronic systems and of videodisks, which we propose to publish under the title "Preservation of Audio-Visual Materials".

A pre-requisite to this is that the Commission will meet again with the generous hospitality of our friends and colleagues of F.I.A.F. member Archives, which we have enjoyed so far.

Herbert V o l k m a n n
President
of the International
Preservation Commission
of F.I.A.F.

Berlin (G.D.R.), March 1978

1st Chapter

1. Historical development and properties of the colour photographic materials used in cinematography

1.1 Invention of the colour film and the first experiments

The invention of the motion picture on a preservable medium was the work of scientists and practitioners from many countries. From the first theoretical knowledge to the achievement of a practical technology of manufacturing, processing and projection of colour film for full scale film production occupied a span of eight decades. Several generations of scientists have worked upon it.

The physicists Maxwell, Helmholtz and Ducos du Hauron described the fundamental requirements for three-colour photography as early as in the middle of the 19th century.

The first public showings of a silent black-and-white film took place in 1895 and immediately after that there were the first efforts to present pictures in natural colours on the screen. Hand coloured films have survived from this period, as well as films which were given a single overall colour (tinting) and others

in which the black silver, forming the image was converted to a coloured silver salt. Some films had a two-coloured effect by employing both of these methods. None of these, however, were real colour films. They were only arbitrarily coloured black-and-white films. They did not reproduce the natural colours of the original scene.

Such valuable films still exist in the older archives. Since they were, of course, manufactured on nitrate base they are endangered due to their age. They can be saved by copying onto acetate colour film. Some good results have been achieved by so doing.

Isensee in 1897 and Friese-Greene in 1898 developed means for photographically taking colour motion pictures. Three filters in the primary colours red, green and blue were rotated in front of the taking lens in the taking rhythm so that three black-and-white colour records resulted in the black-and-white film in the camera. Every third picture belonged to the same colour record. Projection was carried out in a manner analogous to the method of shooting.

These processes were used very little in the commercial cinema. This was true of additive screen methods of the time. These were experiments on a long and as yet unsuccessful road. (Colour separations have more recently been successfully employed for transfer to multilayer film).

1.2 Optical principles of colour photography

All processes of colour photography which gained a certain importance in the past and are important today were based and are based on the principle of light sensitivity of the silver halide salts and the development of the latent picture created during the

exposure. The discovery of the principle of photography with light-sensitive silver halide salts ultimately goes back to the works of the Frenchman Daguerre.

In addition to the already mentioned fundamentals of colour synthesis, the discovery of the chemical sensitization by H.W. Vogel also was important for the realization of colour photography. It was only the development of his discovery that provided the possibility to produce photographic silver halide emulsions sensitive to three different spectral ranges of visible light.

To facilitate understanding of the various processes of colour photography used in practice, brief explanations of the nature of light and colour sensitivity are given before these processes are described.

1.2.1 Light

Of all the electromagnetic oscillations which fill space in the order of magnitude from 10^{12}nm (1 km) down to 10^{-9}nm, only the range between about 400 - 700 nm is perceived by us as light. The whole range of electromagnetic oscillations is represented in appendix 1 - Fig. **6 - 1.**

To this great range of electromagnetic oscillations our sensitivity is rather limited. We 'feel' the infrared rays as heat. However, we 'see' the rays of light since radiation between 400 and 700 nm exerts sensations on our eye which differ according to wavelength. These different ranges we perceive as 'colours'.

700 nm red	520 nm green
650 nm orange	500 nm bluish green
590 nm yellow	470 nm blue
550 nm yellowish-green	410 nm bluish violet

1 nm = 10^{-9} metres

Thus the impressions of light and colour are not phenomena present in nature but sensations of our organism which are caused by electromagnetic oscillations.

Like all processes of oscillation the rays of light follow certain laws; according to these they are either reflected, absorbed or transmitted. If the rays are transmitted they are refracted more or less from their original direction and the degree of refracted more or less from their original direction and the degree of refraction depends on the wavelength (App. 1 - 6-2 Fig.2). The rays, refracted to a different extent according to their wavelength, then form a socalled spectrum when collected on a white screen (App. 1 - 6-2 Fig.1, colour distribution is represented). This spectrum consists mainly of the colours blue, bluish green (cyan), green, yellow and red. Blue, green and red each occupy a third of the spectrum, while cyan and yellow appear at the boundaries of blue-green and green-red respectively. The shortwave third of the spectrum comprises the totality of the blue rays, the centre third the green rays, and the long-wave third the red rays.

If the entire white light passes through a body the latter is transparent and colourless, and a body which reflects all of the incident light appears as white. The white light, however, can also be absorbed fully or in part by a body. If this occurs completely no ray of light can reach our eye and the body therefore appears as black. If it selectively absorbs only certain wave bands it appears as coloured. This differentation of the individual wavelength by colours is a physiological phenomenon.

1.2.2 Sensation of colour

As in a camera, the rays of light outgoing from the object, form an image on the retina of the eye.

The retina has a very large number of rod-shaped cells which contain the visual purple and permit scotopic and mesopic vision.

Cone-shaped cells are also present in a large number for colour vision. These cones are not only light-sensitive but they are also able to distinguish light of different wavelengths and consequently colours.

Now, how is the eye able to distinguish between such a variety of possible colours? Maxwell to whom I referred already in the introduction, found in 1855 that all shades of colour can be mixed from only three coloured lights. You obtain cyan by mixing blue and green, yellow from green and red, magenta from blue and red and finally white from the same portions of blue, red and green. As early as 1852, Helmholtz stated his theory of colour vision according to which he assumed three colour-sensitive organs in the eye which respond to blue, green and red light (the 'cones'). In recent times this theory was corroborated by von Studnitz for it was possible to isolate three pigments from the cones of the retina which absorb blue, green and red light.

Only the action of light on these cones and the transmission of these sensations via the optic nerve into the brain give us the impression of a colour. When the blue, green and red-sensitive cones in their totality are excited we have the impression of colourless light or of a white object. When the blue-sensitive cones alone are excited there results the impression of blue. Likewise the excitement of a group of cones sensitive to other lights gives the corresponding colour impressions. When blue and green-sensitive cones are excited together there results the colour impression of bluish green (cyan) and, likewise, the joint excitements of the blue

and red-sensitive cones results in the impression of magenta and those of the red and green-sensitive ones yield the impression of yellow.

An object will thus have a colour effect only if it neither reflects nor transmits the entire white light but absorbs part of the radiation. If it absorbs the blue portion, the blue-sensitive cones are not excited but only the red and green-sensitive ones - there results the impression of "yellow". In case that the object absorbs the green spectral range, the green-sensitive cones are not excited. The sum of the excitements of the two other groups of cones yields the impression of "magenta". If the object absorbs the long-wave red radiation, the red-sensitive cones are not excited and we have consequently the impression of a bluish green (cyan) colour sensation. If the object absorbs the short and medium wave band only the red-sensitive cones are excited. When the medium and long-wave band is absorbed in the same manner the impression of "blue" is caused and when the short and long wave band is absorbed we have the impression of "green".

The same process occurs when the object is only partially light-transparent and absorbs it partially. Only a certain part of the white light is transmitted then which we perceive as a certain colour according to its spectral position. Such bodies are e.g. coloured glasses which for example may be used as light filters. The same process also occurs when coloured slides and films are projected.

Colouring agents are used to colour objects. These are compounds of special chemical constitution which absorb a fixed spectral range especially well and always appear in the complementary colour of the range of rays absorbed. Colour and complementary colour mix additively to give white light. Pairs are

e.g. yellow and blue, magenta and green, and cyan and red. They are termed complementary pairs of colour.

From the above it follows that colours can be perceived only if less than the entire apparatus of cones is excited. The eye consequently is able to perceive the great variety of the "colours of nature" with only three kinds of colour sensitive organ.

The sensitivity curves of the three types of cones of the eye have considerable areas of overlap. It is therefore possible for very narrowly limited wavebands to excite simultaneously two types of cones. For example the "sodium line" situated at 589 nm is perceived as yellow because it excites equally, both the red-sensitive and the green-sensitive cones. Light of wavelength about 600 nm appears as orange-red because the red cones are more sensitive to this wavelength than are the green cones.

The eye is unable to distinguish whether it is being stimulated by a very narrow waveband (e.g. 589 nm) or whether it is being stimulated by white light from which one third has been filtered. That is, we received the same impression from monochromatic sodium light as we do when the blue third of the spectrum is filtered out of white light. It is this inability of the eye to distinguish individual components of the stimulating radiation which makes colour photography possible.

1.2.3 Colour photography

We have seen that light which comprises only the short-wave third of the spectrum gives a blue impression, the medium third provides a green impression and the long-wave third yields a red impression. The colours yellow, magenta and cyan are so-called

minus or subtractive colours because they originate by the fact that in each case one third of the spectrum is missing from white light.

If the eye were able to distinguish the individual wave-lengths in a mixture of rays, it would be necessary to find a method of colour photography in which every spot of the colour photograph emitted exactly the same wavelength of light as was emitted by the corresponding spot of the original object. In 1891 the Luxemburgian, Lippmann, invented such a method. It was based on the principle of the interference of standing waves. However, there was no practical application because of its insensitivity. Only three-colour photography was put to use; the characteristics of which were explained by Ducos du Hauron in his paper "Solution physique du problème de la reproduction des couleurs pour la photographie" at first in 1862. This paper, submitted to the Académie des Sciences in Paris, was not accepted, so that first publication did not take place until 1897.

1.2.4 Additive process

This method is based on the fact that all colours can be produced by mixing blue, green and red rays of light. Black is originated when no light at all reaches the viewing area. Since light is added to light here, this type is termed "additive colour synthesis".

For the practical application of the process one can separately record the blue, red and green portions of an object light on a photographic material. You obtain the colour records when you expose a panchromatically sensitized photographic emulsion layer behind the corresponding filters. A blue filter, which transmits only the short-wave third of spectrum, is required for the blue record; a green filter which

transmits only the medium third, is needed for the green record; and a red filter which transmits only the long-wave third, must be provided for the red record. Two thirds of the spectrum are absorbed by each of these filters. After producing positive pictures from these negative partial records they are projected in superimposition by means of three different projectors having blue, green and red light sources. Then the coloured lights mix on the projection screen in the ratio in which they were present in the original object (App 1 **Fig.6 - 3**).

In the beginning of colour photography very beautiful coloured pictures could be projected by means of this process. The process, of course, has the drawback that the colour records must be produced separately. If this is done successively, time parallax is involved, and if this is done simultaneously by three cameras, then spatial parallax appears. The process in this form does not lend itself to the production of animated pictures.

To avoid the drawback of time and spatial parallax, complex beam-splitting cameras have been constructed. Such cameras were also used for such processes as Technicolor, which also needed separate colour records.

To avoid the disadvantages of separate colour records the brothers Lumière developed the colour screen process in 1908. They dyed starch grains in the colours blue, green and red, mixed these coloured grains intimately and applied this mixture on a glass plate and made sure that the whole layer had a thickness of only one grain. In this way they obtained a screen layer composed of an immense number of tiny adjacent filters. Then they poured a panchromatically sensitized emulsion on this layer. When it was exposed through the screen layer, the corresponding colour record originated behind each coloured starch

grain. After developing, the plate is blackened by the developed silver at those points at which light passed through the tiny filters. Since, however, light must pass through at these points during projecting to obtain correctly coloured picture, the silver must be removed by dissolving the silver in a bleach bath. The plate must be opaque at those points at which were not struck by light. This is obtained by not fixing out the residual silver bromide afterwards but developing it after a second exposure (reversal process). The fully processed plate is thus composed of numerous individual colour dots which, however, cannot be individually perceived by the eye because of their small dimensions.

Apart from Lumière, such irregular screens were also produced by other firms mostly as plates in modified form. The irregularity of the screen is considerably disturbing in the case of great enlargement and animated pictures. Therefore regular screens were also developed in the form of dot and line screens. A particularly interesting method is represented by the lens screens where fine cylindrical lenses were impressed into the surface of the film base; the focal length of which corresponded to the thickness of the film. By means of these cylindrical lenses a colour filter which is situated in front of the lens and consists of three filter strips in the primary colours blue, green and red is imaged simultaneously with the object on the photosensitive layer. Reproduction is carried out by means of a projector in front of the lens of which there is a similar multi-strip filter. The firms Kodak(R) and Agfa(R) temporarily produced films for microphotography and 16 mm ciné films by this process.

Although the results of the screen processes were quite acceptable as to quality, they could not

succeed. The main reason for it is the loss of light underlying the additive process which results from the fact that each white ray of light must pass a filter which absorbs two thirds of the spectrum before it reaches the emulsion layer. The same conditions apply to the reproduction.

1.2.5 Subtractive process

Theoretically it is not only possible to synthesize all colours of the spectrum from the three additive primary colours, blue, green and red, but it is also possible to use the three subtractive colours yellow, magenta and cyan for this purpose. These colours result when certain wave ranges, namely the additive primary colours, are subtracted from white light having a continuous spectrum. The subtractive colours are much more favourable with respect to the illumination aspect because they absorb only one third of the visible spectral range and they are transparent for two thirds while the additive primary colours are transparent for only one third each and absorb two thirds.

The subtractive colours are created as follows:

If the short-wave spectral third, the blue light, is absorbed from white light the remaining light appears yellow. If the green spectral third is absorbed the other two thirds complete each other to give a magenta impression, and if finally the long-wave red spectral third is filtered out of the white light, cyan is left. All other colour shades can be produced by mixing two of the three primary colours or all of them in different portions. White occurs if no light is absorbed and black results if all of the three primary colours are absorbed in equal portions.

In the beginning the subtractive colour photographic

processes consisted of producing three black-and-white partial records simultaneously or successively and making positives from these partial records. This had to be carried out in such a manner that the blue partial record supplied a yellow component picture, the green one a magenta component and the red partial record a cyan component. If the coloured component pictures are transparent they can be projected arranged one after another, onto a white screen by means of a single source of light, (i.e. a common projector) which results in a correctly coloured positive picture.

However, you also can print the three component pictures on a white surface such as paper by means of dyes. The colour photographic print processes are based on this method, accomplished by photogravure, letterpress-printing, collotype printing and offset printing. This process of producing three black-and-white partial records for the blue, green and red spectral range and printing the corresponding complementary positive pictures can also be used to produce coloured positives by means of the negative-positive process. (App 1 Fig. 6 - 4).

1.3 The Technicolor(R) system

The Technicolor(R) process is a negative-positive process in which negative black-and-white records are used for picture recording. Beam-splitting cameras, the fundamental mode of operation of which is represented in App 1 Fig. 6 - 5, were used in the beginning to produce these records. Both the time parallax and the spatial parallax were eliminated by the application of these cameras.

To produce the colour positives, a print from each of the black-and-white records is made onto a film carrying a light-sensitive gelatine emulsion

(printing matrix). This is processed in a manner which hardens the gelatine in the exposed parts. The unhardened gelatine is then washed away in hot water, leaving the exposed insoluble hardened gelatine still on the film base. Each of these films is then dyed in its appropriate secondary colour, and the dye is then transferred under pressure to a final print film carrying a gelatine layer suitable to receive the dye.

In 1915 the process was introduced as a two-colour process by Technicolor in the U.S.A. and two-colour records were produced in a beam-splitting camera for this purpose. Outgoing from three record negatives which also were obtained in a beam-splitting camera at first, a three-colour process of printing was developed later. Technicolor uses the subtractive basic colours.

The production of the three black-and-white colour separations in the beam-splitting camera was problematic at first because of the high light-level required. In addition to this, the weight of the camera itself proved to be a great disadvantage; it weighs about 170 kg and is therefore very inflexible. When colour negative film (produced by chromogenic development techniques) had been brought to a sufficiently high standard of sensitivity and colour quality, Technicolor abandoned the use of beam-splitting cameras and used colour negative for the original record. The printing matrices were then made from the colour negative. The three-colour dye-transfer process has been continually improved and is still in use to this day for the manufacture of colour motion-picture prints.

1.4 Colour development

By the action of radiant energy in the form of short-wave light certain high-energy conversions take place in the crystal assembly of the silver halide crystals. Thus is created, the so-called "latent" image which externally is not visible. Weak reducing agents, however, are able to reduce this activated silver halide under an enormous intensification of the effect and precipitation of metallic silver proportionally to the incident luminous energy. Silver halides intrinsically respond only to the short-wave rays of visible light and partly to certain ranges of ultraviolet light. However, chemical sensitizing agents also render them sensitive to other spectral ranges, even to infrared light.

The photographic developer is itself oxidized in the process of developing. From well known developing agents such as hydroquinone or aminophenol, a quinonoid substance is produced as the final product of oxidation which reacts with sodium sulphite contained in black-and-white developers in a larger quantity to give hydroquinone sulphonic acid. In the absence of sufficient sodium sulphite, the quinoid oxides precipitate along with the silver and there results a so-called residual image, which may be made visible by re-converting the silver into a silver salt by means of a mild oxidising agent such as potassium ferricyanide, in the presence of potassium bromide, and then fixing it out. A particularly strong yellow image is obtained when pyro-catechin without sulphite, is used as the developer.

In 1907 Homolka discovered that certain dye intermediate products - in particular those which result in indigoid dyes - while, in addition to the developed silver, there is also deposited a water-insoluble dye.

Such developing agents are indoxyl or 3 oxythionaphthene. The precipited dyes are indigo and thioindigo respectively.

However, there are further possibilities to utilize the oxides of the developer for dye production. Particularly the oxides of p-phenylene diamine derivatives; and among them, above all, those of the asymmetric dialkyl derivatives react very readily with the corresponding components to give dyes. Such dialkyl-p-phenylene diamines have been known as photographic developers for a long time. The knowledge that oxides of dialkyl-p-phenylene diamines yield condensations to dyes goes back to two discoveries made in 1882 and 1889. Witt found in 1882 that nitrosodimethylaniline condenses with naphthol to a blue dye, naphthol blue. This dye belongs to the class of quinoimine dyes. In 1889 Sachs discovered that nitrose dimethylaniline, together with active methylene groups formed yellow, orange or violet azomethine dyes, according to the constitution of the coupling component.

In 1909 Rudolf Fischer found that the same dyes also form in the photographic development when exposed silver halide is developed with a dialkyl-p-phenylene diamine in the presence of naphthols, phenols or together with active methylene. As a rule, the dyes are insoluble in water and simultaneously precipitate with the reduced silver (App 1 **Fig.6 - 6a).**

Fischer used this process of chromogenic development to produce monochromatic paper pictures. However, since the principle of subtractive colour photography had been known since Ducos du Hauron, Fischer made the proposal in patent specifications in 1911 to put the different dye forming agents for yellow, magenta and cyan into the corresponding layers of a multi-

emulsion film and then to develop them together with a developer of the p-phenylene diamine series at which yellow, magenta and cyan pictures should originate in the three layers in a single development. Neither Fischer himself nor others who later worked according to these patents, succeeded in realizing the proposal since the diffusion of the dye-forming agents made it impossible to localize them in a given layer.

1.4.1 Diffusion - migration of molecules

Diffusion is a well-known process in the science of materials. Matter cannot be dispersed as finely as one likes without a fundamental change and one finally arrives at molecules as the smallest building blocks. These molecules can be linked by inherent molecular forces to form a regular crystal assembly. If, however, these molecular forces are surmounted by supplying sufficient kinetic energy such as heat the crystals can be transferred into the liquid or gaseous state.

The crystal assembly can also be neutralized by the action of liquids - the substance dissolves. Then it may be observed that the substance disperses homogeneously into the entire liquid after some time even without the application of mechanical means such as agitation.

The same phenomenon can also be observed when two different solutions are mixed. Gases mix with each other in the same way. Moreover, molecules in gases emerge from liquids and gaseous molecules shift into liquids. All of these phenomena are based upon molecular motion which can be considered the cause of the diffusion, i.e. the migration of molecules.

This migration generally cannot be prevented even if

insoluble colloidal substances are used as partitions between the liquids or solutions. Such colloids for example can have the form of cloudy stable suspensions of solid or liquid substances in water. They are also called emulsions. With a suitable composition they can pass from the liquid state (sol) into a peculiar solid state - the gels. Such colloids exhibit behaviour similar to that of gelatine, from which the term 'gel' is derived.

The cohesion of the gels is ensured by the absorptive force of water. The absorptive components of the gel are called 'micelles'. Other molecules can migrate through the micelle space with a diffusion. It is therefore obvious that aqueous solution of crystalline substances such as salts, dyes etc. diffuse in a gelatine gel.

This diffusion in gelatine is the very reason why photography is possible because the gelatine is well capable of retaining the coarse-disperse silver halides in the emulsion, but permit the molecules of the developers and other treatment baths to reach the silver halide without any hindrance. The processing of the black-and-white films carried out in the baths for developing, fixing or washing posed no problem in this respect. On the other hand the gelatine can retain only large, water-insoluble particles. The dyes developing during the colour development therefore can be retained in the gelatine layer only if they are insoluble in water and form larger crystalline or amorphous structures. If the resulting dye is water-soluble, coloured pictures cannot be obtained because the dyes bleed even during development and during the subsequent treatment baths or during the intermediate washes.

All the colour-coupling agents known to Rudolf Fischer

had water-soluble properties. Despite efforts lasting decades it was not found possible to reduce the diffusion of the couplers (by such means as reducing their solubility) to the degree required to meet the practical requirements of multi-layer colour films.

We have to take into account here that the individual layers of colour films have a thickness of only a few thousandths of a millimeter for optical, mechanical and other reasons and that therefore a very small diffusion width does not allow the separation of colours in certain layers and their concentration on certain spots. Furthermore, the colour coupling agents can be quite insoluble in water but dissolve readily in alkaline treatment baths (e.g. the developer) due to their phenolic or enolic hydroxyl groups.

1.4.2 The Kodachrome(R) process

Because it was impossible in the beginning to solve the diffusion problem another process which became very important was elaborated by the two American amateurs, Mannes and Godowsky, and adopted by the Eastman-Kodak(R) Company. This process has become known as the Kodachrome(R) process. It is operated solely as a reversal process and uses a multi-layer black-and-white film which is subjected to black-and-white developing after exposure. To produce the dyes of the picture, the colour coupling agents are dissolved in the colour developer. One colour developer is used for each primary colour. The principle of controlled penetration was applied in the original version, i.e. the whole film is developed cyan after the second exposure, then a bleaching bath is made to penetrate into the layers to such an extent that the silver formed and the picture dye (cyan) are bleached out in the two uppermost layers. During

this process the silver is converted into a silver salt which can be developed. Now it is treated again by means of a colour developer which produces a magenta picture.

Now the uppermost of the two magenta layers is bleached out and treated with a developer in the same way, which produces a yellow component picture in the uppermost layer only. After dissolving out the entire silver, only the respective dye remains in the individual layers.

Although the production of a multi-colour dye picture by this process is very complex and requires a high accuracy during processing to obtain good results; these results indeed are remarkably good. Later the more complex method of controlled penetration was replaced by the simpler and safer controlled colour post-exposure.

Even today, because of certain advantages, amateur and professional Kodachrome materials are processed by this method. The process necessitates a great deal of experience and exactness and requires personnel of many years experience.

1.5 Diffusion-proof coupling agents

In the middle of the thirties two entirely different methods were developed, in Wolfen and Rochester, to solve this problem and to produce the three component colour pictures in the subtractive primary colours yellow, magenta and cyan, according to the idea of Ducos du Hauron, in one developing cycle in three layers arranged one upon the other. (App 1 **Fig.6 - 6b).**

1.5.1 Two different principles of solution

The process which has become known under the term Agfacolor(R) uses colour coupling agents which are soluble in aqueous alkali, the molecule of which, however, is awkward in its structure to such an extent that diffusion is no longer possible in the micelle interspaces of the gelatine gel layer of the photographic emulsion. This was achieved by the introduction of a long alkyl residue into the molecule of the colour coupling agent. To place the colour coupling agents into the photographic emulsion they are dissolved in aqueous alkali and this solution is stirred into the photographic emulsion. Care must be taken to avoid failure, by precise adjustment of the pH value of the emulsion. At that time Agfa obtained a patent for the use of alkyl residues of 5 carbon atoms or more. Alkyl chains of 14 to 18 carbon atoms proved to be most favourable in practice.

A similar solution of the diffusion problem was not available to Eastman-Kodak once these patent specifications became known. It found another solution very quickly - the oil coupling agent; insoluble in water.

According to their process of diffusion-proofing of the colour coupling agents hydrophobic, (i.e. water insoluble) coupling agents were used and dissolved in high-boiling solvents which are not miscible with water at a high concentration partly by means of solubizers. Then these coupling agent solutions were dispersed very finely in the photographic solution so that they were present in the emulsion in microscopically small droplets.

The two processes differ from each other in the form in which the colour coupling agents are present in the layer. The colour coupling agents which are

soluble in water have a relatively uniform distribution in the layer as alkali salts in a quasi-solute form while the so-called "oil coupling agents" solute in the high-boiling solvents are not uniformly present in the emulsion but have the form of very finely distributed droplets.

Diffusion-proofing by these two processes was the basis of the manufacture of colour materials for cinematography for more than two decades.

1.5.2 The first film material with diffusion-proof coupling agents before 1939

The first colour material produced in Wolfen according to this principle with diffusion-proof colour coupling agents soluble in water was a reversible colour film. This film material was used on a large scale for the first time to produce the documentary film "Olympic Games 1936 in Berlin". For a long time this film was the only colour film produced by means of a reversible colour material. About 1950 the Ansco Corporation tried to introduce a colour reversal process for cine purposes but failed due to the difficulties of the system.

The negative-positive system which had been developed in Wolfen as early as 1938/39 was adopted immediately by the cine industry although it had clear defects with respect to the colour reproduction, due to the very imperfect optical properties of the picture dyes and as to sensitivity which clearly was inferior to that of the then black-and-white films. At first there were only two types of colour negative films - one intended for artificial light and one for daylight - and one type of colour positive film, the structure of which was similar to the description above. They differed from each other with respect to sensitivity, sensitization and partly as to the

coupling agents and gradation. The two gradations were adjusted in such a manner that their product equalled about 1.5 to 1.6. This so-called product-gamma is also maintained nowadays.

1.5.3 First post-war developments (1945 - 1950)

With the expiration of Agfa's(R) patents after the Second World War, many firms had the possibility to produce colour films themselves according to the Wolfen principle. In particular the firms Gevaert(R), Ferrania(R), Ansco(R), Ilford(R) and the Japanese firms Fuji(R) and Konishiroku(R) employed the Wolfen principle; put their colour film onto the market and also made vigorous efforts in research. Research in the field of colour films was put on a broad basis in the U.S.S.R., too, and colour film materials were produced. It was soon recognized that the first colour coupling agents developed in Wolfen were inadequate in many respects. To mention just a few very important factors: the optical properties of the dyes were unsatisfactory; they were partly the reason for considerable colour falsifications - especially with the negative-positive process which is important for the cinema industry; they adversely affected the sensitivity of the emulsion layers. There were difficulties in producing the films, difficulties in the storage of the raw films and last, but not least, the durability of the picture dyes left much to be desired.

These and some other properties which can be influenced by colour coupling agents of different constitution caused intensive research in the field of colour coupling agents in connection with the properties of colour films.

As described above the structure of the first cine

material produced in Wolfen is the classic layer structure of blue-sensitive, green-sensitive and red-sensitive emulsion layers from top to bottom with a yellow filter layer made of colloidal silver between upper and middle emulsion layers. Then came a green-dyed, alkali-soluble, anti-halation layer. In the beginning, the negative films were manufactured with a sensitivity of 13 DIN and a gamma of about 0.75. The positive was made with the appropriate gamma of about 2.4.

In 1949 this series was completed by a duplicating film which was developed by the reversal process and immediately provided a duplicate negative when copying from the original negative. The development of this duplicate material has proved necessary because very soon the number of copies required could no longer be produced from the original negative. Moreover, the international exchange of films steadily increased and in correspondence to the practice in the field of black-and white films this exchange was to have the form of duplicates in the field of colour films, too. The structure of the material corresponded to that of the other two cinematograph films with respect to the sequence of layers except that the selective sensitization of the positive film was combined with the colour coupling agent of the negative film in the red-sensitive layer.

During the Second World War, Kodak had elaborated and, shortly after, put on the market a colour film system which differed essentially from the Wolfen product in some respects. From the first the system was offered with complete duplicating process included. The colour materials were composed as multilayer films according to the Kodak(R) principle, i.e. the colour coupling agents, dissolved in high-boiling solvents, were introduced into the emulsion as so-

called "oil coupling agents". While the Wolfen films still were produced on a nitrocellulose base in the beginning and the complete change-over to cellulose acetate was carried out gradually within a few years, the Kodak(R) films were immediately supplied on cellulose acetate. This change-over from nitrocellulose base to cellulose acetate base was decisive improvement to extend the life of films.

From the outset the Eastman-Kodak(R)-positive film had a structure which differed from that of the Wolfen positive film. It has a structure according to the so-called principle of the interchanged sequence of layers. Such films have the following sequence of layers from the upper layer to the base with respect to their light-sensitivity: green, red and blue. This means that the two sensitized layers are arranged above the blue-sensitive layer. Such a structure is only possible if silver-chloride emulsions, which have very little sensitivity in the blue spectral range, are used for the green and red-sensitized layers. A highly sensitive silver bromide emulsion with a corresponding gradation is required for the blue-sensitive layer.

This principle enables the production of visually sharper copies than with positive films having the conventional arrangement of layers. Because of the high sensitivity of the human eye in the green spectral range the magenta component picture of a multicolour picture makes the greatest contribution to the visual impression of sharpness. If the layer which carries this picture is arranged as the uppermost layer in the positive film the magenta component picture can be imaged more sharply in the copying process.

The Eastman(R) positive film in its original structure

was considerably less sensitive than the Wolfen positive film. However, it did not need a filter layer and consequently permitted a substantially simpler processing, in respect of sound track redevelopment.

For duplicating purposes a panchromatically sensitized black-and-white film (Type 5235) was offered, on which the three colour records were produced separately. These three records were then printed in register onto a special colour duplicate negative. This procedure is still sometimes used today. Similar colour-separations are also used by Technicolor to produce copies. This duplicating process is no doubt more difficult to handle than, for example, the colour reversal duplicating negative process offered by Wolfen in the beginning and it requires a great deal of experience to obtain good results. On the other hand, however, it offers the advantage for archives that a colour film can be stored as black-and-white material. This considerably facilitates storage when certain conditions are observed, which will be explained in detail later.

The colour negative film of Eastman Kodak(R) had the same sensitivity as the Wolfen material but characteristically differed in two properties. The gradation of the film was more flat at about 0.6 and this was the first camera negative film to have automatic dye masking. This achieved an essential improvement of the colour quality.

1.5.4 Colour reversal process

It should be mentioned in this context that the colour reversal processes could not make their way in the cinema industry as camera and print materials except for the use of colour reversal films as duplicating films. One of the reasons for this is that

reversal processing is too inflexible and that there is practically no possibility of individual artistic shaping of pictures during shooting and in the copying process at least as far as the colour information is concerned.

In more recent years, however, reversal processes increasingly gain in interest. Reversal colour films are used particularly for topical telecasts in 16 mm size for direct transmission in colour television. In comparison with the negative-positive process they are of interest because of the shorter access time due to the absence of need to make a print. A short processing time is of great importance. Moreover, the higher sensitivity of the reversal film materials is a decisive factor especially with artificial lighting. The scanning is normally carried out from the original; but sometimes from a copy if circumstances demand it.

1.6 Theory and production techniques of dye masking

1.6.1 Theory

It is not within the scope of this paper to discuss in detail the extensive field of masking and its different methods and applications. Since, however, masks of various kinds have been extensively used with cinematographic colour materials and photomechanical works in the colour sector for many years it appears necessary to explain the purpose and mode of operation of the main process of automatic dye masks.

The term "masking" is used in the photographic and photomechanical industry to express different meanings. As the term is used a mask can be defined as a photographic picture which is superimposed upon

another photographic picture and thus changes the reproduction characteristics of the latter.

In the simplest case a mask can be used to change the density range and contrast of a photographic picture e.g. a negative picture. For this purpose a photographic positive picture of a low contrast is used which is superimposed upon the negative picture. Let us look at the picture of a step wedge on a black-and-white negative material as a photographic picture. If the silver densities are measured step by step after developing and the values measured are plotted against the logarithms of the respective exposures one obtains the so-called characteristic curve of the material.

In the same way is obtained the characteristic curve of the mask picture, which has the opposite direction of the curve of the negative picture. These curves characterize the essential properties of the photographic material and give, above all, information on the light sensitivity and the contrast range. The tangent of the angle of inclination of the straight-line part is designated as gamma and a measure of the gradation.

The results of the combination of masks of different gradation with a negative picture the gamma-value of which is 1.0 are represented in App 1 Fig 7a - c. If a mask picture the gamma-value of which is 1.0 is combined with a negative picture of gamma = 1.0 as shown in App 1 Fig 7a the sum of all corresponding mask and negative densities is the same over the entire exposure range of the pictures, i.e. a uniform density, without picture information, results (dotted line).

If a negative picture is combined with a mask the gamma-value of which is lower than that of the

negative a negative picture with a reduced contrast results. The combination of the negative which has a gamma-value of 1.0 with a mask which has a gamma of 0.5 is represented in App **1 Fig 7b. A flatter** negative with a gamma of 0.5 results from this combination.

If the positive mask picture is steeper than the negative picture then combination of both of them results in a positive picture. In the case of **7c** there results a positive picture which has a gamma-value of 0.5 (from negative - gamma 1.0 - and positive - gamma 1.5).

This principle of masking according to which by superposition of a photographic picture by another one the photographic information content of the latter is modified or extinguished has also been used sucessfully in the field of colour cinematography for decades.

Modern colour photographic processes exclusively use the method of subtractive colour synthesis, i.e. a subtractive primary colour yellow, magenta or cyan is produced in each of the three layers of a colour photographic multilayer material, proportional to the amount of silver precipitated; from the mixture of which all colours are synthesized. Each of these three subtractive primary colours theoretically should absorb one third of the spectrum of the white light and totally transmit the two other thirds. This means that the cyan dye should absorb the red portion of the light completely. In the same way the magenta dye should absorb completely the green third of spectrum only and transmit the blue and red portions without loss and finally yellow should absorb the blue rays only and transmit the green and red ones.

The absorption curves of the subtractive primary

colours theoretically should show flat maxima of the same height only in the respective third of spectrum and all together enclose the whole visible spectrum. If this is not the case they cannot absorb the whole visible radiation and thus cannot permit correct colour reproduction.

However, this theoretic demand is not met by any dye in practice, even the best ones still absorb light in spectral ranges in which they should not absorb and still transmit light where they should absorb it completely.

App 1 Fig 6 - 9 shows that, above all, the magenta and cyan dyes have quite considerable faulty absorptions and only the best yellow dyes approximate the theoretic requirements. The faulty absorptions have adverse effects on the colour reproduction. Here are two examples to explain this briefly. Since the cyan dye does not transmit as much green and blue light as it should the green shades which are formed from the green and blue available are too dark and also out of shade in the direction of blue. The magenta dye, above all, absorbs too high a proportion of blue light and therefore all red shades are reproduced too yellow.

The faulty absorptions of the dyes become especially apparent in copying processes. The negative picture dyes control the light reaching the colour positive.

The selectivity of the dyes is of particular importance in this process because each picture dye of the negative is to control only the light for one layer of the positive in each case, i.e. the yellow dye should control the light reaching the blue-sensitive layer, the magenta dye should control the light reaching the green-sensitive layer and the cyan dye the red-sensitive layer of the colour positive.

In consequence of the side absorptions, however, they also produce a picture impression in other layers of the positive e.g. the magenta dye exerts some influence in the blue-sensitive layer and the cyan dye in the green-sensitive layer and to a lesser extent in the blue-sensitive layer. It is a common practice in the cinematographic industry to obtain the major part of show copies from duplicate negatives. Therefore several copying processes are involved before the final colour positive, so that the faults described accumulated before it was possible to extensively eliminate the faulty absorptions of the picture dyes by means of masking processes.

One can imagine that for example the magenta dye in practice is composed of the ideal magenta dye plus a certain portion of a yellow dye; and the cyan dye is made up of the ideal cyan dye, plus a magenta component and a small yellow component. If one succeeds now in eliminating the yellow component from the practical magenta dye and the magenta component out of the cyan dye, almost ideal dyes remain. The removal of these dyes which cause the faulty absorptions can be obtained by correspondingly coloured dye masks, and that according to the same principle as described above for black-and-white films.

The characteristic curve of a negative magenta dye wedge is represented in App1 **Fig 6-10. It was obtained** by measuring a wedge behind a green and a blue record filter. Measuring behind the red filter was omitted for the sake of clarity.

It can be seen that the magenta dye also has a considerable density in the blue third of spectrum in addition to that one in the green spectral range and consequently transfer picture information in the two thirds of spectrum. In the copying process the dye influences not only the green-sensitive layer

of the colour positive according to its main dye density but also its blue-sensitive layer. This, of course, results in shade displacements and a loss of colour saturation in the copy.

If one succeeds now to superimpose upon the negative magenta dye picture a weak positive yellow dye picture (dye mask) the side density of the magenta dye, is thereby changed in the blue spectral range. It can be eliminated completely if the two yellow dyes are matched in their properties and if the gradation of the mask picture and that of the picture of the side absorption of the magenta dye match together, too. In the same way the undesired side absorption of the cyan negative picture dye can be eliminated.

Large-sized pictures are generally used as a printing pattern for photomechanical work. Here it is possible to produce the mask pictures on some other material in separate operations and then unite them with the printing pattern.

1.6.2 Applied techniques

Such a procedure is not possible in the cinematograph industry. The colour mask has to be produced in the colour negative material itself. For example, this can be obtained by uniting the mask formation with the colour coupling process. If one uses e.g. coloured coupling agents for the negative instead of the usual colourless colour-coupling agents; namely yellow-red to red colour-coupling agents for cyan, from which the chromophore group is separated during the colour coupling process while forming the magenta and cyan picture dyes respectively, then the required colour masks are produced automatically for the magenta and cyan component pictures respectively. Suitable colour coupling agents which meet these requirements, for example, are certain azo dyes of

magenta and cyan coupling agents. If one uses such colour-coupling agents in colour negative films then the azo residues are separated in the colour-coupling while forming the magenta azo-methine and cyan indoaniline dyes. The colour masks are thus formed from the portion of the coloured coupling-agent not used for the colour-coupling and consequently their density is in the opposite direction to the density of the colour picture.

The same effect can also be obtained when the residual coupling-agent remaining after the colour-coupling is converted later into the appropriate dyes.

A different process is used by Agfa-Gevaert(R). Auxiliaries incorporated in the emulsion layers together with the residual coupling-agent which was not converted to picture dye in the colour development are coupled oxidically with the mask dyes in the bleaching bath during the normal processing operation.

The dye masks belong to classes of dyes which are at least as durable as the picture dyes and durable under the conditions found to be optimum for them.

1.7 Coupling agents insoluble in water without oil forming agents

It was not until the last decade that a third type of diffusion-proof colour-coupling agents made its way in practice for cinematograph materials. This method is almost a combination of the two methods mentioned under 1.6.1. Hydrophobic coupling agents which have longer alkyle chains are dissolved in low-boiling solvents which are partly miscible with water and partly immiscible with water; are placed

in the emulsion in such a manner that the coupling agents are dispersed very finely. The solvents are removed during the drying process when water is used for washing. The coupling-agents are thereby finely dispersed in the emulsion in an insoluble form.

This process was introduced by the firm Perutz(R) in the middle of the fifties, not however, for a cinematograph film but for the Perutz amateur reversible colour film C 18 and has continued to be used ever since then. Coupling agents incorporated in the individual layers in different ways are used with the reversible colour films type 600, 605 and 615 of the firm Gevaert; intended for television and with the colour positive film type 985 of the same firm. While the yellow and magenta coupling agents are soluble in water (according to the Wolfen principle) the cyan coupling agents are insoluble in water without oil-forming agents.

Coupling agents insoluble in water without oil-forming agents are considered more diffusion-proof and better coupling with the dye. The dyes formed, however, do not differ colorimetrically from those made of water-soluble colour coupling agents. Certain cyan water-insoluble coupling agents have the advantage of a better resistance against moisture, heat, and, above all, light. The firm Foma(R) (Czechoslovak Socialist Republic) has used water-insoluble coupling-agents (without oil forming agents) for yellow and magenta, not however, for cinematograph film but for the colour paper PM 20 produced by this firm. However, mixtures of water-soluble and water-insoluble coupling agents within a single layer are practicable.

Water-insoluble colour-coupling agents are prohibited to various manufacturers, except Kodak(R), Fuji(R), Konishiroku(R), 3M(R), Since the oil forming agent,

which has to be used at least at a ratio of 1 : 1 to the colour coupling agent according to the original Kodak(R) process, actually is a ballast material it can be expected that the coupling agents will succeed in the cases which are advantageous.

On the other hand it is undisputed that the oil forming agents favourably influence the physical-mechanical properties of the layers, especially the swelling, the drying times during processing and the flat position of films. Because of the advances in emulsion technology, and chemistry of high polymers it is possible to produce emulsions very rich in silver and poor in gelatine on the one hand and use suitable plastics to form layers on the other hand so that the problems of swelling, cure and flat position (also due to more recent knowledge in base manufacture) can be influenced in the desired direction by controlled dosage of gelatine, plastics and other additives.

1.8 The development of colour film materials since 1950

1.8.1 Cinematograph films

The process of automatic colour masking was first introduced by Kodak(R) with its colour negative film in 1950. Soon after that the internegative film followed (1951) as a masked material and the intermediate film in 1956. Both of the latter materials serve to produce duplicate negatives.

The Wolfen(R) factory offered its first masked film, the reversal dupe-negative film, later called DC2, in 1954. Masking is based on the principle of the azo dye coupling agents both with the Wolfen films and the films of the Soviet film factories. As mentioned above they differ from the Kodak(R) coupling agents

by having long alkyl chains for diffusion-proofing. This masking process was introduced by the Wolfen factory and the Soviet film factories using diffusion-proof azo dyes also with their colour negative and duplicate films for the negative-positive-dupe-process. The films in question are Colornegativ NC 3 (1970) and DC 6 (1970) of the Wolfen factory and the colour negative films DS 5, LN 5, LN 7 as the duplicating materials KP 4, KP 4 U and KP 5 of the Soviet film factories.

The colour negative films of the Japanese firms Fuji(R), Konishiroku(R) and Sakura(R) as well as the Ferrania(R) (now the 3 M(R)) colour negative film, are all made by the Kodak process, employing azo dye masks.

Later Kodak(R) offered the Eastman-(R) Color Intermediate film (type 5253), a colour film for duplicating purposes. This process essentially is simplified by using this film. It is a very fine-grained film which has about the sensitivity of colour positive, a flat gradation of theoretically 1.0, - (it is slightly higher in practice) - has automatic colour masks in the lower and middle layers, (i.e. the red and green-sensitive layers) and it permits production of a duplicate negative in a two-stage process. It has the sensitization of a colour positive film. However, the colour-coupling agent of the lower layer corresponds to that of a colour negative film.

In recent years - since about 1970 - Kodak(R) has also offered a reversal dupe negative film (type 5249) which corresponds to the Orwo(R) colordupfilm DC 2 with respect to structure and function and which also is masked both in the lower and middle layers.

A duplicate film KP 4 corresponding to the Eastman(R)

Intermediate is offered by the Soviet film factories since about 1967, which has been improved with respect to the reproduction of the colour values and the physical-mechanical properties in the meantime and now is offered as KP 5.

In addition to the reversal-dupe-negative film DC 2 the Wolfen factory has offered the film DC 6, which also corresponds to the Eastman(R) Intermediate, since about 1969.

There is a great number of positive films. Colour positives are supplied by all of the firms mentioned above. There were great changes with the positive films with respect to their structure and their photographic properties in course of time. The colour positive films of all firms, except the Eastman(R) color positive film, were composed according to the so-called classical sequence of layers, in the beginning their colour coupling agents were of the Wolfen type, they had no separate yellow filter layer made of colloidal silver, their processing thus was simpler than that of the Wolfen colour positive film type 4, i.e. the application of bleaching paste to the picture part was not necessary, which meant that a process step which involved many sources of error was nct required.

In the beginning the films were adjusted in their gradation to colour negative films with steep gradation. As the Eastmancolor(R) negative film made its way in the film studios more and more of the remaining firms adjusted their colour positive films in their gradation to the flat gradation of the Eastman(R) film. They also matched their own negative films to the Eastmancolor(R) negative film more and more. In the beginning these colour positive films, which had a steeper gradation still had the conventional sequence of layers. When, however, Eastman-

Kodak(R) dyed the colour positive film for the first time about 1960 to reduce the diffusion halo using washable filter dyes this film was so clearly superior to the other colour positive films with respect to its definition performance that the majority of the other firms such as Gevaert(R), Ferrania(R) and the Japanese film manufacturers also adopted the exchange of layers and dyeing for their colour positive films. Nowadays all notable manufacturers of cinematograph films, except Wolfen and the Soviet film factories produce colour positive films according to this principle.

In recent years there has been another fundamental change in the field of cinematograph films which was carried out by all factories, except Wolfen and the Soviet film factories. There has been a unification of processing of cinematograph films. Processing of both the colour negative films and the colour positive films is carried out uniformly according to the formulae of Kodak(R). Consequently most firms adopted the method of Kodak(R) for the colour coupling agents with the exception of Agfa-Gevaert(R) with its cinematograph films which partly use coupling agents soluble in water without solvents and partly coupling agents insoluble in water.

Although not yet decisively proved, it appears from studies on the cinematograph films of Kodak(R) that this development had no decisive influence on the durability of the picture dyes during storage.

1.8.2 Television films

In the last decade the development of colour television has opened a new field of application for the colour film because colour films are used on a large scale for colour transmissions in addition to magnetic picture recordings.

As far as the 35 mm size is concerned the same materials are used as in the feature film industry. They also employ the negative-positive process. The films in question essentially are television films which are produced according to this process. For economic reasons they are anxious to establish as close a connection as possible between colour television and the cinema business. (i.e. to show television films in the cinemas on the one hand, and use feature films in television on the other).

Different aspects are decisive for television news films. Here the aspect of being up-to-date is decisive. That is why the proportion of magnetic recordings is larger; but here too the film has an essential share due to the mobility of the equipment. Here the 16 mm size is preferred and reversal colour films are used almost exclusively because of the shorter time of availability. Short processing operations are preferred partly at an elevated temperature (the Kodak M.E. 4 process). Copies are produced on suitable conventional or new special copying films for the exchange of programmes or for the initial transmission. In addition to this magnetic picture recordings are transferred to film in many cases. The treatment of the magnetic recordings for keeping in Archives will be described in detail later.

Complete systems of reversal camera and copy films are offered for the purposes of television. Photographically the television reversal films differ from the amateur films by flatter gradation and lower maximum density. The copying materials are also flatter in gradation and lower in maximum density. These special needs result from the particular conditions of electronic scanning and reproduction.

Kodak(R) offers as camera films suitable for

television, Ektachrome(R) EF and ER for daylight and artificial light 7241, 7242, 7257 and 7258 and as copying film Ektachrome print film 7389.

Agfa-Gevaert(R) produces the camera films Type 600, 605 for artificial light and Type 615 for daylight and as copying film Type 902.

Orwo(R) offers, for special use in television, Orwocolor(R) reversal film Type UF 1.

The sensitivity of the camera films - except Gevaert(R) film Type 600 - lies between 21 and 23 DIN or 100 to 160 ASA or 90 to 180 GOST.

There are no new problems for the archives in keeping the colour television films. There are also no fundamental differences as to durability between the films of the negative-positive chain and those of the reversal system.

1.9 Durability of the picture dyes

Despite the fact that there were other problems in the foreground in the beginning such as improving the colour reproduction, increasing the sensitivity, stabilizing the processing etc. it must be stated that the unsatisfactory durability of the picture dyes very soon led to studies directed to their improvement.

1.9.1 It is regrettable that the colours in these films, especially the positives, fade rather quickly. Further the three components fade at different rates so that there is a distinct change of colour balance after a relatively short period of time. Some copies - mysteriously - exhibited better durability. The resistance of the picture dyes against light,

moisture and temperature was different. While the yellow picture dye faded first, being the upper layer next to the light in the classical sequence of layers when exposed to light, the cyan dye (lower layer) was the least durable when stored in the dark. The first copies on the Wolfen material showed a considerably poorer durability of this dye in comparison with the other two so that the copies showed a colour character which had shifted to yellow-red to such an extent after a one year storage at room temperature that they were useless for further showings.

Studies showed that two negatively acting complexes affect the durability of dyes:

1. system-conditioned properties and
2. external influences upon the film

System-conditioned factors are:
the dye-classes of the picture dyes, the influence of the base, residual chemicals of processing baths, the pH value of the emulsion layers of the films processed.

These factors can be influenced only by the use of other materials and the introduction of new techniques, i.e. by the raw film production and film processing.

External factors acting upon the film are:
light, temperature and moisture.

Here both the film manufacturers and processors and the Archives can provide optimum conditions favourable for durability which, however, are limited by the frame imposed by the system-conditioned factors.

1.9.2 Rapid test methods

It was necessary to elaborate rapid test methods for a directed research in the field of the durability of picture dyes by means of which well repeatable results could be obtained. Till now, however, the transfer of the results of this rapid test to the behaviour of the dyes is rather uncertain with long-term storage under room conditions. On the whole the results of the rapid tests can only give hints to the behaviour of the dyes under the conditions of the long-term storage on the statistical average. This is a fact which does not simplify the treatment of this complex. The conversion of the results of the rapid tests by means of the Arrhenius equation can only give approximate values for the behaviour of the dye. More exact results can only be obtained by prolonged observations under the conditions of storage. This, of course, renders the treatment of this field more difficult. However, one can notice that an improvement of the durability has been achieved in all colour materials.

1.9.3 Dye classes

The dyes themselves rank first among the system-conditioned factors. The durability of the picture dyes of different processes differs very much. The dyes which are used for dye-transfer processes (Technicolor) and bleaching processes (Gasparcolor) are substantially more durable than those dyes which result from chromogenic development.

1.9.4 Azo dyes

The Technicolor$^{(R)}$ system was developed as a printing process for copies. It uses azo dyes for printing. These dyes are transferred from a set of three matrices onto the final print film. Given favourable conditions of storage, these prints have a relatively

long life.

The same applies to the colour films which were produced by the silver-dye-bleach process (Gaspar-color) which was used at one time. This process is based on the fact that certain azo dyes are bleached catalytically in the presence of metallic silver as a function of the amount of silver. When to a photo-graphically sensitized emulsion is added an azo dye complementary to the sensitizing range and the silver picture is developed after the exposure, then the azo dye can be bleached out subsequently in a special bleaching bath. A positive colour picture remains after the removal of the residual silver which is carried out according to well-known processes.

The disadvantage of the process for original photo-graphy is the very poor light-sensitivity due to the strong dyeing of the film by picture dyes. Conse-quently this process was only employed for making copies, and is no longer in use. More recently a form of this process has attained some importance as a copying material (Cibachrome(R)) but it has not yet made its way into cinematography. The firm of Ilford(R) was granted a patent for a masking process employing the silver dye-bleach procedure. Because of the complicated processing, however, it was not used in practice. As azo dyes the picture dyes are much more durable than those of the chromo-gen processes.

This higher durability of the azo dyes, of course, is of great importance for the preservation of colour films. However, it would be a disastrous error if the Archives considered the problem of the preservation of important colour films to be solved by this. Although the azo dyes are at least three to four times more durable than the classes of dyes

[content of this page missing]

influenced the durability of the cyan picture. The nitrocellulose base then commonly used had an adverse effect especially on the durability of the dye of the lower layer which was more durable on a base made of cellulose acetate but did not reach the degree of durability of the dyes of the other two layers that way. It was only by the change of the cyan coupling agent that the durability could be approximately matched in all of the layers.

1.9.7 Constitution and incorporation of the colour-coupling agents

The constitution of the colour-coupling agents and the method of their incorporation also are system-conditioned.

It became evident that the numerously synthesized colour-coupling agents of different constitution also supplied differently durable picture dyes. It was possible by various means to influence the constitution of the colour-coupling agents. In correspondence with the experiences of the dye chemistry regularities could be derived from the studies which became available more and more for the structure of colour coupling agents which supplied especially durable picture dyes. Electro-negative substituents in ortho-position to the coupling group generally yield dyes of a better durability. Dyes which have a linear structure are less durable. On an average, the magenta dyes are more durable than the cyan and yellow dyes.

The colour developers also influence the durability. In this case there is a relationship between the durability and the length of the alkyl chains at the tertiary nitrogen atom of the p-phenylene diamine. Among the three developers used in cinematography

the one derived from toluene diamine generally provides more durable dyes than the derivatives of p-phenylene diamine.

To summarise, it can be stated that the knowledge of the relationship between the constitution and the durability of the picture dyes was put into practice as far as possible. It has been indicated already that quite a number of properties of colour film such as colour reproduction, colour purity, physical-mechanical properties of the finished layer etc. are influenced by the constitution of the colour coupling agent by means of which the structure of the dyes can be influenced to the greatest extent and the way of incorporating these coupling agents. It is for these reasons that coupling agents cannot be selected solely on the basis of the durability of the resulting dyes. Moreover, the resistance of the dyes against temperature and moisture are within the limits set by the classes of dyes of azo methine and indoanilines. Till now these limits have not been exceeded in any case, i.e. a picture dye for the chromogen development which has the resistance of e.g. an azo dye has not yet been found. It also has been proved that the different way of incorporating diffusion-proof colour coupling agents described above - "oil coupling agents" as hydrophobic (insoluble in water) coupling agents without solvents in the layer or as hydrophylic (soluble in water) coupling agents - on principle has no decisive influence on the durability of the picture dyes produced.

Of course, there are, however, some differences in the durability with each kind of incorporation e.g. hydrophobically incorporated cyan coupling agents on an average form more durable dyes than the coupling agents soluble in water. On the other hand it is known that e.g. magenta dyes made of pyrazolone

coupling agents react with the residual coupling agents to form colourless compounds. This reaction takes place very readily with "oil coupling agents". A special final bath (stabilizing bath) is therefore necessary by means of which the residual magenta coupling agent is inactivated. The reaction described, which results in a colour shift towards green with positive copies is thus avoided. This final bath has proved to be very advantageous for colour film materials which contain the other types of coupling agents.

1.9.8 Residual chemicals

Even residual chemicals which are present after processing, i.e. after developing and fixing have a destructive effect on the dyes. The components of the processing baths are difficult to remove from the gelatine layers. Considerable amounts of colour developer substance for example are retained (about 25 gm diethyl-p-phenylene diamine on 1000 metres of 35 mm film). Surplus developer adversely affects the durability of the picture dyes according to studies by Soviet authors. Before the film gets into the bleaching bath, however, the developer has to be removed completely because otherwise it would cause the formation of bleaching fog - the colour developer is oxidized and the oxidates react with the residual coupling agent to dyes. The magenta layer especially is susceptible in this respect.

The sodium thiosulphate is retained very obstinately and it proved that a thiosulphite content in excess of 4 $\mu g/cm^2$ causes an accelerated destruction of the picture dyes the rate of which increases proportionally with the thiosulphate content. The durability of the magenta dye mostly is influenced by a too high content of residual thiosulphite. The other

two component pictures are decomposed somewhat more slowly but to the same extent. During storage the major part of the thiosulphite very quickly changes to polythionates which cannot be detected by a number of analytical methods. The determination by reduction by means of boron hydride to sulphide under the formation of methylene blue is considered the safest method.

1.9.9 pH Values

The pH value of the layer structure can also be influenced by the processing. Obviously there are different optimum pH ranges for films of different structures. The term "optimum pH range" does not mean a range within which there is practically no decomposition of the picture dyes, but a range within which it takes place as slowly as possible, and at the same rate for all component pictures so that the colour balance of the picture is preserved for a long time. The dependence of the picture dyes from the pH value of the layer structure obviously has not yet been studied for all the cinematograph materials. Comparable values are available on the behaviour of the Eastman(R) color positive film type 5385, the Orwo(R) color positive film PC 7 and the Soviet positive film CP 8. The optimum pH-value ranges are pH 5 - 6 for type 5385 and pH 7 - 8 for PC 7 and CP 8. With the type 5385 the yellow dye is most unstable in the acid range and the cyan dye in the alkaline one. With PC 7 and CP 8 the cyan dye is more unstable in the acid range than the other two dyes and the yellow dye is more unstable in the alkaline range. The magenta dyes can be influenced least of all in all films by different pH values and the decrease of the dye densities of all three component pictures is least of all different in the ranges mentioned so that colour balance of the

picture is preserved for the longest period of time by observing these conditions. It would be welcomed if these studies were extended to the other colour films to be stored in the archives and the method was developed so that it can be applied as a routine test in the archives without great expense.

1.9.10 Humidity, temperature, light

In addition to these factors there are still a number of external factors determined by storage conditions. The most essential factors are relative humidity and temperature. The higher the values of both of them the quicker the decomposition.

Studies showed that the decomposition of all picture dyes increased proportionally with the increase of the values of relative humidity and temperature but the clear difference in the durability of the yellow and magenta dye component picture compared with the cyan one remained the same.

The destruction of the picture dyes is due to hydrolysis in a multi-stage reaction, the final product of which is a colourless hydrate. This hydrolysis of the dyes is temperature-dependent, it takes place the slower the lower the storage temperature and, of course, also the lower the relative humidity in the storage facility. With regard to this there are certain optimum conditions which are determined by a number of factors which will be indicated in the following chapter.

If the matter is viewed solely from the view-point of the durability of the dyes one should aspire to keep the two values as low as possible. However, one has to consider the behaviour of the entire system which means that one also has to take into consideration the gelatine layer and base. Then it

proves that it is not possible to keep the two values as low as possiblecver a long period of time because otherwise irreparable mechanical damage occurs.

This is somewhat different as to the resistance against light which, by the way, does not change necessarily in parallel to the resistance against heat and humidity. There is the possibility to increase the light fastness considerably by using substances which absorb ultraviolet light, i.e. by a measure which is outside the system. The light fastness generally is sufficient for cinematography and does not play the same role as the dark-storage durability. The situation is quite different as to the conditions for pictures, which are to be exposed to light for a longer period of time.

1.10 The precedence of the chromogen development

It is noteworthy that the colour development in which azo methine and indoaniline dyes are developed which are completely unsuitable for e.g. dye-works due to their poor durability nowadays have gained such a world-wide significance. The Technicolor actually was intended as a printing process from the first to produce colour positives but colour negative films also are used as a camera stock for it, the dyes of which are produced according to the colour development process, i.e. they are not very durable.

There is a number of reasons, of course, for the increasing successful use of the chromogen development process in colour photography:

1) The fact that such universal picture recording processes use silver halide is the basis of the colour development process.

2) The colour development process practically is as simple to handle as the black-and-white process with silver halide by means of the invention of the multi-layer materials in the development of which there is developed one picture in one of the three primary colours each in each layer by means of a single developer.

3) Of all the colour processes known till now the colour development process is most universal and very flexible.

4) The weak point is the storage stability but the conditions of storage of the colour materials are adapted to the properties of the dyes, i.e. they are not continuously subjected to changing outer conditions like textile dyes.

5) Steady improvements of the durability have been achieved by structural changes of the dyes by means of colour developers and, above all, colour-coupling agents.

However, this method slowly reaches the limit of what can be obtained within the system.

6) The physical structure of the photographic materials is such that significant improvements can be transferred to this system as to the durability of the picture dyes at any time.

At present there is no possibility in sight to enable an increase of the resistance of the dyes against the influence of heat and moisture beyond the limits set by the system in a similar way like e.g. it is possible with the stability against light by using substances which absorb ultraviolet light. It is certain, however, that the strict observance of the storage and processing conditions found to be favourable provides

the prerequisites to well preserve also the picture dyes created by colour development over a long period of time.

Chapter 2

2. The preservation of original colours in developed colour films

2.1 Cultural aims and economic prerequisites

It has been shown, in the first chapter, that the characteristics of colour film are such that it is much more difficult to preserve the colour record in a film than to preserve black and white pictures. This is particularly true of the dyes produced by chromogenic development. This is the process which for more than two decades has been used for almost all colour negatives and positives for both cinema and television use with the one major exception of Technicolor-type dye-transfer positives. The dyes in these are significantly more stable, but even these cannot be depended upon to survive for a very long time.

What has one to understand by the term 'long time' from the point of view of the archivist? An archivist reckons in centuries and for archives of documents and document paper such a reckoning is absolutely real; for document paper can be kept, if well treated, at least for two to three centuries.

It is different with audiovisual records as far as they are based on optical film.

The possibility of preserving such records improved very considerably when - after more than fifty years of film production - nitrocellulose was replaced as the base material by cellulose tri-acetate which is less easily inflammable and does not emit harmful gases which destroy the picture. This applies even more to polyester base, which is increasingly being used for narrow-gauge films. The life of colour film too, has been extended by these new bases; but this has not diminished the effect of other harmful factors.

According to the technical press over 90% of film-production for cinema and television in Europe and North America consists today of colour films. The colour in the film has thus become the major preservation problem.

This chapter is not concerned with colour film as a whole; but with the possibility of preserving the dyes in original colour films.

Nobody can foresee exactly how long a colour film will be copyable and showable. That depends on many factors. It is, however, certain that after a few years, colour films are very often not useable any more because of gross changes of colour balance. One can say with certainty that dye-image films of any kind which are being stored without special measures of preservation will have only a short useable life. This has been proved true in practice and by scientific investigations carried out in the U.S.S.R. and U.S.A.

Most important is the preservation of the original dyes, especially of the original negatives, but also of copies and duplicate negatives.

The possibility of the preservation of colour films by means of silver-image colour-separations, and by

electronic means, will be discussed in the following chapters.

Economy plays a very important part with regard to the existence of audiovisual archives. All equipment needed, in order to be really able to ensure the preservation of the records for a long time, is very costly. But if one were to renounce the building up of audiovisual archives at the present time, then invaluable historical and artistic works would be lost.

We are today in a transition period: we worry about the preservation of less stable materials but science and technology are already developing completely new information media which will facilitate our task. Thus the task of the archivist today consists in saving, with the support of his government, everything that is worth keeping in audiovisual records, and has been created in our century up to a time in which it will be possible to preserve audiovisual records for posterity with greater safety and less cost.

This does not mean that one can already stop constructing air-conditioned stores. These potential new media are not yet developed to a standard where they can satisfactorily serve our purpose; and even when they are, it must take some decades, and a great expense, for archives to transfer their records onto any new medium.

In view of the high costs involved in properly preserving colour films; it is understandable that less expensive methods are sought. It must be emphatically pointed out here, that while emergency solutions may prolong the life of colour films to some extent, they cannot ensure their survival until the time when it will be possible to transfer the records onto some really durable medium. Each economy adds to the serious risk of loss of the records.

2.2 Injurious factors outside the control of Archives

The injurious factors which may totally destroy the film dyes, are enumerated in section 1.9.1.
The system-limited factors, viz. the factors which are inherent in the film material itself, and which deteriorate without any external influence, are beyond the control of the Archive.

2.2.1 Dye-stuffs

Decisive for the preservation of colour in films is the choice of the class of dye-stuffs employed in them, and in their associated, more-or-less stable character. As in the case of the introduction of the system of dye-couplers, the archivist must leave this to the research scientists and film stock manufacturers, who find their limits in the laws of nature.

Damage due to destruction of the dyes is more difficult to correct. The possibilities of restoration and regeneration are reported in chapter 4.
The sole means of retarding the destructive process, is optimum climatic conditions of storage (sections 2.3.2 and 2.3.3).

2.2.2 Bases

The second factor in 1.9.1 the support, is today no longer a decisive factor on the colour. In general, nitrate-based colour films must be copied onto acetate base as soon as possible; both for their own preservation and for the safety of the surroundings. Cellulose acetate gives off no harmful gases, it shrinks as does nitrate film; which can be a serious matter, particularly for colour separations (Chapter 3).
Polyester fulfils all the requirements of a base (gives off no gases and endures long in storage) but it suffers with some difficulties with the adhesion of the emulsion. Present-day bases offer no threat to the dyes in colour film.

2.2.3 Residual chemicals

The third factor, associated with the film process itself, is the consequences of incorrect developing, fixing and washing of the film. In this case also the archivist usually has no control since he is not usually the customer of the laboratory which carried out the processing, and thus cannot ensure that the processing procedures, laid down by the film stock manufacturer, are exactly adhered to.

The danger lies in any residue of chemicals remaining in the film at the end of processing; but particularly the fixing chemicals, which can cause the image-forming dye-stuffs to fade or change hue. The effects of residual chemicals occur more quickly in dye-image films than they do in black and white silver-image films.

There are a number of methods for determining the presence of residual chemicals, but some of them are complicated, and there is difficulty in employing them in practice to check a large collection. It is necessary to understand that the original negative of a film, normally consists of several hundred individual shots, which were not necessarily developed all at the same time, or in the same processing bath, or even in the same laboratory. Therefore, in order to monitor such an assembled negative fully, it would be necessary to test every single shot.

At Gosfilmofond, Moscow, special facilities were constructed for the purpose of carrying out such tests on all shots; but the procedure had to be abandoned, since it was so laborious that it was not feasible. It is true also of normal copies, from which it is necessary to take several tests, since a copy is not always consistent throughout all the reels. Desirable as it would be to have exact knowledge about the level

of residual chemicals in the films, there is no procedure by which it is practicable to examine more than some peculiarly precious film which warrants special protection. Gosfilmofond is the first archive to adopt the procedure with all film entering the archive (old or new, colour or black and white) of thoroughly re-washing, or treating with chemicals which eliminate harmful residues.

2.2.4 pH Values

There is a danger that an excessive concentration of residual chemicals, due to inadequate washing, will have a destructive effect during storage. Of importance here, is that the pH value does not exceed the standard value for the film. The raw stock manufacturers provide processing instructions concerning pH values. It is next pointed out that optimum storage climate help to minimise the effect of too high a pH value.

The processing laboratory is responsible for checking pH values, but during subsequent storage of the films (at over 60% Relative Humidity for black and white film and over 30% R.H. for deep frozen colour film) the original pH values can change.

2.3 Harmful factors within the control of the archive

Whereas with the instability of the dyes and processing errors the archivist is unlikely to be in a position to have direct control over the harmful effect; this is, to a great extent, possible with regard to other factors and he can influence the strength of these effects on the film. From the moment the film arrives at the archive it is the responsibility of the archive's technicians to avoid any further harmful effect. Damage caused by wrong storage

and/ or wrong treatment beforehand can only be corrected with difficulty. The checking of the film before storage must show whether any colour changes have already advanced to such an extent that the costly storage in the archive is no longer worthwhile.

2.3.1 Light

The first factor which has a damaging influence on the film dyes is light in any form, especially ultraviolet radiation. Light is the factor which is the least worry to the archive. The film is stored in closed tins which do not admit any light and generally also in dark rooms. The effect of light is also relatively minimal. The light to which film is exposed when showing or copying may be very intense, but the duration of exposure is so brief that it has no significant effect upon the dyes.

Only upon examination on the winding table and at restoration is the film likely to be exposed to light for a prolonged period. In the case of normal examination there is hardly any danger. One can be more sure, if one excludes light sources with high content of ultraviolet rays and e.g. use glass which absorbs ultraviolet rays (for the windows in such rooms). But if one wants to be quite sure one can equip the winding table for prolonged restoration work with covers over the reels of film.

2.3.2 Temperature

A factor which has considerably more importance is the temperature at which the film is treated or stored. The higher the storage temperature the quicker the colours change. It was shown in chapter one that the colours change in different ways; that in the films manufactured in earlier years (till about 1950) cyan changes quicker and in films currently being manufactured, yellow is the most sensitive dye. The fading

of one colour is sufficient to disturb the colour balance and to make the film unusable.

2.3.2.1 A wide range of temperatures have been advocated as the optimum for storage of colour films. These data fluctuate between + 20° C and -18° C. It is self evident that such a temperature range cannot be correct. In exact trials which were carried out by the NIKFI (the Central Scientific Institute for Filmtechnology of the USSR); as well as by the research department of KODAK in the USA it has been proved that, for permanent storage of colour film, a temperature below 0° C is necessary.

The recommendations of these two bodies also vary. Kodak recommends storage at -18° C; the NIKFI, -5° C. Kodak made researches down to freezing-point. The -18° C of Kodak is only determined by the fact that -18° C equals approximately 0° Fahrenheit; that is, there was chosen a temperature which the western world can remember much more easily. Such a temperature is not wrong, but to maintain it permanently is very costly.

NIKFI in Moscow carried out their trials down to -50° C and they have found that below 0° C the changes of the colour occur so slowly that it is scarcely measurable even if the film is stored for years. Since during the trials at temperatures of + 4° C down to -2° C there was damage to the substratum, and as one has to allow for certain tolerances in the refrigeration equipment, NIKFI recommends, on the basis of their trials, an **maximal** storage temperature of -5° C. The Preservation Commission of FIAF follows this recommendation.

This storage at -5° C means indeed considerable savings of money at the whole installation of the vaults compared with -18° C, nevertheless it means

considerable changes in the construction of stores and also requires additional facilities.

Three things should be noted in particular:

1. Sufficient insulation of the entire construction, whereby must be guaranteed that at summer temperatures of +30° C (in medial latitudes) the temperature of the air-conditioned storage rooms will not exceed -5° C.
2. The safeguarding of the foundations of the building against possible damage caused by frost.
3. The acclimatization of the films when it is put in and when it is taken out.

2.3.2.2 At almost all film vaults built in recent years, in which air conditioning was built in, it was found that the insulation was not adequate to eliminate the fluctuations of temperature due to seasonal variations. Therefore it has to be urgently recommended to make greater rather than lesser insulation and especially to note that large roofs absorb a great deal of heat from solar radiation and therefore must be protected, by, for example white-painted over-roof, which at his highest point allows the escape of circulating warmed air.

Of course all entrances must be shielded by sufficient air locks so that warmer outer air cannot penetrate the deep-cooled stores.

In order to establish additional shielding against heat exchange, one can build above the actual vaults e.g. rooms for the storage of documents which will have an air conditioning with the air escaping from the vaults with higher values (e.g. instead of -5° C., +5 up to 10° C). In any case it must be seen to it that the temperature in the film vaults will remain constantly in the range fixed.

Whether it is preferable to construct vaults below or above ground level, depends upon the level of the water table. If it is deep enough, it is recommended to dig the vaults in because of easier insulation.

2.3.2.3 One problem that needs attention is the prevention of frost damage to the foundations and side walls of vaults built below ground level. If the vault is air conditioned to -5° C not only the film but also the whole building with all its equipment will be brought in the course of several months to -5° C. This has the consequence that also the surrounding soil may freeze up to a certain distance from the building and thus there will arise serious dangers. Such frozen soil may thaw in the higher external temperature of the summer months. Since water increases in volume when it freezes, the return of winter and re-freezing of the water in the soil surrounding the building can create such pressure upon the foundations and walls, as to cause serious damage or even total destruction.

This must be countered by appropriate insulation of the endangered parts of the vault, which excludes the influence of cold from the surrounding soil. From these matters of deep freezing and strong insulation it is shown that the building of colour film vaults is not cheap. But we have always realized that, as science stands today, the preservation of precious audiovisual material necessitates considerable expense.

2.3.2.4 If one comes from the winterly cold, enters a heated room and wears spectacles, these are immediately dimmed because droplets of moisture condense upon the surfaces of the lenses.

The same applies if a film is brought in the tin

from the cold into the warm. On the can and, in the event of entry of humid air, in the interior of a can which is not firmly sealed there will form condensed water. If this is not eliminated immediately by drying, it will certainly destroy the film. One must be warned to be cautious of assuming that an adhesive tape forms an adequate seal.

If we store the film at a temperature below 0^{o} C then we must see at any event that the films will be acclimatized before being stored and when being removed, that is to be brought to store temperature and or to the temperature of the environment without the dew point being exceeded and permitting the condensation of water upon the film.

There are two methods of preventing this; the natural and the artificial re-acclimatization. These methods serve the same purpose and also have the same results, but the difference is the time required and that is a not unimportant factor.

With natural acclimatization the film reels which are to be adapted to the temperature are stored in rooms whose temperature is below the dew point and are stored in sealed cans. According to the temperature of the environment and the format of the films there will be an adaption of the temperature in a period up to 6 hours for 35 mm. Then the cans may be opened in order to permit the film to come into equilibrium with the external humidity. Depending upon the difference in humidity within the store and outside, and the format of the film, the necessary length of time will vary, up to 30 days. Thus a 70mm film which had been stored in a humidity of 30% may need as much as 30 days to reach equilibrium with the external humidity. The same time would be necessary before placing films into store. These are periods which are not practicable in the normal operation of an archive.

Therefore the possibilities of artificial acclimatization have been explored; and the Staatliches Filmarchiv of the D.D.R. has constructed special cupboards for the acclimatization of 200 reels, each of 1,000 feet, at a time. These plants have been in continuous use for between 5 and 6 years and permit the safe change of temperature from +25°C to +5° C or vice versa in a period of 8 hours. It is considered that, if the lower temperature required were -5° C, the time necessary would probably be 24 hours.

2.3.3 Humidity

Of even greater importance than temperature is humidity. It has been stated in Chapter 1 that increase of humidity accelerates change in the dyes. It is therefore desirable to have as low humidity as possible.

On the other hand, too low humidity causes shrinkage and brittleness of the film. Therefore it is recommended that, at -5° C, the relative humidity should not exceed 30%, nor fall below 15%.

In deciding the air-conditioning values for the storage construction it is necessary to remember that the conditioning installation is affected by the environment; and to allow the necessary tolerances.

Concerning air-conditioning and insulation of the building and also on humidity, all that is necessary has been said in the relevant sections 2.3.2.2 - 2.3.2.4.

2.3.4 Harmful gases

There is a harmful effect also from gases, especially industrial exhaust gases, e.g. sulphur gases, which are contained in the air. It has already been

mentioned above that in industrial areas there has been established a strong concentration of such gases even 40 to 50 km from the point where they arise. The best protection against this is, of course, to transfer archives to areas in which industrial gases are not present, e.g. in extended woodland. However in modern industrial nations such areas have become extremely rare, they are always far away from the large cities and therefore in such condition the transport problem becomes more serious for the archive.

There is, of course, also a protection against these gases by the installation of appropriate air filters, which can be easily done in air conditioning installations which are here a pre-requisite. The filters must be fitted in such a way, that they keep all the harmful gases away from the vaults in order to avoid fading, change of colour balance which might arise in colour films.

Although there exist only comparatively small amounts of colour film on nitrate base, it is necessary to point out that, unless safety film is very thoroughly isolated from nitrate, any conservation measures applied to the safety base film is wasted, since the gases from the nitrate film will damage the images on the safety film. Colour films will be affected more quickly than black and white films. It is not sufficient separation to store the two types in adjoining rooms. The best thing is to keep them in entirely separate buildings. It is urgently recommended that when storing nitrate films the safety regulations in the relevant country are strictly adhered to.

2.4 Aids for the temporary protection of colour films

Everything that has been said so far about the necessary measures for the maintenance of the stocks of colour films and in particular of the colour in the film was based on the knowledge that there are cogent demands for permanent storage which are difficult to fulfil, without which however the maintenance of preservation for a long period is not possible. The reality is, however, so: There are only very few large archives which are able to create these necessary facilities, although in recent years the technology of the film archives has made much progress in many countries. But those archives which have to work without support of the state corresponding to the necessities, are not in a position to do everything immediately in order to create the best conditions of preservation for their stocks. They too must be helped by advice as to how they can lengthen the existence of the endangered colours for a certain period until they also can hope to be able to create optimal conditions.

It must however be emphasized that the following statements are only dealing with temporary measures which can serve for a short period for the preservation of colour but which are by no means replacement for those necessities which are described in paragraphs 2.2 and 2.3.

2.4.1 Stabilisation of humidity by hermetic sealing

First and foremost we talk about the control of humidity, which is the most important element for the preservation of colour. How important the production of optimal humidity is can be seen from the fact that the dye density at 60% humidity decreases at twice the rate of that at 40% humidity.

It is known that temperature and humidity are interdependent. It is further known that humidity must be kept within certain limits so that there do not arise on the one hand the destruction of the colour and/or the black and white picture, and on the other hand increased shrinkage and brittleness. A transitionary solution can only be that - just as the climatic storage - the undesirable humidity and temperature equilibrium between the contents of the can and the surrounding atmosphere is prevented.

This can be achieved in the following way: the colour film must be acclimatized in a special room at the temperature of the subsequent storage relative humidity amounting to no more than 30%. The procedure of acclimatization takes several days with 35mm film. The humidity can be maintained within the limits envisaged by an air dehumidifier with automatic defrosting. The installation which, of course, can also be erected in the vaults will operate at temperatures from -5° C to $+30^{\circ}$ C.

In the same room the acclimatized film will be put into cans, closed with impermeable, self-adhesive plastic tape and hermetically sealed. The hermetic seal can be made by welding in possibly vapor sealed polyethylene bags which have approximately the same size as the tin. An air exchange, and in particular, a humidity exchange will thus be prevented to very high degree.

Upon removal of the film from storage when we open the polyethylene bags the dewpoint of the air in the room must be taken into consideration.

The complete air seal can of course be only made with safety if the film has a triacetate or polyester base. Nitrate base must on no account be treated in this manner. Desiccating agents such as silica gel, must

not be used. On the one hand the quantity to be used, must be related to the weight of the film; on the other hand silica gel will be decomposed to a dust which will become dangerous when showing or copying the film.

2.4.2 Regulation of temperature

It is necessary to ensure that the film is stored at a constant temperature. It must be remembered that any room which is not fully air-conditioned will show seasonal variations of temperature. These variations may be minimised by using a 'cellar climate'. That is; one takes the sealed film to a dry room underground; or that one creates similar conditions by means of the nature of the construction of the building, as was done by the National Film Archive in London; as described in 'Film Preservation 1963'.

In middle latitudes the temperatures of cellars are about 9^{o} C to 12^{o} C, and in winter 2^{o} C to 4^{o} C. These variations are within reasonable limits, but a constant temperature below 0^{o} C cannot be obtained in this way.

This combination of low humidity and low temperature, where the films are hermetically sealed and stored at constant temperatures as much as possible, will only be effective for certain periods. The process must under all circumstances be repeated at least once every year. The best season for this is, of course, winter with relatively low temperatures except in tropical latitudes. The welding-in of the film will of course avoid the effects of harmful gases from the air.

2.4.3 The imperfections of these interim solutions

The imperfections of such auxiliary systems are clear:

1st a completely constant temperature below 0° C with the least fluctuation is not possible to achieve without full air-conditioning.

2nd also the welding-in of the sealed film cans in plastic bags or other material does not prevent a slow exchange of heat and to a certain extent also of moisture with the surrounding air.

The destructive influences are thus more effective here than with the full air-conditioning on optimal level mentioned above. Only a some-what longer life of the colour films can be achieved by this.

It is a matter of course that if one succeeds in storing the films for longer periods in low temperatures and with a minimal humidity with such means that before opening the seals it will perhaps be necessary to carry out acclimatization just as is done upon removal from a deep-freeze vault (see 2.3.2).

It has already been repeatedly said, and cannot be emphasized often enough that all those solutions are nothing but interim solutions. It is imperative that the time gained must be used in order to obtain from the government the necessary means for planning and installing of plants which will provide better safety.

Chapter 3

3. Conservation of Colour Films by means of Colour Separations on Black-and-White Film

It has been established that black-and-white film can be preserved for a much longer time than can the dyes in colour film. There is, therefore, an interest in eliminating dye images for preservation purposes as far as possible. In principle this is not difficult.

It has already been said in Chapter 1 that, from the beginning, colour film processes have been based upon the three primary colours and that all possible colours can be matched by appropriate mixtures of these three primaries. The first processes of cinematography were based upon separations. Technicolor for example, depended upon a set of three black-and-white separations, one for each primary colour. In this case one need only preserve these three colour-separations, in the same way as ordinary black-and-white film; and it is then possible at any time to reconstruct a film copy in the original colours.

Simple as the production of separations may be, so difficult is their subsequent re-combination after the passage of time, when it is required to re-create the film in colour. Theoretically this is also simple,

but we must also consider the practical possibilities; and here we are faced with problems which we shall deal with in the chapter.

3.1 The purpose of making colour separations

Photographic black-and-white separations from colour films consist of three extractions of the same picture, each recording one of three primary colours. These three records may be made each on a separate film; or all three may be made on a single film.

The creation of separations may be done in the original shooting, or may be done in a subsequent printing process. The separations may consist of either negative or positive images.

The process is of particular interest for the preservation and re-generation of colour motion pictures, because it offers the possibility of preserving the pictures in the form of silver images which are far more durable than dye images.

During photographic duplicating processes employing separations there is the possibility of restoring colour balance which has been lost during prolonged storage. (see chapter 4)

3.2 The principles of photographic reproduction of colour by means of black-and-white colour separations

Any photographic process consists of three different stages:

colour separation
colour contrast
colour synthesis.

Colour separation consists of dividing the whole

gamut of visible light reflected from the object being photographed, into three spectral zones, blue, green and red, and the photographic recording of these as a set of colour separations.

The stage of colour balancing is concerned with the quantitative connection between the degree of photo-actinic flux acting upon the photo-sensitive layers, and the quantities of dyes which are finally formed.

The last stage of the process consists of colour synthesis; the re-combining of the three colour records.

In order to appreciate the best possibilities of photographic colour reproduction it is necessary to quantitatively evaluate the three process stages. For every actual colour photographic method the stages of separation and synthesis are fixed because they are not dependant upon the conditions of exposure and chemical processing. But colour balance is determined by the technical and technological conditions of the photographic process, and demands strict sensitometric control.

3.2.1 Colour separation

The stage of colour separation or analysis is the most important stage of the photographic process because it alone provides information about the colours of the object photographed. In principle, colour analysis can be carried out on black-and-white films or on multi-layer colour films.

Colour separation on black-and-white film is achieved with the help of precise selection filters of blue, green and red.

Formerly, this technique was used in original photography of colour films in the form of black-and-

white separations. For the purpose, special cameras with beam-splitting optics were employed. One obtained colour separations of the three primary colours on either three separate films (e.g. Technicolor) or all on one single film (e.g. Gaumont Chronochrome; or, Colorvision).

In order to achieve an exact separation on black-and-white film it is necessary that the filters, through which the scene is photographed, each transmit only one third of the visible spectrum (blue or green or red). In the same way, the films on which the pictures are recorded must each be sensitised to that part of the spectrum which is transmitted by its respective selection filter.

Modern processes of colour photography are based upon multi-layer films and chromogenic development. If one uses multi-layer colour film, colour separation is obtained by means of the different colour-sensitisation of the three emulsion layers and with the help of a yellow filter layer, or yellow-dyed emulsion, which prevents the blue light reaching the green-sensitive and red-sensitive layers.

The completeness of the colour separation, and consequently the quality of the reproduction of the colours, is determined by the three curves of spectral sensitivity of the three photosensitive layers. They must ensure selective recording, on their respective emulsion layers, of the blue, green and red radiation.

The colour photographic processes are characterised to a great extent by the complexity of their interim stages and forms. The phenomenon of colour separation appears not only in the course of the original photography (primary colour separation) but also in the course of subsequent copying processes (secondary colour separation).

The character of the secondary colour separation depends upon the spectral absorbtion of the dyes of intermediate colours (e.g. the dyes of the elementary layers of the negative film; i.e. the layers sensitised to the three primary colours) and upon the spectral sensitivity of the emulsions of the print film (e.g. the spectral sensitivity of the sensitised layers of colour positive).

From a physical standpoint, these two types of colour separation are quite independant of each other, but they have equally great influence on the quality of colour reproduction.

In order to obtain correct colour separation in the course of a copying process it is necessary that each of the three separations of a negative picture, is printed only onto the appropriate layer of the positive (see **app 3 fig 8 - 1a**).

For this purpose, the dyes forming the negative image must absorb only the radiation of one part of the spectrum. The yellow dye must absorb only the blue part of the spectrum; the magenta dye only the green, and the cyan dye absorb only the red.

But in practice, the dyes formed in colour film absorb other parts of the spectrum as well. These are parasitic absorbtions. The magenta dye absorbs some blue. The cyan dye absorbs some blue and some green (see **app 3 fig 8 - 2**).

Because of these parasitic absorbtions of the dyes in photographic materials there is formed in each layer, as well as the wanted image, a parasitic image in colour complementary to that of the parasitic absorbtion.

For example, in the green-sensitive layer of the negative, along with the principal magenta image

(which will be printed onto the green-sensitive layer of the positive) there will also be a parasitic yellow image, (which will be printed onto the blue-sensitive layer of the positive). In the same way, in the red-sensitive layer of the negative, in addition to the principal wanted cyan image, there is also a parasitic magenta image and a parasitic yellow image, (which will be printed respectively onto the green-sensitive and the blue-sensitive layers of the positive).

The dyes formed in the colour positive, have similar spectral deficiencies to those of the negative, so that they do not exactly absorb the corresponding light. Because of this, the process of subtractive colour synthesis suffers from colour de-saturation.

The distortions are cumulative with those due to any imperfect colour separation and those due to reproductive conditions. The result is loss of colour saturation, dirty blacks and falsification of colour rendering with respect to the natural colours.

The character and scale of the distortions which are apparent upon projection of the colours, are different from those due to imcomplete colour separation. They depend upon the original colour; upon the proportion of parasitic absorbtions of the dyes of the negative and positive, upon the relation of the parasitic and the wanted absorbtions; and sometimes upon the gradation etc..

Efforts to reduce the colour distortions due to the separation process are central to the pre-occupation of the raw stock manufacturers. They are concerned with the improvement of spectral sensitivity curves, and with the spectral quality of the dyes formed in the emulsion layers.

But in spite of these deficiencies the users of

photographic materials can compensate for these undesirable effects by means of appropriate technologies. For this purpose the following procedures are recommended:

To use, for original photography, negative materials which are provided with masked colour couplers.

To reduce as far as possible the number of copying stages involving dye images. For this purpose it is recommended that reversal processes can be employed, or that processes of copying via black-and-white separations be used.

To use the additive printing system.

To use separations and external masks for the making of duplicates.

3.2.2 Gradation

After colour processing the latent colour separation image in each emulsion is transformed into a monochromatic image of yellow, magenta or cyan. The quantity of dye formed depends upon the sensitivity of the emulsion and on the exposure.

The relationships between the densities of the various parts of the monochrome image is determined by the photographic properties of the emulsion and the processing.

The properties of the photographic picture are determined by the sensitivity and contrast of the photographic material, by its exposure and processing. This determines the gradation of the picture.

The gradation properties of a black-and-white photograph can be completely expressed by means of the characteristic curve. In colour photography, the

characteristics of all three sensitive layers of the film must be recorded. Interpretation must be made of each of the three images separately and of the three integrally.

The gradation of the colour photographic process depends upon the gradation of each single monochromatic picture and upon the balance of their contrasts and the sensitivities of the light-sensitive layers.

The most usually used technical method of sensitometric control of colour photographic materials is based upon the capability of the materials to reproduce a grey scale. Under identical test conditions the best material is considered to be the one in which the three characteristic curves are most perfectly superimposed. The three characteristic curves of a colour photographic material can result from four different situations, (see **app 3 fig 8 - 3).**

The imbalance of sensitivity - case b - can easily be rectified by modifying the spectral composition of the exposing light by means of colour filters for camera negatives or by means of corrections in the printing process in the case of copying processes. In practice filters are hardly ever used in original photography in order to avoid loss of sensitivity. The imbalance of the negative is corrected by means of colour-compensating filters in printing.

The imbalance of the contrasts (see **app 3 fig 8 - 3).** case c) is corrected only within certain limits. Neither by modification of the exposing light, nor by any adjustment of the chemical processing is it possible to alter the relationship between the contrasts of the three components. The only practical means of correcting the relationships between the contrasts consists of modifying the characteristic curves of the emulsions having the higher contrasts,

by means of a uniform overall supplementary selective exposure. As may be seen from app 3 fig. 8-4 (effect of different quantities of uniform light on the characteristic curves) along with the contrast reduction there is an increase of fog and a shortening of the straightline portion of the characteristic curve. In practice it is not possible to eliminate the imbalance completely.

The imbalance of this sensitivity is evaluated by the relationship $\frac{S_I}{S_{II}}$ and $\frac{S_{III}}{S_{II}}$

determined according to the same sensitivity criteria.
In the ideal case $\frac{S_I}{S_{II}} = \frac{S_{III}}{S_{II}} = 1$

S_I is the sensitivity of the blue-sensitive emulsion.
S_{II} is the sensitivity of the green-sensitive emulsion.
S_{III} is the sensitivity of the red-sensitive emulsion.

In the same way the balance of the contrast is determined: $\gamma^{III} - \gamma^{II} \approx \gamma^{I} - \gamma^{II} = 0$

Imbalance of sensitivities is acceptable with a tolerance of $\pm$ 50% which is capable of correction. Imbalance of contrasts creates colour distortions such that different colours dominate in the dark and light parts of the picture. Similar distortions are also caused by exposure errors and the limited latitude of the photographic materials.

An easy way to understand the photographic process is the diagram of the reproduction of grey tones. These diagrams permit a detailed analysis of the characteristics of the appropriate picture and offer data on the reproduction process.

Within certain limits this permits the determination of the best conditions for the reproduction process in its various stages of exposure, processing and printing.

In its simplest form the diagram shows in figure 8 - 5 (appendix 3) the negative/positive process in colour. In the upper right quadrant is the characteristic curve of the negative, in its co-ordinates D_{ef}^{neg}, log H_{neg}.

In the lower left quadrant is the characteristic curve of the positive in its co-ordinates **D.pos/Lg E.pos.** (visual density of grey equivalent)

If one discounts the effect of certain factors affecting correct reproduction of the picture (such as diffusions of light in the camera, or in printing) exposures of the negative E_{neg} are proportional to the brightness of the object B_{ob}; and the positive exposure H_{pos} to the co-efficient of the transmission of the negative.

The straight line of the upper left quadrant inclined at 45^{o} to the co-ordinates establishes the relationship between Log. H_{pos} and D_{ef}^{neg} due to the quality and quantity of the printing light.

In the lower right quadrant is given the three reproduction curves of the grey tones in the coordinates D_{pos}/ Log. H_{neg}.

In the case of ideal reproduction of the grey scale, all three reproduction curves superimpose in a single straight line inclined at 45^{o} to the co-ordinates.

If these conditions are not achieved one must alter the printing or developing conditions, or the spectral composition of the exposing light by means of correcting filters. In the last case, instead of one transfer line there are three, spaced along the ax Log H axis with the imbalance corresponding to the effective density of the filters.

3.3 Colour reproduction system with the help of black-and-white colour separations

The process of colour reproduction by means of black-and-white colour separations is used in cinematographic practice in two main variants (see app 3 fig 8 - 6a).

3.3.1 Imbibation

The first variant consists of the process of making colour prints by imbibation. Original photography is made onto black-and-white colour separations obtained through the appropriate primary filters. From these three colour separation negatives, three positive partial images are printed, which after special processing take the form of relief matrices. These matrices are dyed; each with its appropriate subtractive colour, yellow, magenta, cyan. The dyed matrices are then impressed, successively upon the same gelatine-coated blank film; whereupon the dye transfers to the blank. The result is a colour photographic picture of the original scene.

Modern colour filming technology has abandoned the system of original photography on colour separations because of its great disadvantages. The method requires a special and somewhat immobile weighty camera, and special technology and equipment for the making of colour copies.

3.3.2 Multi-layer colour film

All the modern processes of colour cinematography employ multi-layer colour negative films. The photographic performance of these colour negatives is fully satisfactory in respect of tone and detail. Therefore, in current practice, black-and-white separations are employed only as part of complex intermediate processes such as the

production of duplicates, or for special processes (see chapter 4).

The second variant (see **app 3 fig 8 - 6b)** is the classical procedure of making colour duplicate negatives via a set of colour separation positives.

In this procedure, original photography is on a three-emulsion colour negative. From this negative a set of separation positives is made on a film such as Eastman Panchromatic Separation film, type 5235 (type 5235 has been superceded by type 5296) the separation being effected by printing through blue, green and red filters appropriately. The resulting separations are then printed successively onto an intermediate colour negative film such as Eastman 5253 through the appropriate selection filters.

A positive colour print made from such a duplicate colour negative may, if the duplicate negative is good, be indistinguishable from a print from the original colour negative.

3.4 Conditions for exact colour reproduction in duplicate negatives made via colour separations

A duplicating process is considered to be correct from the point of view of correct tone reproduction when the printing density of the duplicate negative D_{ef}^{in}, is equal to the printing density of the original negative D_{ef}^{neg}, or when there is a consistent difference D_{ef}^{in} over the whole density scale which is capable of correction in the making of the positive copy.

In the tone reproduction diagram, (see **app 3 fig. 8 - 7)** this is shown by the relationship between the effective density of the original negative, and the effective density of the duplicate negative which is represented in quadrant 1 by a straight line at

45° to the co-ordinates.

In order to obtain good photographic reproduction it is necessary to adjust the exposure of the three separation positives so that this falls within the straight-line portion of their characteristic curves (quadrant 2).

When re-combining the three images onto a single colour duplicate negative, the maximum densities of the separation positives will be recorded at the lower end of the straight-line portion of the characteristic curve of the duplicate negative (quadrant 6).

The gradation of the picture is determined by the contrast of the three black-and-white separation positives. By choosing suitable conditions of development of the three colour-separation positives it is possible to ensure correct gradation in the final picture.

When Eastman Panchromatic Separation film type 5235 is developed in a conventional negative bath it is possible to obtain a gamma of 0.8 which permits the solution of the practical problems of correct tone reproduction.

If one did not take into account the special printing conditions, the development of the separation positives would be carried out so as to obtain a gamma of 1.0.

The gamma is also affected by the spectral composition of the exposing light (see **app 3 fig. 8 - 8).** For this reason, in order to achieve correct tone reproduction, it is necessary to develop the three separations for different times.

In order to ensure good colour separation it is necessary to respect the following conditions:

The spectral absorbtions of the separation filters must correspond to the spectral absorbtions of the dyes of the three images of the original negative.

The spectral absorbtions of the filters used for re-combination onto the duplicate negative must correspond to the spectral sensitivities of the three emulsions of the duplicate negative film.

When making duplicate negatives from originals on Eastman 5254 the following separation and re-combination filters are recommended:

Blue separation:- Kodak Wratten filter N98;
or, N47B plus N2B.

Green separation:-Kodak Wratten filter N99;
or, N16 plus N61.

Red separation:- Kodak Wratten filter N70.

3.5 The possibility of preserving colour films in the form of black-and-white separations

As we have already shown above, these colour separations are intermediate forms in a complex process of photographic colour reproduction. For this reason the preservation of colour film in the form of separations can only be analysed in the light of the technical and technological problems which arise from the complexity of the photographic process.

3.5.1 Preservation of colour films on three black-and-white separations

This procedure has the undoubted advantage that the films can survive far longer under more easily attainable climatic conditions, compared to dye image films;

because their silver images are more durable than dyes.

Although excellent from a theoretical point of view, the procedure presents serious difficulties in its practical application, e.g.:

When recombining onto a single film, these three images may be capable of exact super-imposition only with difficulty, du to different shrinkage of the three films during storage.

The production of separation films on polyester base could solve this problem. Unfortunately the manufacturers do not yet produce these films on polyester base because of difficulties with adhesion of the emulsion.

The process of tone reproduction through three colour separations is expensive and technically complicated and demands specialised staff and equipment.

The procedure requires four times as much storage space and consumes corresponding quantities of raw stock.

Because of these disadvantages, the preservation of colour films in the form of colour separations is only to be recommended for films of particular artistic or documentary value; and if it is possible to make all three separations on a single film.

3.5.2 The preservation of films in the form of colour separations on a single film.

This idea is prompted by the difficulties arising from different shrinkage of three separate films (see 3.5.1).

The three separation images could be disposed upon a single film in one of the following arrangements:

a) Images in succession

The most elementary arrangement is to have normal frames of separation images successively on 35 mm film; which results in the length of the film being multiplied three times.

It is possible to reduce the film to only double the length by placing a frame on every three perforation intervals (14.25 mm).

In the case of "wide-screen" pictures (1:1.65) the frames could still retain their original size (13.25 x 22 mm).

In the case of normal size frames a slight reduction in height would be necessary, with a co-efficient of 0.875; the frames being 14x19.25mm. The proportions of these would be practically equivalent (see **app 3 fig. 8 - 9a).**

b) Three normal frames

By placing the frames in horizontal arrangement along 65 mm films, the space between the two rows of perforations is sufficient to accommodate the height of 3 normal 35 mm frames (16 x 22 mm) and still leave room for a sound track. Each set of 3 frames would be encompassed within the normal 65 mm advance of 5 perforation intervals (see **app 3 fig. 8 - 9b).** The recording in the three colours should not be carried out successively but simultaneously, using an optical block.

Another arrangement using 65 mm film in vertical file consists of recording the three separation images in chess-board fashion with the use of a quadruple optical combination. The advance of

the film is then alternately 4 and 7 perforation intervals (see **app 3 fig. 8 - 9c).**

c) Three unequal pictures

The three colour separations do not contribute equally to the definition of the final colour picture. From this point of view the green record is of primary importance.

The suggestion has therefore been made and experimented with, of reducing the red and blue record images. It would be possible to record the three frames in the form of two reduced frames placed side by side and below a normal sized frame (see **app 3 fig. 8 - 9d).**

The advance of the 35 mm film is then 6 perforation intervals (28.5 mm).

d) Three reduced images

The most economical arrangement may be based on the use of a quadruple optical block, such as was used for Roux colour; supplying four reduced frames of 8 x 11 mm within the area of a normal 35 mm frame (see **app 3 fig. 8 - 9e).**

It is possible to envisage less loss of definition by employing two green-record frames; the other two would be the blue and red records. This is similar to the proposal in c) above.

Because the three records are on a single film they cannot be developed to different gammas. This has serious adverse effect upon the reproduction quality which requires that it is possible to adjust the gamma of each record.

Within certain limits (0.3) the contrast can be decreased by a uniform supplementary exposure.

The system of film preservation in the form of separations on a single film demands absolutely perfect apparatus both for printing the separations and for re-combining onto a single colour film.

Since 1976 the Service des Archives du Film, in Paris possesses such a printing machine. It was constructed according to the ideas of the late Jean Vivié by Armand Roux of Paris.
It operates according to scheme a) above (cf. 3.5.2).

The three separations, (blue, green, red) are registered successively in their original size.

In U.S.A. Linwood Dunn proposed another system for the same purpose. So far the machinery has not been constructed. The difference between the French and the American system is that Dunn reduces the 35 mm images to 16 mm size during the colour separation process, and enlarges it again for projection purposes. This is, of course, good for economy but the price is paid in terms of loss of quality because of the reduction in size. So far, only some test films have been seen.

Chapter 4

4. Regeneration and restoration of the colour in multi layer colour films

Let us suppose that somewhere in the world an historically and artistically important colour film is found which had been thought to be lost. Only that one rediscovered copy of the film exists and it has suffered deterioration; disturbance of the colour balance, a fading of certain dyes, etc., - Briefly, the film cannot be used as it is; even the best storage conditions can only slow down the decay and its state will further deteriorate if nothing is done.

This film will have to be restored so that it can be copied and projected in its original colours. Theoretically this is possible, but in practice one may encounter insuperable difficulties. Not only are the required methods different in different cases, but very often appropriate raw stock types are not manufactured, or one does not have the special processing machines, because nobody has built them.

At any rate the attempt to save such a colour film is a very complicated matter, and only a very experienced film chemist can be successful. The layman - skilled or otherwise - who today forms the staff of many film archives - has no hope whatever of

success. What he may do is to destroy completely the already seriously damaged film.

The following remarks about the regeneration of colour films are therefore deliberately written for film chemists or engineers, as well as being a suggestion for action and also for the further investigation of a field in which insufficient work has been done so far.

4.1 Establishing the degree of destruction of the colours

In the film archives are preserved colour films in the form of original negatives, duplicate negative, duplicating positives and positive projection copies etc. which come from various stages of technology and are produced on film stock of all possible kinds and by different processes. These pictures may show colour reductions of various intensity and disturbance of the colour balance which depend upon the chemical composition and the individual properties of the dyes, the processing and storage conditions of the films etc. Therefore the provision of a regeneration technology which is effective for all colour films is not possible.

The regeneration of colour pictures in the film should be carried out with great care, taking into consideration the special properties of each image, the degree of decomposition of the dyes, the degree of disturbance of the colour balance, mechanical damage etc. and therefore for each film the particular technical regeneration method must be chosen which promises success.

Therefore a correct assessment of the chromatic changes having occurred in the colour pictures in

the course of time must be made at the beginning of the work.

Unfortunately the archives have not so far considered it necessary to introduce an objective control and evaluation system for the degree of destruction of the colour, and this very important work must be carried out subjectively. Since this evaluation has been carried out without any comparative control image (image of a neutral grey-scale or an undamaged frame of the same shot) considerable differences in the evaluation and assessment of the colour distortions cannot be avoided.

These chromatic changes, established in a subjective manner, are the result of several damaging factors; destruction of dyes which has occurred in the course of time as well as of deficiencies in the reproduction of the natural colours by the original photographic process, or of errors in processing and other factors.

It is very difficult to establish which distortions of the image existed at the start and which have occurred subsequently; how the destructive mechanism occurred, which regeneration treatment has to be chosen for this reason and what will be the results of the treatment carried out.

4.1.1 Determination of the degree of destruction of the dyes in positive copies

In order to determine the degree of destruction of the colours, the positive images will be analysed visually with the help of special control appliances, (viewing equipment), by projection on the screen or by direct observation. The dominating colour will be established, the chromatographic imbalance between the light and dark parts of the picture, the complexion etc.

Technicians with experience in processing of films estimate this chromatic change in terms of the value of the subtractive correcting filters which would be necessary in order to restore the colour balance by a printing process.

4.1.2 Determination of the degree of destruction of the dyes in negatives

In negative colour pictures the determination of the degree of destruction of the colour is much more difficult and only possible through photographic tests. Since the spectral sensitivity of the human eye is different from the spectral sensitivity of colour film; and since the colours of the negative are complementary to the colours of the positive copies, one cannot estimate to what extent the changes of colour as visually observed in a negative picture will be effective in printing onto positive film. Nevertheless, from negatives which at first sight exhibit very worrying changes of colour, it is sometimes possible to obtain satisfactory positives.

Television technology can make an important contribution to the analysis of the colours in negatives. The electronic colour analyser can reproduce all the factors influencing the quality of the positive picture (curves of spectral transmission of the dyes of negative, the curves of spectral sensitivity of the positive, processing conditions etc.) and shows on a screen the positive colour picture that may be obtained from the analysed negative and the corrections required for the achievement of an optimal quality. The high price of this device limits the extent to which it is possible for archives to use it.

4.1.3 Objective control system

In consideration of the importance to film archives of the determination of the degree of deterioration

of colour pictures and the disadvantages of the subjective assessment mentioned, it will be necessary to establish a system of periodical measurement of the chromatic changes occurring in colour films during ageing.

4.2 Chemical restoration of colour films

Theoretically one may use a variety of methods of regeneration for colour pictures. With some, the pictures will be treated directly (chemical restoration). Others are based on the transfer of the picture photographically onto a new film, at which stage the necessary corrections will be made when copying and processing the new film ('photographic regeneration' or 'corrective printing').

The use of such methods in the archives encounters many difficulties and needs much study and experimentation in order to become perfect.
The chemical restoration of colour pictures consists in the use of some chemical treatment for the selective reduction or intensification directly on the damaged colour pictures with the aim of restoring the colour balance.

4.2.1 Selective reduction

The term "selective reduction" means the selective destruction of dyes of the colour film picture by chemical treatment. The dyes forming the three partial pictures of a colour film picture (yellow, magenta, cyan) act differently under the influence of chemical reagents, such as acids, reducing and oxidising agents etc.

When ways have been found to affect separately each part of the colour picture with chemical agents then the undesired dominant factor can be reduced.

E.g. under the effect of acids the magenta azomethine dye will be easily destroyed, whereas the indoaniline cyan dye is much more resistant.

In this case the magenta partial picture can be reduced with diluted acids without the yellow and cyan partial pictures suffering through this action. One could also choose other chemical substances with selective reduction effect. The literature recommends many methods for the reduction of the colour dominants in order to correct the colour pictures, which are badly exposed or processed. But this applies almost exclusively to still picture materials. In the field of the archive film these methods have so far not been sufficiently checked. The use of these methods in the restoration technology of archive films must not be carried out routinely but should be carried out with great care and only following a thorough checking. Selective reduction is generally applied only to positives. Negative colour pictures can be saved by corrective printing without endangering the unique original by chemical treatment.

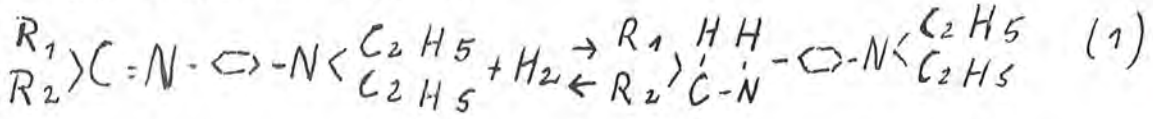
In most cases it is necessary to modify two of the partial images to restore colour balance. For this purpose the film will be treated successively in several reducing solvents in order to obtain the required degree of reduction of the dominant dyes.

For this purpose one can also use solutions which can reduce two partial colour pictures at the same time. Formulae for such solutions may also be found in the literature.

4.2.2 Intensification of colour pictures

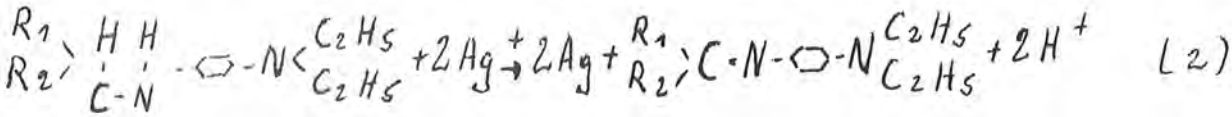
In the field of restoration processes for the colour picture the problem of intensification plays the more important part, because in the process of deterioration the partial images are already fading, their

restoration by selective reduction is no longer possible. Colour pictures, which have been obtained by chromogenic development methods with non-diffusing colour-formers, and in which colour-formers are still present, may be intensified by chemical treatment in accordance with the following scheme:
At first the picture is treated with a strong reducing solution. Under the influence of this reducing agent the dyes forming the partial pictures change into colourless leucobases according to the following schematic equation:



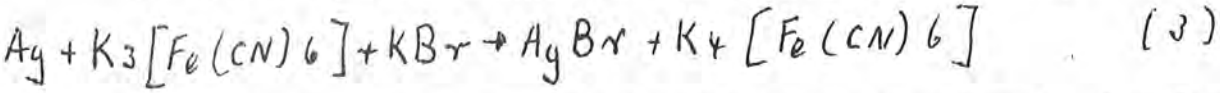
(1)

The leucobases which are formed are reducing agents. Under the effect of silver nitrate solution the leucobases are reconverted into dyes and the silver ions from the solution are reduced to metallic silver, in an image-wise manner in the emulsion layers.



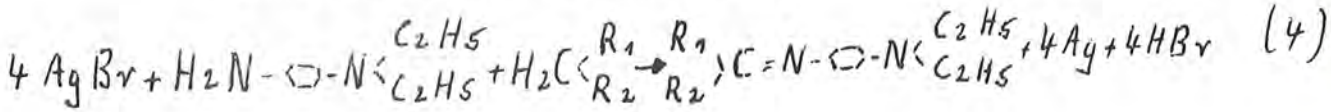
(2)

The picture which now contains the original dyes and the metallic silver is treated with an oxidising solution of sodium-ferricyanide and potassium bromide. Under the effect of this solution the metallic silver is oxidised and reconverted into silver bromide.



(3)

The silver bromide is developed in a chromogenic development solution, whereupon dye and metallic silver are deposited on the original dye.



(4)

The metallic silver just obtained can be eliminated from the emulsion layers by application of a bleaching process with subsequent fixing. If, however, greater intensification is needed, the picture must be re-halogenized and redeveloped again (according to the reactions 3 and 4) and only then the silver may be removed from the picture.

There are positive colour copies which have been obtained according to the chromogenic development principle with non-diffusible colour-couplers or by older processing methods which contain, as well as the dye-image, a silver image which has been left in the film in order to ensure better sound quality for the reproduction of the sound track. Thanks to the silver which is contained in these prints they can be intensified by a simpler chemical treatment. For this purpose the picture is first bleached with a classical bleaching solution of potassium-ferricyanide and potassium bromide (reaction 3) and is then reconverted in a chromogenic developer (reaction 4) on which occasion new dyes will be formed.

If the residual silver picture was obtained as a consequence of depth-controlled partial bleaching it is usually in the lower emulsion layer and less so in the middle layer. For these reasons the colour enrichment of films having the classical order of emulsion layers, is mainly in the cyan layer. Positive prints in dark storage have suffered destruction of the cyan dye during storage. They can be restored by applying this intensifying treatment. In general, chemical intensification cannot be carried out selectively for each partial picture; therefore, for a successful chemical restoration treatment, one has also to carry out selective reducing work.

4.2.3 Combined chemical restoration treatments

These treatments comprise selective intensification as well as reducing processes. In principle they can offer much better restoration results, especially if the degree of the destruction of the colours is not too advanced. Their use however encounters great difficulties in connection with the establishing of optimal restoration processes for each part of the film and the uncertainty of the results caused by operating conditions on the machines.

4.2.4 Risks of chemical restoration

The restoration of colour pictures by chemical treatment is very much restricted by the following disadvantages:

- the risk of total destruction of the colours owing to inadequate control of chemical agents;
- the risk of the mechanical destruction of films during treatment;
- the uncertainty whether the results may be repeated
- the empirical nature of the restoration work;
- the limited possibilities of correcting the dominant colour.

Colour distortions arising from parasitic absorptions of the dyes cannot be corrected by chemical means. Chemical restoration can also be used as a preliminary stage of a regeneration process which is to be continued by means of corrective printing. In this variation of the application the chemical restoration does not achieve totally satisfactory results but only some improvement which will be useful for the process of regeneration of the colour by corrective printing.

4.3 Regeneration by corrective printing

The regeneration of colour pictures by corrective printing consists in the correction of the unwanted colour changes during the transfer of the pictures to another film by making adjustments to the photochemical processes.

4.3.1 Advantages of the regeneration

The regeneration of colour pictures by corrective printing has absolute advantages in comparison to the chemical restoration as follows: -

- it ensures a maximum of safety of the original film since the treatments will be restricted to those films to which the picture is being transferred and will not affect directly the damaged film as is the case with chemical restoration;
- the regeneration possibilities are applicable in many different cases and are much safer in their use;
- it renders possible the setting up of generally applicable working methods and the control of the results;
- it offers better results and may be repeated;
- it offers the possibilities of the controlled flexibility in the correction of individual dominant colours as well as of the chromatic disturbance between the light and the dark parts of the picture.

4.3.2 Deficiencies of the regeneration

However, the regeneration of colour pictures by corrective printing also has significant disadvantages owing to the technical and technological complexity of the processes. It demands special equipment for the printing of the films; and the

material required are very expensive. Some theoretically possible methods of corrective printing cannot be tested in practice owing to the lack of special film which corresponds to the requirements.

The possibilities of regenerating colour pictures by corrective printing are theoretically wide but they are not sufficiently investigated.

They are based on factors influencing the quality of the photo picture, such as: -

The photographic properties of the light-sensitive materials;
The quantity and quality of the printing light;
The properties of the resulting latent image;
The influence of processing solutions and the manner of processing etc.

4.3.3 Technological principles and processes

The regeneration of colour pictures by the method of corrective printing may be carried out in accordance with the following principles:

1. the picture density and its colour dominant are corrected by using the corresponding parameter of the printing light (quantity and quality of light) in transferring the picture onto other films.
2. faulty colour balance between the light parts of the picture can only be corrected through the contrast balance of the films onto which it is printed. For this there must be the possibility to alter the contrasts of each light sensitive layer irrespective of the other layers. For this purpose we can use various technical methods, e.g.:

- selective and uniform previous exposure of the light sensitive layers;
- successive chromogenic development with diffusing components of reversible films;
- carrying out colour separation on panchromatic black and white film;
- copying with gradation masks etc.

4.3.3.1 In the first of the methods to act upon the contrasts mentioned above, the layer of the multilayer colour film the contrast of which has to be reduced will be exposed uniformly and selectively before the exposure in the printing process. Together with the decrease of the contrast the exposure latitude of the layer is also reduced. Therefore the method of selective previous exposure can only be applied in cases in which a change of the contrast factor smaller than 0.4 is required.

4.3.3.2 The system of the successive chromogenic development with slow-diffusing components has the great advantage that the three light-sensitive layers of the film can be developed with different contrast factors. Unfortunately the films which are being manufactured today, and which might be used in this method (e.g. Kodachrome) do not correspond to the demands of regeneration work on colours. The use of this method is only possible if special films are manufactured for this purpose.

4.3.3.3 In the colour separation process on black and white film (method 3) the partial images (yellow, magenta and cyan) of the deteriorated film are extracted with the help of the selection filters blue, green and red, respectively, onto three black and white panchromatic films, which are separately developed. Through the choice of favourable development parameters, the desired contrast for each colour

separation can be obtained, so that after superimposing the three separations onto the same colour film, the picture obtained will have a pre-determined colour balance.

4.3.3.4 The faulty colour balance can also be corrected with the help of the gradation mask (method 4).
The mask is a photographic image which, superimposed in registration upon a corresponding photographic picture, changes the densities in this second picture. The mask of a negative picture consists of a faint positive printed from this negative. Superimposed with the negative picture from which this print was made, the mask changes the contrast of this negative picture; the change being greater when the contrast of the mask is greater.

In order to be able to change the contrast of the partial images independently of each other, the masks will be made in the same manner as colour separations, by means of exactly established selection filters, by printing the pictures onto panchromatic black and white films. For the correction of the chromatic non-equilibrium the pictures will be printed one after the other by these exactly determined three filters onto a suitable colour film. The gradation mask covers the picture and the printing is done with the same filter with which the mask was produced.

4.3.4 Correction of parasitive absorptions

The colour distortions due to parasitic absorptions of the dyes can only be reduced with the aid of corrective masks in the form of colour separations.

The mechanism of correction of the separate colours by means of masks, consists of superimposing upon the affected negative image, a positive picture mask

of the same contrast. The superimposition of the two pictures will create a uniform veil which is eliminated in printing.

For this purpose the pictures which suffer from parasitic absorption of the dyes, will first be printed on panchromatic black and white film using the corresponding filters. Thereafter the picture-masks obtained in this way will be superimposed successively with colour film pictures in the same way as if being printed from colour separations. The colour transmission of the print filter should here correspond to that zone of the spectrum in which the discoloured picture shows the maximum absorption.

The printing process with colour separations can be carried out either with the colour-separation method onto panchromatic black and white film or by successive printing with the corresponding filters onto ordinary colour film.

4.3.5 Regeneration of colour negatives

In principle one can employ the transfer schemes shown in App 4 fig 9 - 1 and 2 for the regeneration of colour pictures by means of corrective printing.

With colour negatives there are three possible variations which may be used. They may be carried out with the films and methods employed in normal laboratory practice. (App 4 fig 9 - 1)

These variations have as their objective, the production of well corrected duplicates of the original negatives. They will be carried out according to classical printing systems on films normally used in cinema practice.

4.3.5.1 Thus, for variation "A", Eastman Intermediate film type 5253 can be used; or alternatively other similar products such as Orwo DC6, or the U.S.S.R. product KP.

4.3.5.2 For variation "B" one can use a film such as Eastman Colour Reversal Intermediate type 5249, or Orwo DC 2. The "A" and "B" variations, used under normal conditions offer only limited possibility of colour restoration, since the emulsions of the duplicating negative stocks used do not provide the appropriate contrasts required for correction of the colour balance. The use of selective pre-exposure (flashing) of the duplicating negative can extend the usefulness of these methods.

4.3.5.3 Variation "C" offers much greater possibilities for the regeneration of colour negatives. In this variation, there is first made a set of three separation positives onto Eastman Panchromatic Separation Film Type 5296 (Eastman 5296 has superseded type 5235) through red, green and blue filters in order to separate the three layers cyan, magenta, yellow, respectively. These three separation positives are then printed in register onto Colour Intermediate Film type 5253 through the same corresponding filters as were used for making the separation positives.

By choice of the most suitable printing and developing parameters, it is possible to achieve a duplicate negative in which the dominant colour is well corrected, and having a satisfactory colour balance.

In comparison with the other variants for the regeneration of colour negatives, this method offers definite advantages:

- it permits the use of different developing conditions for each of the three separations,

and thus permits adjustment of their contrast independently in either direction.
- it can be supplemented by the use of masks for the correction of parasitic absorptions.
- the black and white separations are superior, for preservation purposes, to dye-image materials.

4.3.5.4 In all variants of the regeneration of negative colour images, it is necessary to ensure that the corrections do ultimately achieve the desired effect in the final positive print. The newly obtained duplicate is also a negative and its suitability can only be finally judged by the quality of the prints obtained from it.

4.3.6 Regeneration of colour positives

The regeneration of colour positives by corrective printing can, in principle, be carried out by the use of one of the three transfer variants from **app 4 fig 9 - 2.** .

4.3.6.1 According to variant **"a"** the positive original picture is first printed onto a colour negative film. For this purpose all commercial negative colour films can be used. A further advantage is provided by films permitting the adjustment of the general sensitometric contrast according to the time of development; because they render possible a very exact reproduction of the picture contrast. The necessary corrections of the contrasts of the three emulsions of the film can be achieved by using the method of selective pre-exposure, which is especially effective in the case of negative films.

From the colour negative obtained there will be made a well-corrected positive colour copy on commercial positive colour film.

4.3.6.2 Variant **"b"** offers possibilities of correction through schemes based on black and white colour separations. From the positive original colour picture one first takes a set of three colour separations on panchromatic black and white duplicating negative film (e.g. Eastman 5234 or Orwo DN2) with the help of three corresponding filters (red, green, blue).

The period of development for each extract is determined by the desired level of the general picture contrast and the requirement of correction for the chromatic equilibrium. In principle, the panchromatic black and white duplicating negative films of any manufacture may be used. So far no special cinema films have been manufactured for this purpose. The recombination of the colour separations will be made directly onto the final print on positive colour film. The difficulties of exact superimposition of the partial pictures in the printing process, and the complexity of the technical process make the advantages of this regeneration method appear unconvincing.

4.3.6.3 Unfortunately, there does not yet exist a 35 mm colour reversal film, capable of meeting the demands of colour regeneration work.

At present one can duplicate only 16 mm. film according to modern methods on reversal films of the type Eastman reversal colour print-film 7387, Eastman Ektachrome R print-film 7389 or **Gevachrome** print-film type 9.02. The manufacture of 35 mm colour reversal films for direct copying, would open new possibilities in the regeneration of positive colour pictures which will be simpler and more economical than those mentioned above.

In general the positive colour prints show maximal high densities and very wide differences of densities. Therefore the necessary quantity of light for the penetration of the high densities is much too great for the low densities and the light diffuses into the light sensitive layer with the photographic quality of the picture being destroyed in the process. In order to avoid this phenomenon in all three variants, gradation masks can be used according to the general principles mentioned above. If necessary one can also use corrective masks which have been obtained by the production of colour separations.

Chapter 5

5. Historical Development and Properties of Sound Records used in Cinematography

5.1 Sound Recording Methods used in Cinematography

5.1.1 Brief Historical Survey

The kinetophone, designed by T.A. Edison in 1890, when the cinematograph was not yet in existence, is the prototype of the modern sound film. It consisted of a mechanically coupled kinetoscope and phonograph and made it possible to accompany moving pictures with sound.

Attempts to provide sound accompaniment for motion pictures were made in the earliest years of the "Golden Age of Silent Films". The Lumiere Brothers placed actors behind the screen to read the text. Simultaneous projection of a film and sound reproduction from a gramophone record was proposed (Ch. Pathé, O. Messter, etc.). The main drawback of this method was that image and sound were recorded on different media and their simultaneous reproduction during projection was a problem.

The most technically promising invention was made by Lauste (1906) who worked out a system of photographic recording of sound oscillations onto a film. Further development of this concept resulted in the appearance of sound in cinematography. Some systems of sound cinematography were introduced in the late

1920s. Image and sound were recorded on one and the same medium (35 mm light sensitive film) thus ensuring their proper synchronization.

In the late 1940s magnetic sound recording was introduced. Magnetic sound recording found application primarily in post-synchronization of motion-picture films in studios as it permits immediate re-play, provides the possibility of multiple recording on one and the same area of magnetic tape and is of higher quality than a photographic sound track.

Most release prints for movie theatres are still produced with photographic sound track. This is due to the fact that photographic track and image being of the same physical nature are more compatible when recorded on one and the same medium. As a result, motion picture films with photographic sound tracks are cheaper and more convenient in exploitation. At the same time, motion picture films with multi-channel stereo-sound are produced with magnetic sound only.

5.1.2 Photographic Sound Recording

Photographic sound recording is based upon the physical principle of transforming sound oscillations into variations of light flux which affects the light-sensitive emulsion; after development a sound track is formed (5/10-1). Light-modulating devices modulate the length, width or illumination of a recording slit in accordance with a recording signal. Changes in the slit width lead to a variable-area recording, while changes in the slit length or the modulation of its illumination result in variable-density recording (5/10-2).

The reproduction of the photographic sound track is based on the changes in the light flux which

passes through it to reach the photocell. In the course of recording and reproduction the film moves at a speed of 24 frames per second (45,6 cm/sec and 18.3 cm/sec for 35 mm and 16 mm films, respectively).

Types and characteristics of photographic sound tracks depend greatly upon the type and characteristics of the light-modulating devices (galvanometers) used in recording. Their classification is given in 5/10-3.

Modulators used for some time in the early 1930s modulated the light flux by means of various electro-optical phenomena (for instance, the Klangfilm and Tagephone systems). They produced variable-density sound records. The same years saw the application of electro-mechanical modulators (R.C.A. electro-magnetic ones and magneto-electric devices, such as the Shorin tape oscillograph and the mirror modulator of the Klangfilm system). In this case both unilateral and bilateral variable-area sound tracks and variable-density tracks were obtained.

Magneto-electric mirror galvanometers were mainly developed since the 1940s.

The problem of expanding the dynamic range of sound transmission has resulted in the invention of devices for making the sound track noiseless by reducing the level of the noise due to the film itself. The exposure value was reduced when recording variable-density sound tracks (at signals of low value and during unmodulated passages). Noise reduction in such systems is about 6 - 8 db.

Light-modulating devices with noise reducing shutters were introduced into variable-area sound recording. According to the envelope of the

recorded signals, the shutters moved up and down relative to the mechanical slit and thus varied the illuminated areas of the recording slit.

In some systems the film noise is reduced by displacement of the centre line of the sound track. In this method both audio frequency current and low frequency current were applied to the galvanometer, the latter current corresponding to the envelope of the sound signal and inducing an additional turn of the mirror, which results in the displacement of the centre line of the film sound track. In these cases noise reduction is about 8 - 10 lb.

Another problem in obtaining photographic sound records was sound transmission with minimum non-linear distortions. Proportional relation between the value of the transmission factor of individual areas of the positive and the values of the exposures of the corresponding areas of the sound record negative, i.e. $T_p = f(HN)$ is the condition for undistorted signal transmission for variable-density sound records. 5/10-4 shows distortions due to the non-linear photographic characteristic of sound transmission. Linearity of the characteristic can take place only if the Goldberg condition is observed:

$$\gamma_N \cdot \gamma_p = 1$$

where γ_N and γ_p are the gammas of the negative and positive of the sound record.

Sensitometric tests of the negative and positive films can be used to control variable-density sound records. Their characteristic curves provide the means for plotting a curve $T_p = f(HN)$ which is used to set the negative exposure, recording amplitude and printing conditions under which

non-linear distortions are small. Due to its features, however, this method does not provide high accuracy in choosing the optimum conditions for recording and printing sound records. The delta-decibel method, applied for a long period in the U.S.A., is more efficient. It consists in the checking of the linearity of the entire region of the characteristic under different recording conditions.

The method of intermodulation has been used since 1946 to control the distortions of variable-density sound records. Special measuring signals with different unmodulated densities were recorded on the negative. After development, measurements were taken to determine the relation between the output and non-linear distortions on the positive density at different negative densities; which provided a higher accuracy in choosing the optimum recording and printing conditions.

The conditions for recording and processing variable-area sound tracks are more complicated from the point of view of undistorted sound transmission. The reason for this is the effect of the filling-in of the troughs between successive modulations, when these are very fine (high frequency sounds). This filling in is due to diffusion of light within the emulsion (image spread) **(5/10-5)**.

The filling-in of the troughs results in the appearance of low frequency components in the recording, which, when reproduced, were heard as bumps and booms on sibilant sounds. This phenomenon (known as the "thunder effect") was discovered as far back as 1925 by the specialists of the Siemens firm when recording was made over the entire area of a 35 mm film.

To reduce the distortion due to image spread, an attempt was first made to reduce the light diffusion in the emulsion, for which purpose a special fine-grain negative raw stock was used. It was later discovered, however, that it was possible to cancel the effect of image spread, provided that the image spread in the negative was matched by the image spread in the positive. Cancellation is achieved by selecting appropriate densities for the negative and positive. The instrumental method of determining the required densities is the most efficient. This method is as follows: Special signals are recorded on the negative at a range of densities. From this a positive is printed at the optimum density (between 1.2 and 1.8).
Measurements are taken to determine the relationships between output and non-linear distortion. The curves thus obtained 5/10-6 are used to determine the value of negative density at which greatest cancellation occurs, distortion is at a mimimum, and there is sufficient output.

5.1.3 Magnetic Recording

Magnetic recording is based on the ability of ferromagnetic materials (iron, cobalt, nickel and chrome dioxide) to become magnetized under the influence of external magnetic fields and to retain a residual magnetization. In the simplest case the change of magnetic field intensity from 0 to +H, then to -H and again to +H can produce a diagram illustrating the process of ferro-magnetic body magnetization (limiting hysteresis loop), (Fig. 7). Here J_{rm}- maximum residual magnetization of a ferromagnet: H_c- coercivity; H_s - magnetic field intensity resulting in magnetic saturation of a given body: J_s- saturation magnetization. Residual magnetization of a ferromagnet depends on the intensity value of

the effecting external magnetic field, its magnetic susceptibility and relative permeability.

5/10-8 shows the functional diagram of a sound transmission chain, based on magnetic recording and reproduction. As a medium for sound-recording a magnetic tape is used which consists of a plastic base (diacetate, triacetate, polyester) coated with a thin magnetic layer containing fine particles (fractions of a micron) of ferromagnetic material.

Recording is made in the following way. The recording head winding 2 is fed with acoustic frequency current which creates magnetic flux in core 1 (5/10-9). A part of the magnetic flux is closed over the outer side of the core via air at the recording gap 3. It is that part of the magnetic flux which affects the ferromagnetic layer of the tape closely contacting the recording head surface at the gap when moving with a constant speed. After being magnetized the tape comes from the magnetic field retaining its residual magnetization which varies along the tape length and thus forms a magnetic sound track.

The fact that the $J_r = f(H)$ relation is non-linear is the main reason for non-linear distortions in sound transmission. To reduce such distortions sound recording with high frequency biasing, proposed by Braunmühl and Weber in 1941, was introduced.

This method involves passing a 60,000 Hz ultrasonic signal through the recording head winding simultaneously with the recorded signal. A composite signal (ultrasonic frequency alternating current whose mean value changes in accordance with the law of recorded oscillations) is formed in the recording head(5/10-10). The mechanism of recording with high frequency biasing is complex and its theory has not yet been fully explained. When passing the working gap of the

recording head, each element of the magnetic tape several times changes the direction of its magnetization; however, after coming from the magnetic field action zone the tape is magnetized in accordance with the recorded signal. Residual magnetization during periods of no signal is practically zero and, hence, the background noise is also very low.

The maximum output of the recorded signal at the minimum non-linear distortions for each roll of magnetic tape is ensured by the setting of the optimum value of high frequency biasing current in recording.

A play-back head is used for reproducing the signal from a magnetic sound record. Lines of magnetic force of the sound record external magnetic field are closed through its core; as a result, electromotive force transmitting the recorded signal is induced in the head winding. In case of undistorted transmission the given signal must be proportional to the value of residual magnetization formed on the magnetic tape when recording.

5/10-11 shows the frequency characteristics of individual components in the magnetic recording and reproducing channel (1). They are rather non-uniform. The level of high frequency transmission in the recording and reproducing heads is reduced due to the finite width of the working gaps and their azimuthal skewness, finite size of the heads, eddy currents in cores, etc. For correcting the frequency response of transmitted signals, a control for raising the high frequency components is provided in the recording amplifier. To avoid overmodulation the relative raising of the highest frequency in recording is not to exceed 14 dB. Therefore, if a large amount

of frequency correction is required, it is made additionally during reproduction.

In reproducing amplifiers a constant rise of frequency response at low frequencies of 6dB per octave and adjustable high frequency correction are provided. The non-uniformity of the resulting frequency response does not exceed, as a rule, ± 2 dB.

Chapter 6

6. Sound Records

6.1 Types of Photographic Sound Records

Since the invention of sound film two main types of photographic sound records have been used, namely: variable area and variable density. Depending on their purpose and recording features, sound records can be classified as shown in (6/11 - 1). Further, each of these sound records can be negative, positive, black-and-white or colour.

The main advantage of variable-density sound records as compared to variable-area sound records is a smaller effect on sound quality of errors of uniform illumination and azimuth of the light beams for recording, printing and reproduction. Also, the quality of variable-density sound records is less affected by wear and dirt. Such sound records were recorded by the apparatus of the Fox Case Movietone, Westrex, Tagefon and Maurer systems.

Variable-area sound records permit the transmission of signals at the standard value of acceptable non-linear distortion with greater dynamic range (about 42 dB as compared to 35 dB in case of variable-density sound records). These sound records could be recorded by the apparatus of the Westrex, RCA, Maurer, Tobis, Auricon, Klangfilm, Reevesound and Lenkinap systems.

For both types of sound records, roll-off in the high frequency region is approximately the same due to light scattering in the photographic layer. The upper limit for the recorded frequency band is about 8,000 Hz.

It should be noted that it is difficult to differentiate between sound records of the same type recorded by the apparatus of different systems.

The sound quality of any type of sound record is determined by non-linear and frequency distortions, by the value of the transmitted signal dynamic range, and by background noise.

The sound records of the early 1930s are characterized by a high level of **background** noise (the dynamic ranges for variable-density and variable-area sound records are about 23 dB and 33 dB, respectively), by sharp sound change over on spliced film sequences and discrepancy in the recording levels of speech, music and effects when heard simultaneously.

The recording systems began to be improved by including in the optical light modulator a multiplier to make bilateral variable-area sound records. Noise reduction equipment, compression and limiting systems were used in the 1940s. 6/11-2 shows a variable-area sound record rendered noiseless by displacing the centre line of the sound track, while 6/11-3 shows a double-track sound record rendered noiseless by special shutters.

Later on, multi-track variable-area sound records with up to 14 tracks were used 6/11-4 . Despite a number of advantages (lower non-linear distortion, less sensitivity to azimuth errors of the scanning beam and non-uniformit of its illumination, etc.), this type of sound record failed to find wide

application due to the necessity of significant modification in the generally accepted sound reproducing equipment. Multi-track sound records may be found in the film archives and a magnifying glass may be necessary to distinguish them from variable-density sound records.

In the late 1940s film studios used push-pull variable-area and variable-density sound records (mainly of Class "A"), as intermediate recordings (6/11-5). These sound records comprise two tracks recorded in a reverse phase mode (180° displacement). If they are reproduced on an ordinary apparatus, no useful signal is detected. During playback the light fluxes, after passing through each half of the sound track, have to be divided optically and fed to two separate photocells, and then the electric signals are summed; one being directed at 180° to the other.

The sound quality of such sound records is much higher (broader frequency band, smaller effect of splicing, etc.), but they found no wide application either due to the need to have special playback equipment.

Film archives may have sound records with a control track carrying a signal controlling volume level of the main recording, and permitting extending the dynamic range by up to 7 dB. 6/11-6a shows a control track consisting of a transparent strip of variable width in the spaces between the perforations. 6/11-6b and 6/11-6c show control tracks near the main sound track, and 6/11-6d shows control tracks outside the perforations. Such sound records found rather limited application in sound films.

In the late 1930s a number of countries conducted research to obtain stereophonic accompaniment for motion picture films on the basis of photographic

sound records. Various kinds of multi-track sound records were suggested (6/11-7). But the research did not go beyond the frame-work of an experiment. It was only in the 1950s, when magnetic recording was mastered, that stereophonic sound transmission found practical application.

The last decade has witnessed the widest application of double-track noiseless variable-area sound records in release prints, which are characterized by lower non-linear distortions during playback as compared to single-track sound records (6/11-8).

Another type is represented by sound records on multilayer colour film. Colour sound films appeared in the late 1930s. Some of them have variable-density sound records, but variable-area sound records were more widely used.

When printing sound records on multilayer colour films, special correcting filters control the spectral transmittance of the dense part of the sound track. The combination of cyan and magenta filters forms the sound record only in the upper, blue-sensitive, emulsion layer of the positive multilayer film (visually, such a sound record is yellow). The combination of cyan and yellow filters - in the middle, green-sensitive layer (magenta sound record), and the combination of magenta and yellow filters - in the lower, red-sensitive layer (cyan sound record).

Depending upon the photochemical processing employed, a sound record on the multilayer colour film can be either dye only, or dye plus silver, or silver only. Due to a number of peculiarities of colour film processing a dye plus silver sound record has the widest use. It is composed of both silver and dye, and its characteristics depend upon the content of silver as well as on the spectral characteristics

of the exciter lamp radiation and photocell sensitivity.

In former times sound reproduction equipment used two types of vacuum photocells: antimony-caesium and oxygen-caesium. Germanium and silicon semiconductor photodiodes have recently been employed. From the point of view of increasing sound record output in reproduction by various types of photocells, cyan filters producing a yellow sound record are recommended to be used in printing.

For printing colour films the sound negative is made on a black-and-white sound-recording film. The method for selecting the cancellation density for a sound record negative does not differ from that of selecting the cancellation density for a negative in printing black-and-white films.

6.2 Magnetic Sound Records

Magnetic sound records have a number of advantages over photographic ones. The recording of sound on a magnetic tape ensures the transmission of signals with 50-60 dB dynamic range, the non-linear distortion coefficient being not more than 1.5%, and frequency band of 30-16,000 HZ.

Magnetic sound tracks do not deteriorate so much as photographic tracks as a result of wear and dirt.

The main drawback of magnetic sound tracks lies in difficulties in their editing, due to the invisibility of the track, in difficulties in combining an image with a track on the same film, and their exposure to external magnetic fields. Film studios use magnetic sound records mainly to obtain intermediate recordings. 6.25 mm tape and 17.5 and 35 mm perforated film are used for this purpose.

6/11-9 shows the various locations of the tracks on these films.

The recording on magnetic tape or film is invisible, which renders it difficult to determine the type of a magnetic sound record (the number of tracks). To render them visible magnetic development methods are used. One of them is to cover the magnetic layer with carbonyl iron suspension in heptane or benzine. The volatile substance quickly evaporates, and iron particles are concentrated on the magnetized parts of the surfaces, thus showing the recording trace. A special device (visualizer) can be used for this purpose. It is placed upon the magnetic layer of a sound record and the sound track becomes visible through its glass window.

Magnetic originals for mixing are produced on 35 mm film in the form of a single-track recording. The U.S.A., Romania, Poland, Great Britain and a number of other countries use a recording original which is a three-track magnetic sound record with separately recorded dialogue, effects and music. Such a sound record is used for release printing (the signals from the three tracks are automatically mixed to be recorded on a photographic sound negative) and for dubbing (only effects and music tracks are used).

Beginning with the 1950s the development of wide-screen and later wide-format films resulted in practical application of stereophonic systems. For this purpose 4-, 6-, 7- and 9- channel sound transmission systems were worked out. Rerecording magnetic originals were produced on 35 mm films with 4 to 9 channels.

6.3 Sound Tracks on Release Prints

Motion picture theatres use combined prints (image + sound) produced on 16mm. 35mm. and 70mm films. On them narrow, normal, wide-screen, wide-format and panoramic pictures are printed. Sound tracks on them may be either magnetic or photographic and of different types with various numbers of channels.

In the early 1930s a photographic sound record on 16mm. release prints was produced by optical printing from 35mm. sound negative. By the end of the 1930s apparatus was manufactured for recording sound on 16mm. film, copies were then made by contact printing.

The sound quality of 16mm. photographic sound tracks is inferior to that of 35mm. tracks. The upper limit of the transmitted frequency range is usually about 6 kHz, while the reproduced dynamic range is 30-35 dB. Application of magnetic tracks on 16mm. release prints doubled the frequency range and increased the signal/noise ratio in reproduction up to 50 dB. The drawbacks of 16mm. release prints with magnetic sound records include their higher cost and unreliability: a sound record can be demagnetized and the magnetic track can be peeled off under unfavourable storage conditions. Therefore, photographic sound records are mainly used in 35mm. and 16mm. release printing. 6/11-10 shows the location of sound tracks on 16mm. release prints, and 6/11-11 on 35mm. release prints.

Scanning beams of 1.8 mm. in width and up to 0.015mm. in length are used for reproducing 16mm. photographic sound prints; in case of 35mm. photographic sound prints the figures are 2.15mm. and 0.023 mm. respectively.

6/11-12 shows the location of magnetic tracks on 35mm. Cinemascope prints with stereo sound. The main stereophonic sound record is on the 1st, 2nd and 3rd wide tracks to be reproduced by three loudspeakers behind the screen, while the 4th, narrow, track is used for recording effects reproduced by the loudspeakers located around the perimeter of the hall.

There is a type of Cinemascope print which has both a magnetic and photographic sound track (the so-called "Magoptical" print). This type of print has a narrow magnetic track which occupies half the width of the normal photographic sound track area **(6/11-13).This** type of print is capable of being shown on installations which have either only magnetic or only photographic track reproduction facilities.

6/11-14 shows the location of magnetic tracks on a 70mm. print. The main sound, reproduced by loudspeakers behind the screen is recorded on tracks 1 - 5; and effects on the 6th track.

In the 1950s - 1960s the U.S.A. and the U.S.S.R. produced several panoramic films (three films were used for shooting). The sound record was recorded on a separate 35mm. magnetic film and reproduced in a motion picture theatre simultaneously with image projection. The American Cinerama system recorded sound on 7 tracks, while the Soviet system used 9 tracks **(6/11-9 g and h).**

Since, during picture projection, the film movement is intermittent and during sound reproduction the film must move smoothly; in combined prints the sound is always shifted with respect to the corresponding image. In 70mm. prints sound delay during projection is 24 frames; in 35mm. prints with photo-

graphic sound, the sound is 21 frames in advance, and in 35mm. prints with magnetic sound, the sound delay is 28 frames. In 16mm. prints with photographic sound, the sound is 26 frames in advance, and in prints with magnetic sound, the sound is 28 frames in advance.

6.4 Checking and Release Printing of Sound Tracks

Checking of sound records is effected in two directions: technical state and sound quality. In the first case films are checked for technical defects, emulsion peeling, presence of mould, condition of the base, perforations and splicing. Shrinkage is measured and new leaders are substituted for obsolete ones. If necessary, the defects are eliminated by restoration.

Photographic sound records are to be checked every 3 years and magnetic sound records - every 5 years.

In monitoring, the general characteristic of the sound is determined, namely, sound mean level, frequency balance (low, high, normal), intelligibility of the dialogue, music quality (clarity, tone colour, wow and flutter), and additional noise.

In release printing of sound records their sound quality must exactly correspond to the master tape (same tone colour, absence of additional noise and distortions). It is essential to ensure image and sound synchronization. Based on dialogue continuity lost frames may be replaced. Film materials are synchronized on special editing tables.

It should be noted that until the 1940s tracks on release prints were made by duplication from positives, which considerably reduced the sound quality of the tracks thus obtained. Film archives

still often use this method. A more efficient method is re-recording from positives or magnetic sound tracks onto a negative film followed by positive printing. The sound quality of the print is a criterion of re-recording processes and the perfection of sound track printing.

Chapter 7

7. Preservation of Sound in Films

The possibility of further usage of sound records is the only criterion for the evaluation of their state in long storage. Their quality is mainly affected by temperature and humidity conditions of storage (destruction of a film or tape layer and changes in its geometrical dimensions) and various operational effects resulting in mechanical defects and noisiness. To preserve a sound record as long as possible, it is necessary to keep certain requirements for their checking and preparation for storage, provide the appropriate temperature and humidity in places of storage, restore their physico-mechanical properties and sound quality.

7.1 Requirements for the Preparation and Storage of Sound Tracks

Films with sound tracks, which are to be stored, should be rewound with the beginning at the outside, which is convenient for further checking and use. Films should be wound with uniform tension, and the lateral surfaces of the roll must be smooth, otherwise the edges can be damaged.

A sound record should be kept in a special can. It is recommended to enclose the reel in ethylene bags to protect the record from dust.

Cans containing sound records are normally stored in racks. Magnetic tracks should be stored in metalic cans, made of magnetic-conductive material to protect the record from the effect of external magnetic fields. If metal racks are used, their contours must be closed for protection from external magnetic fields.

Upon removal from storage, the cans should be kept in an intermediate storage area for as long as 24 hours for the purpose of their conditioning (if there is no artificial re-acclimatization, see 2.3.2.4). Recording and periodic inspection of records must be made in clean premises. The records must be protected from exposure to direct sunlight to avoid their overdrying and curling.

The records should not be sent outside the archive for any work to be done on them, since in this case they can be either damaged or lost. A copy of the stored original is to be made for this purpose.

Magnetic tracks should be stored at a maximum temperature of +12° C and relative humidity of 50 to 60% (i.e. at the same climatic conditions as black and white triacetate films), with air conditioning and excessive pressure being 0.2 atmosphere as compared to the atmospheric pressure. That means it is better to separate picture and sound before storing colour films with magnetic sound tracks.

Recommendations for the storage of photographic sound records and other film materials are the same as for film pictures

nitrate film,	black-and-white	- not higher than +6°C;
	colour	- not higher than -5°C;
triacetate,	black-and-white	- not higher than +12°C;
	colour	- not higher than -5°C.

Relative humidity is to be from 50 to 60% for black-and-white film, and for colour film 20 - 30%.

7.2 Restoration of Sound Tracks

Restoration is carried out on sound tracks which have suffered physical damage, deteriorating mechanical condition, or loss of sound quality as compared to the original. The restorative procedure includes: manual restoration, chemical treatment, reprinting of positives from negatives and re-recording positives with unsatisfactory sound quality onto magnetic film while employing devices for improving sound quality.

Manual restoration removes traces of cement, repairs patches and broken perforations, removes dirt, retouches the film, checks synchronization with the picture, and replaces obsolete leaders with standard ones. With magnetic tracks adhesive tapes are renewed, perforation damage is repaired and synchronization with the picture is made.

The necessity for any chemical technological treatment of photographic tracks is determined, depending upon the nature of any defects found. This may include polishing, ultra-sonic cleaning etc. The methods of treatment do not differ from those used for picture film.

Long-term storage and utilisation can result in an accumulation of dust and particles from the magnetic coating on the surfaces of magnetic films. This can result in poor contact between the sound track and the play-back head which causes loss of sound quality and scratching of the magnetic coating. Therefore it is necessary to remove these defects before the film is used.

A sound record negative which does not require the above procedure can be used for photographic printing of the sound positive. If there is lateral shrinkage, an effective humidifying method is to be used. In case

of sound track shrinkage, special printers are recommended, with a variable pitch movement. If the negative has suffered considerable wear, wet printing is recommended.

The conditions for printing sound record positives are determined in the following way. On a sound negative, sections containing speech with sibilants ("s", "ch", etc.) are selected. A series of positives at a range of densities is printed from them. Then the prints of the sections are monitored for determining the optimum print density, which ensures the maximum cancellation for non-linear distortions in variable-area records and the optimum output of variable-density records. The densities of positive silver, and dye-plus silver tracks may be of values not less than 0.8 and not more than 2.5 Then the entire sound record is printed under the recommended conditions.

The positive thus obtained is listened to for determining sound quality. Such defects as non-uniform sound signals, high level of additional noise and unintelligibility of cues can appear. These defects can be eliminated without discernible distortions in tone quality by means of using noise supplressors filters and manual control of level in rerecording. The magnetic record thus produced is used for obtaining a sound negative with a density close to that selected as giving greatest cancellation.

The correct observance of these requirements for storage and restoration preserves sound tracks for many years.

Appendix
to Chapter 1 - 5

The figures are already marked for the complete edition of the Preservation manual and for other linguistic versions.

Nr 6 corresponds Chapter 1

Nr 7 corresponds Chapter 2

Nr 8 corresponds Chapter 3

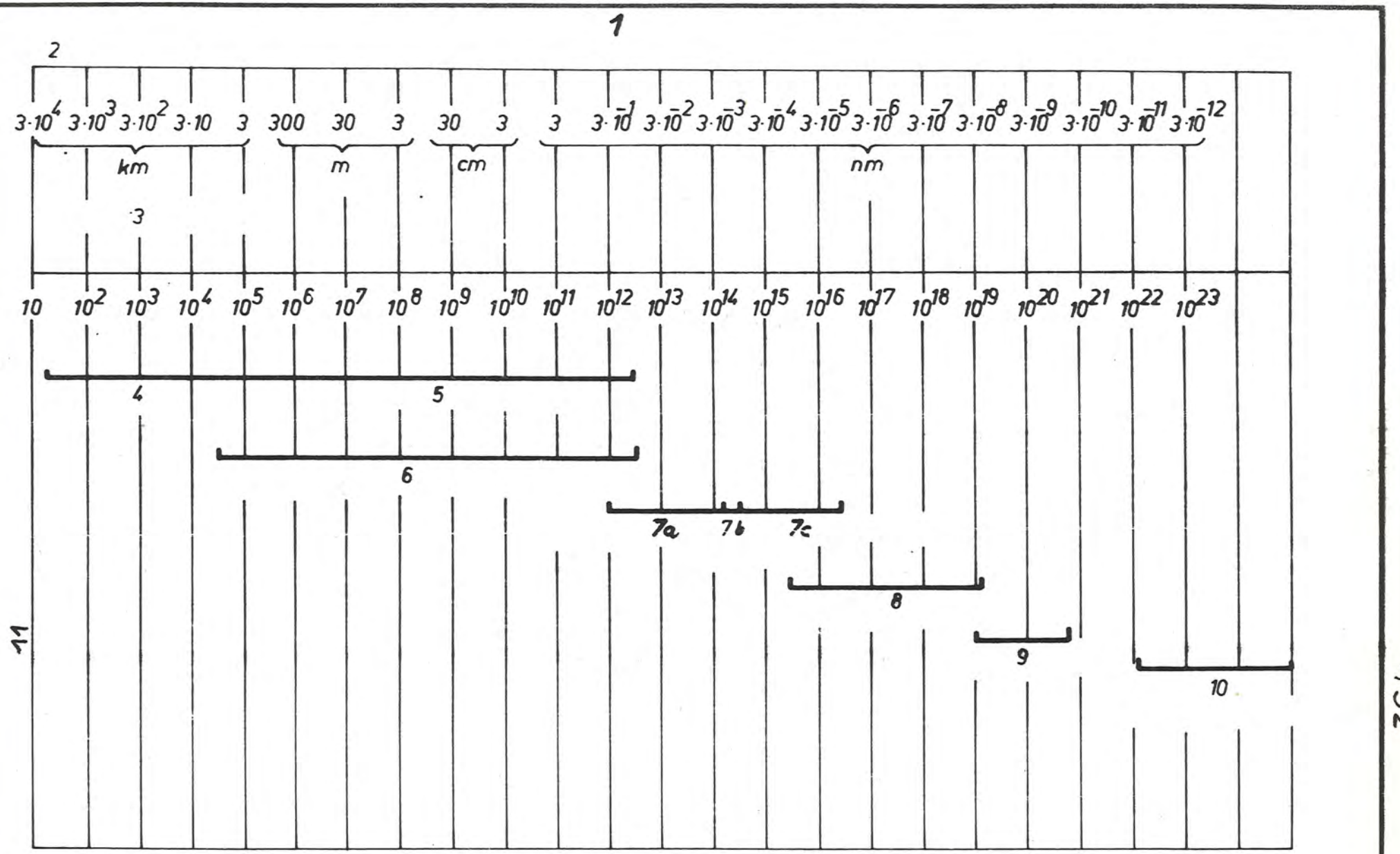
Nr 9 corresponds Chapter 4

Nr 10 corresponds Chapter 5

Nr 11 corresponds Chapter 6

Appendix
to Chapter 1 (6)

Fig 6 - 1/9


1
2
3·10^4 3·10^3 3·10^2 3·10 3 300 30 3 30 3 3 3·10^-1 3·10^-2 3·10^-3 3·10^-4 3·10^-5 3·10^-6 3·10^-7 3·10^-8 3·10^-9 3·10^-10 3·10^-11 3·10^-12
km
m
cm
nm
3
10 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20 10^21 10^22 10^23
4
5
6
7a
7b
7c
8
9
10
11

Appendix I - 1

Fig. 6 - 1

1 Electromagnetic vibrations

2 Wavelength

3 Frequency in Hertz

4 Low frequencies

5 High frequencies

6 Long, medium, short, ultra-short waves

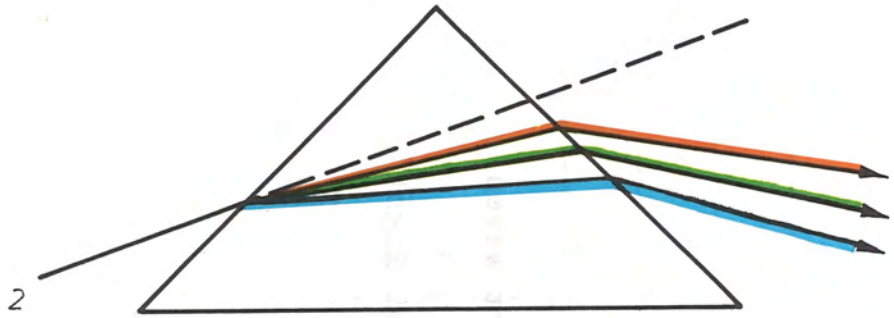
7 Infra-red, visible, ultra-violet light

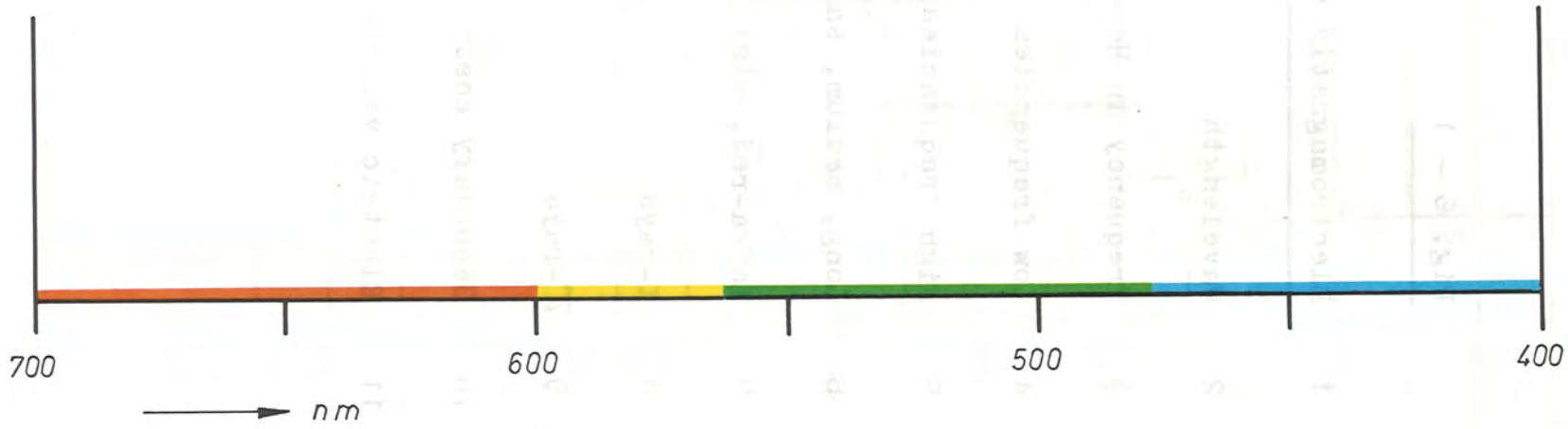
8 X-rays

9 γ-rays

10 Secondary cosmic radiation

11 Electric vibrations





1

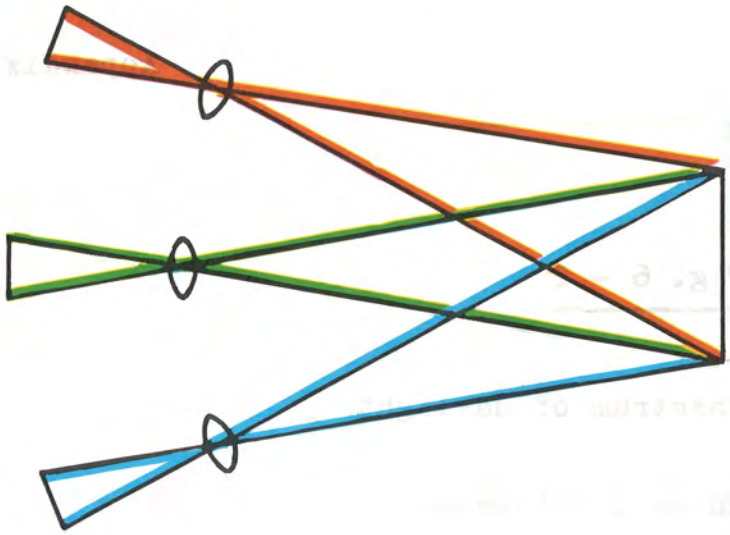
Appendix I - 2

Fig. 6 - 2

1 Spectrum of daylight

2 White light beam

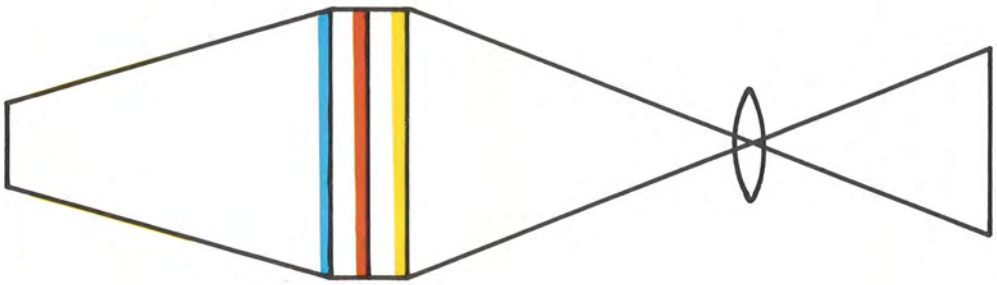
3



1

2

4



1

2

Fig. 6 - 3

1 Schematic representation of an additive colour process

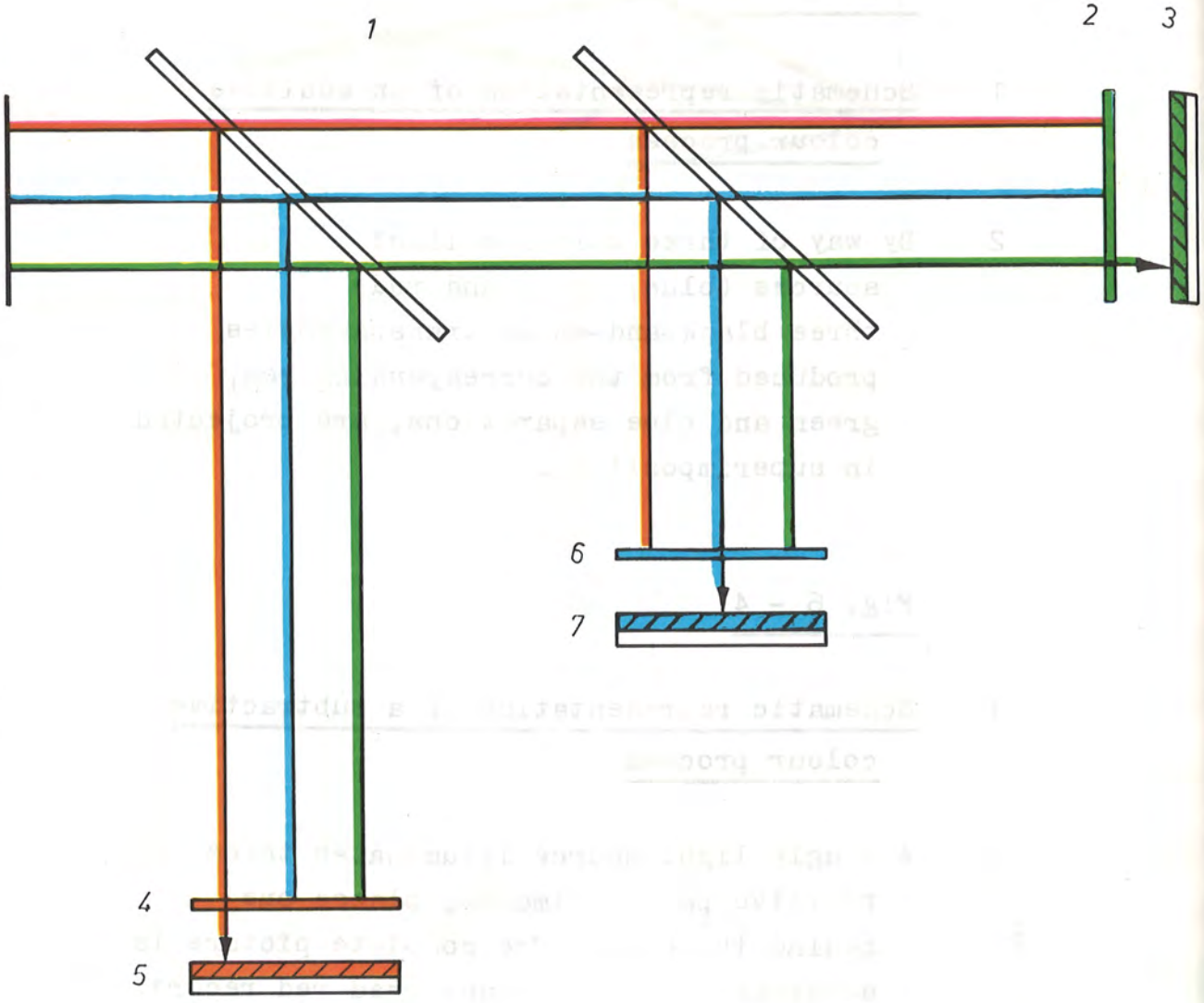
2 By way of three coloured light sources (blue, green and red) three black-and-white transparencies produced from the corresponding red, green and blue separations, are projected in superimposition.

Fig. 6 - 4

1 Schematic representation of a subtractive colour process

2 A single light source illuminates three positive partial images, placed one behind the other. The complete picture is constructed from a Cyan-toned red record, a magenta-toned green record and a yellow-toned blue record.

5



8

9

Appendix I - 5

Fig. 6 - 5

1 The arrangement of a beam splitter for the simultaneous production of the three separations.

2 Semitransparent mirrors

3 Green filter

4 Green separation

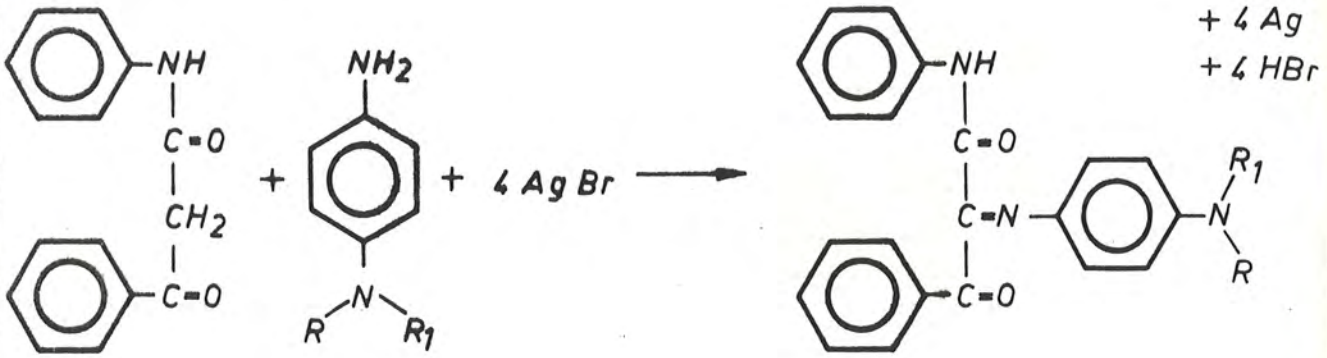
5 Red filter

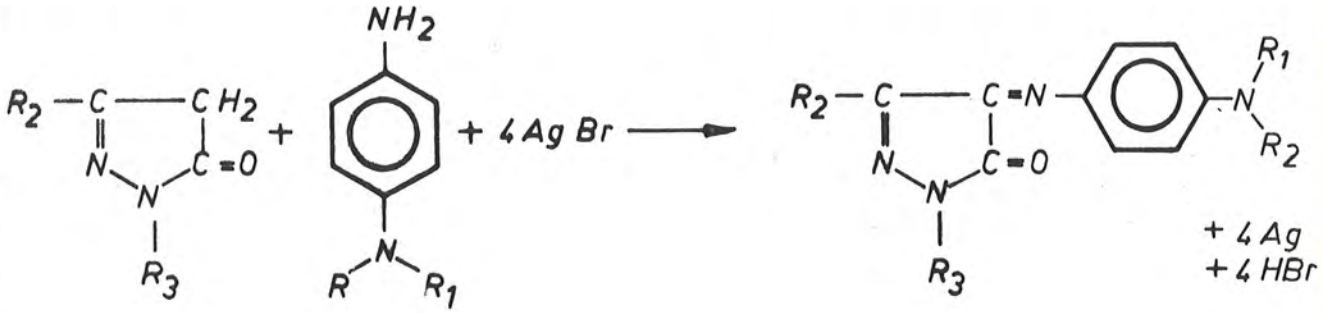
6 Red separation

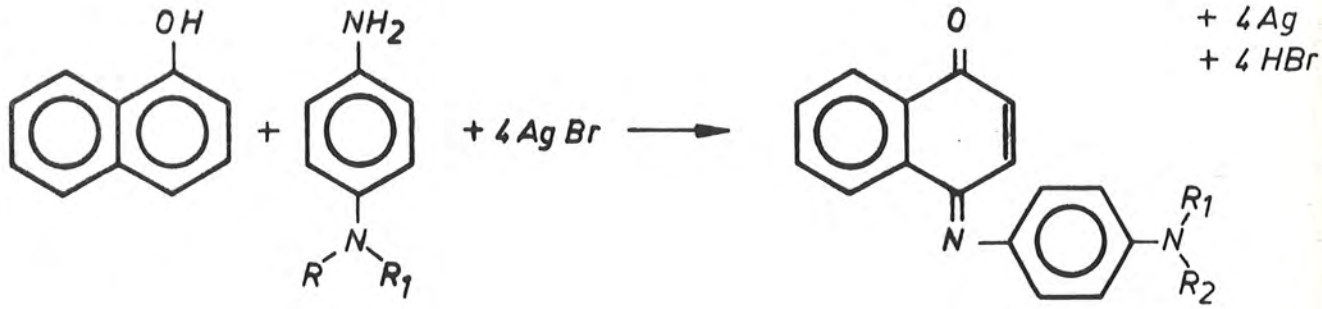
7 Blue filter

8 Blue separation

9 The light beam coming from the lens is partly reflected at two semi-transparent mirrors and the corresponding separations are produced from the three beams with the aid of red, green and blue filters. These devices serve to avoid both time and space parallax during photography.


NH
C=O
CH2
C=O
NH2
N
R
R1
+ 4 Ag Br
NH
C=O
C=N
C=O
R1
N
R
+ 4 Ag
+ 4 HBr


R2
C
CH2
N
C=O
N
R3
NH2
N
R
R1
+ 4 Ag Br
R2
C
C=N
N
C=O
N
R3
R1
N
R2
+ 4 Ag
+ 4 HBr


OH
NH2
N
R
R1
+ 4 Ag Br
O
N
R1
N
R2
+ 4 Ag
+ 4 HBr

6a

1

2

Appendix I – 6a

Fig. 6 – 6a

1 Chromogenic development

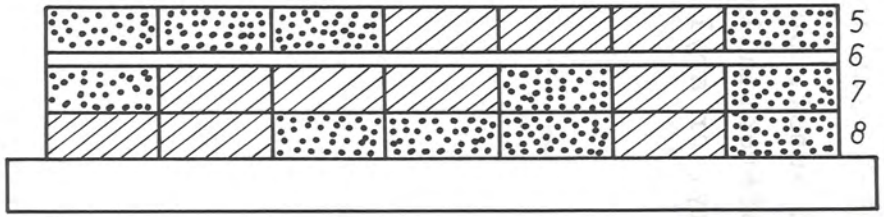
2 Schematic representation of the generation of the three subtractive primary colours yellow, magenta, cyan in colour developing.

R and R_1 mean subst. or unsubst. alkyl residues
R_2 and R_3 preferentially subst. or unsubst. alkyl or aryl residues.

6 b



1



2
3
4
5
6
7
8

9

10

11

12

Fig. 6 - 6b

1 Original

2 Blue-sensitive,

3 Green-sensitive,

4 Red-sensitive,

5 Yellow dye,

6 Yellow filter,

7 Magenta dye,

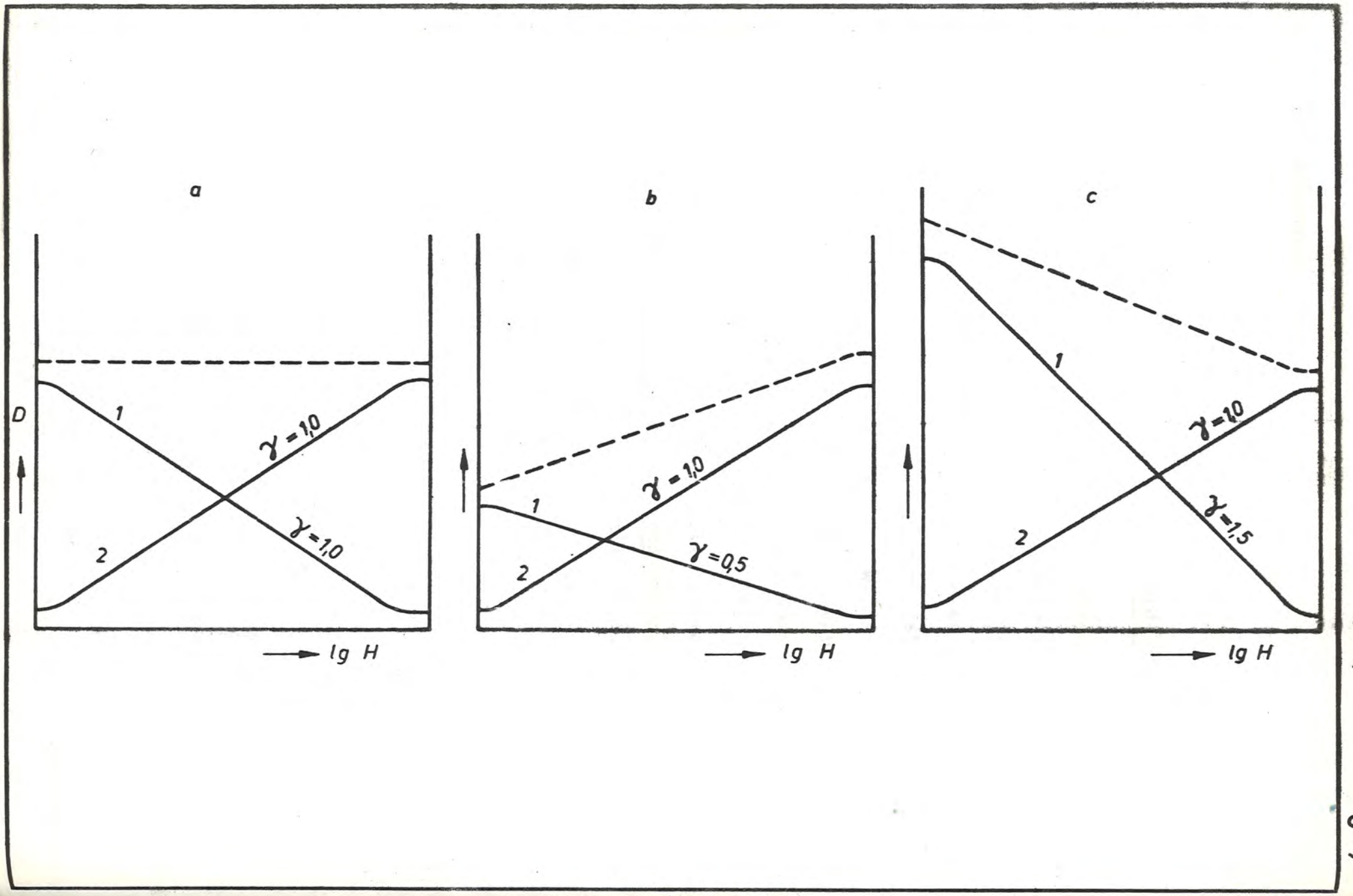
8 Cyan dye,

9 Silver halide,

10 Latent image,

11 Schematic representation of a multi-layer film

12 The various emulsion layers are firmly adherent to the film base.

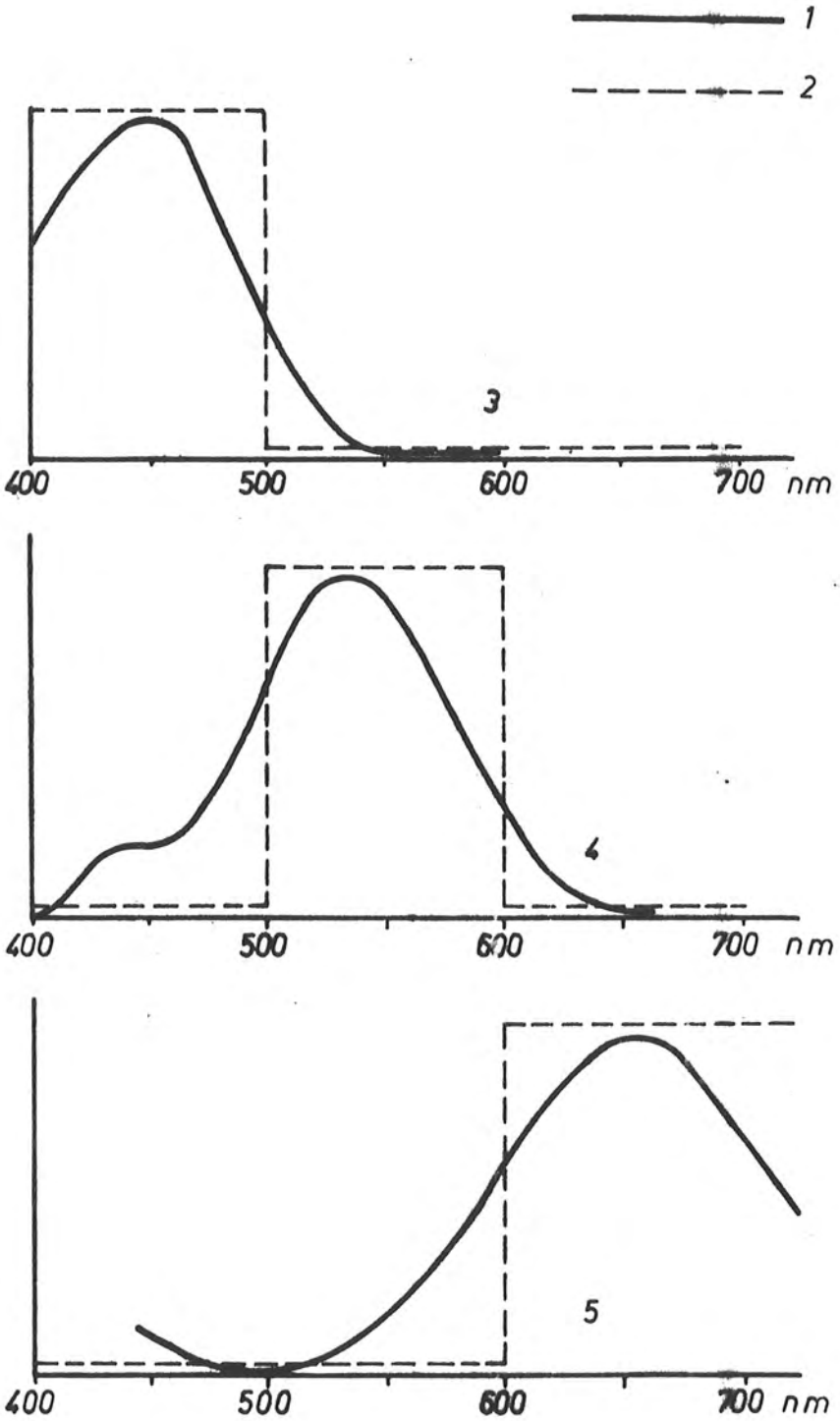

a
b
c
D
1
2
γ=1,0
γ=1,0
γ=1,0
γ=0,5
γ=1,0
γ=1,5
lg H
lg H
lg H

Appendix 1 - 7

Fig. 6 - 7 (a - c)

1 Mask

2 Negative


1
2
3
400
500
600
700 nm
4
400
500
600
700 nm
5
400
500
600
700 nm

Appendix 1 - 8

Fig. 6 - 8

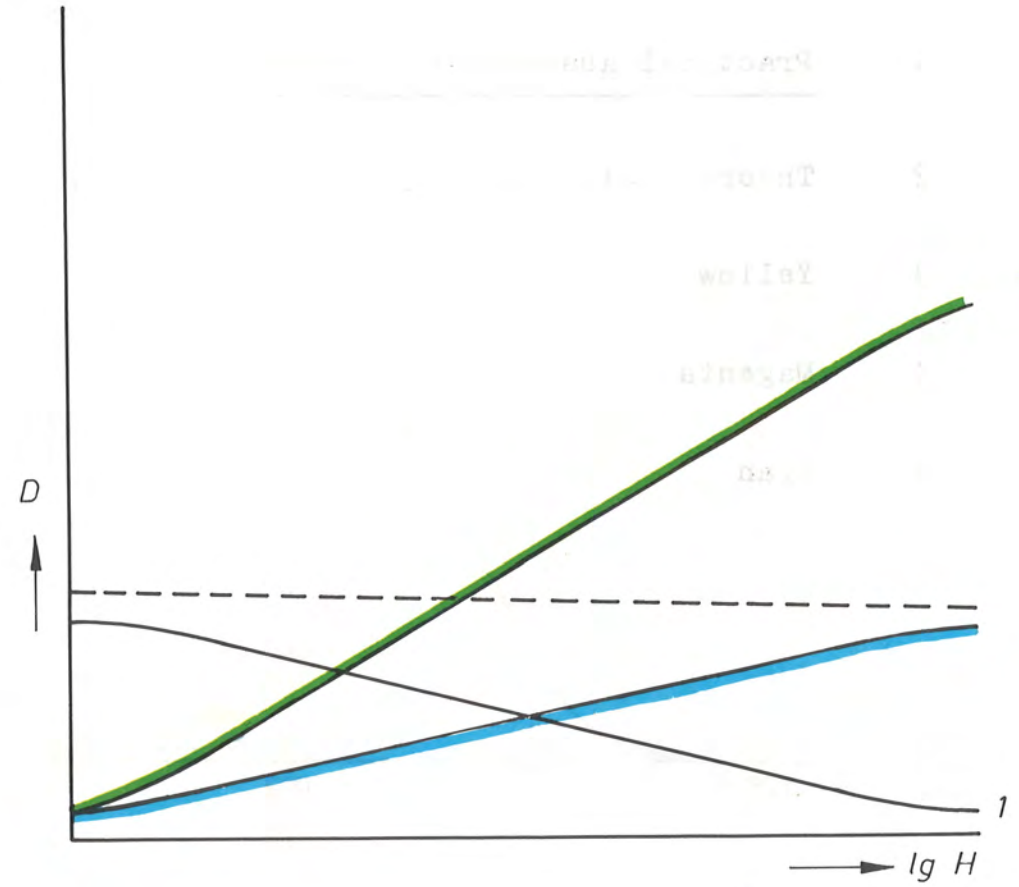
1 Practical absorbtion curves.

2 Theoretically ideal absorbtion curves.

3 Yellow

4 Magenta

5 Cyan


D
1
lg H

Appendix 1 - 9

Fig. 6 - 9

1 Mask

Appendix

to Chapter 2 (7)

Appendix Chapter 2 (7)
fig 1

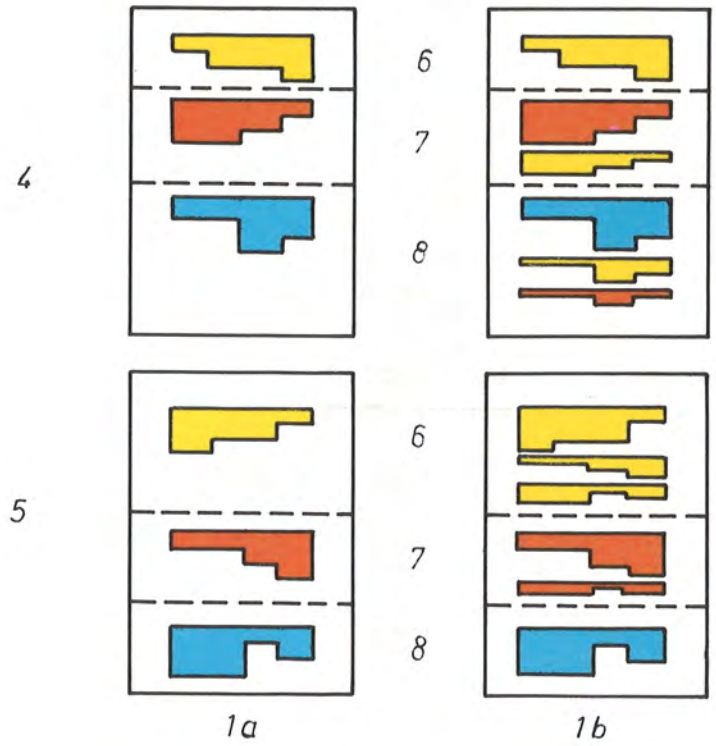
Temperature of air	Relative Humidity %							
°C	60%	65%	70%	75%	80%	85%	90%	95%
	Dew point temperature °C							
6	-1	0	1,0	2,0	3,0	4,0	4,5	5,0
7	0	1,0	2,0	3,0	4,0	5,0	5,5	6,0
8	1,0	2,0	3,0	4,0	5,0	6,0	6,5	7,0
9	2,0	3,0	4,0	5,0	6,0	6,5	7,5	8,0
10	3,0	4,0	5,0	6,0	7,0	8,0	8,5	9,0
11	4,0	5,0	6,0	7,0	8,0	8,5	9,5	10,0
12	5,0	5,5	7,0	8,0	9,0	9,5	10,5	11,0
13	5,5	6,5	8,0	9,0	10,0	10,5	11,5	12,0
14	6,5	7,5	8,5	10,0	10,5	11,5	12,5	13,0
15	7,5	8,5	9,0	10,5	11,5	12,5	13,5	14,0
16	8,5	9,5	11,0	11,5	12,5	13,5	14,5	15,0
17	9,0	10,5	11,5	12,5	13,5	14,5	15,5	16,0
18	10,0	11,5	12,5	13,5	14,5	15,5	16,5	17,0
19	11,0	12,5	13,5	14,5	15,5	16,5	17,5	18,0
20	12,0	13,0	14,5	15,5	16,5	17,5	18,5	19,0
21	13,0	14,0	15,5	16,5	17,5	18,5	19,0	20,0
22	14,0	15,0	16,0	17,5	18,5	19,5	20,0	21,0
23	15,0	16,0	17,0	18,5	19,5	20,5	21,0	22,0
24	16,0	17,0	18,0	19,5	20,5	21,5	22,0	23,0
25	17,5	18,0	19,0	20,5	21,5	22,5	23,0	24,0
26	18,0	19,0	20,0	21,0	22,5	23,5	24,5	25,0
27	18,5	20,0	21,0	22,0	23,5	24,5	25,0	26,0
28	19,5	20,5	22,0	23,0	24,0	25,5	26,0	27,5
29	20,5	21,5	23,0	24,0	25,0	26,5	27,0	28,0
30	21,5	22,5	24,0	25,0	26,0	27,0	28,0	29,0
31	22,0	23,5	25,0	26,0	27,0	28,0	29,0	30,0
32	23,0	24,5	26,0	27,0	28,0	29,0	30,0	31,0

Appendix

to Chapter 3 (8)

fig 8 - 1/9

1

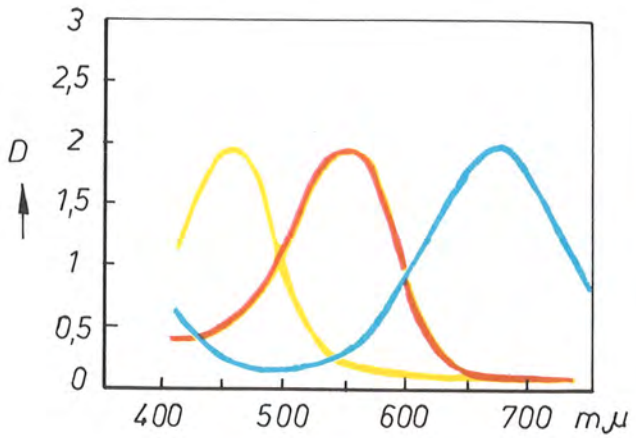


1

2

3

2



9

Appendix 3 - 1 - 2

Fig. 8 - 1

1 Colour separations

2 1a ideal separation

3 1b normal separation

4 Negative

5 Positive

6 Blue

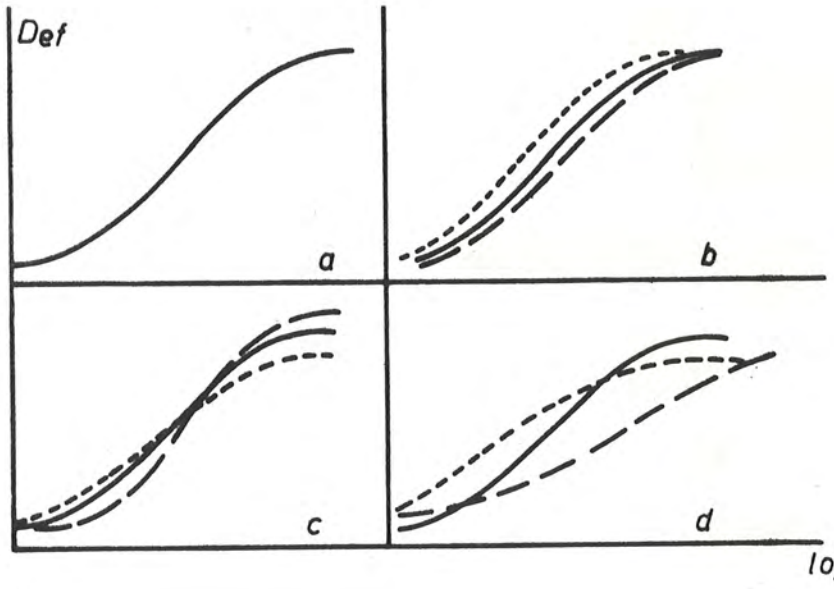
7 Green

8 Red

Fig. 8 - 2

9 Spectral absorbtion curves of the dyes.

3



1

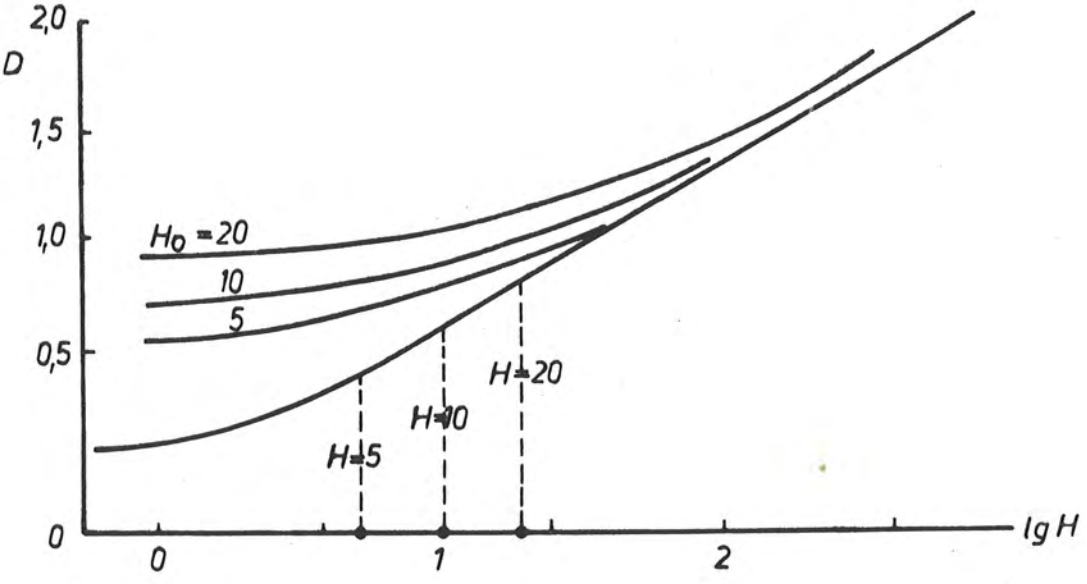
2

3

4

5

4



6

Appendix 3 - 3 - 4

Fig. 8 - 3

1 Non-conformity of properties of the light-sensitive layers of photografic colour materials

2 a. Perfect coincidence of the three characteristic curves

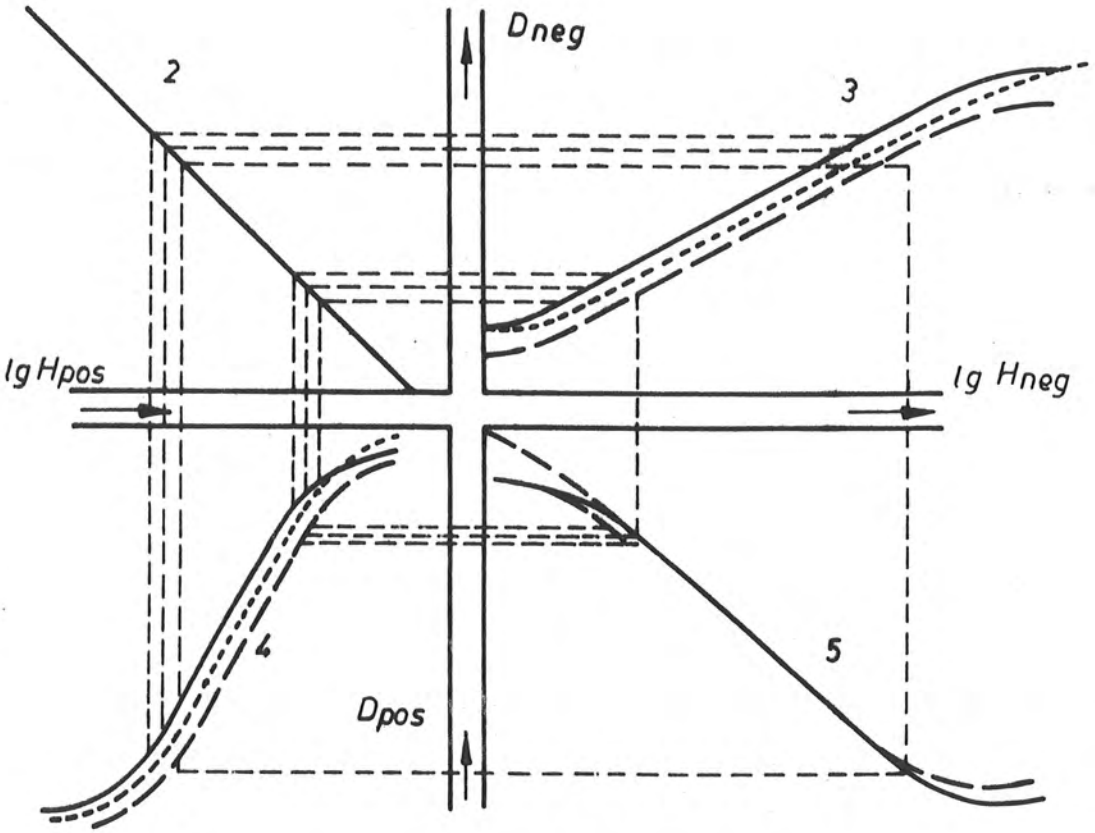
3 b. Non-balance of sensitivity

4 c. Non-balance of contrast

5 d. Total non-balance: sensitivity and contrast

Fig. 8 - 4

6 Illustrative scheme of the influence of different quantities of supplementary lighting (H_o) to the form of the characteristic curve.



1

Appendix 3 - 5

Fig. 8 - 5

1 Illustrative diagram of the reproduction of grey tones for a colour photografic process negative / positive.

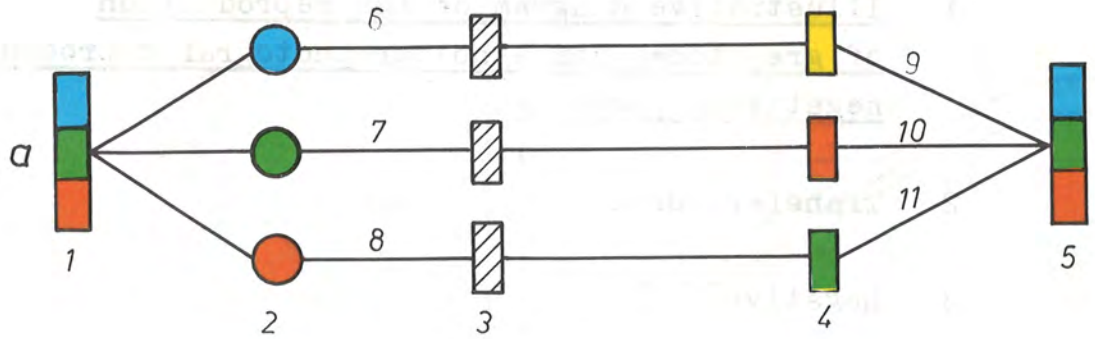
2 Transfer curve

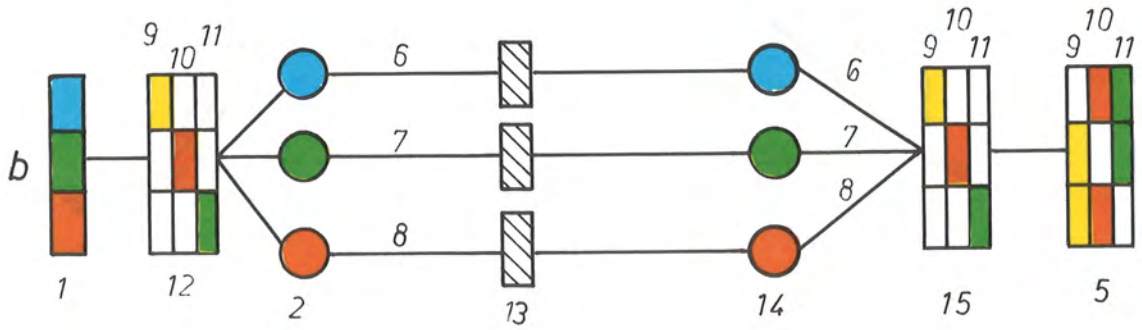
3 Negative

4 Positive

5 Reproduction curve

6



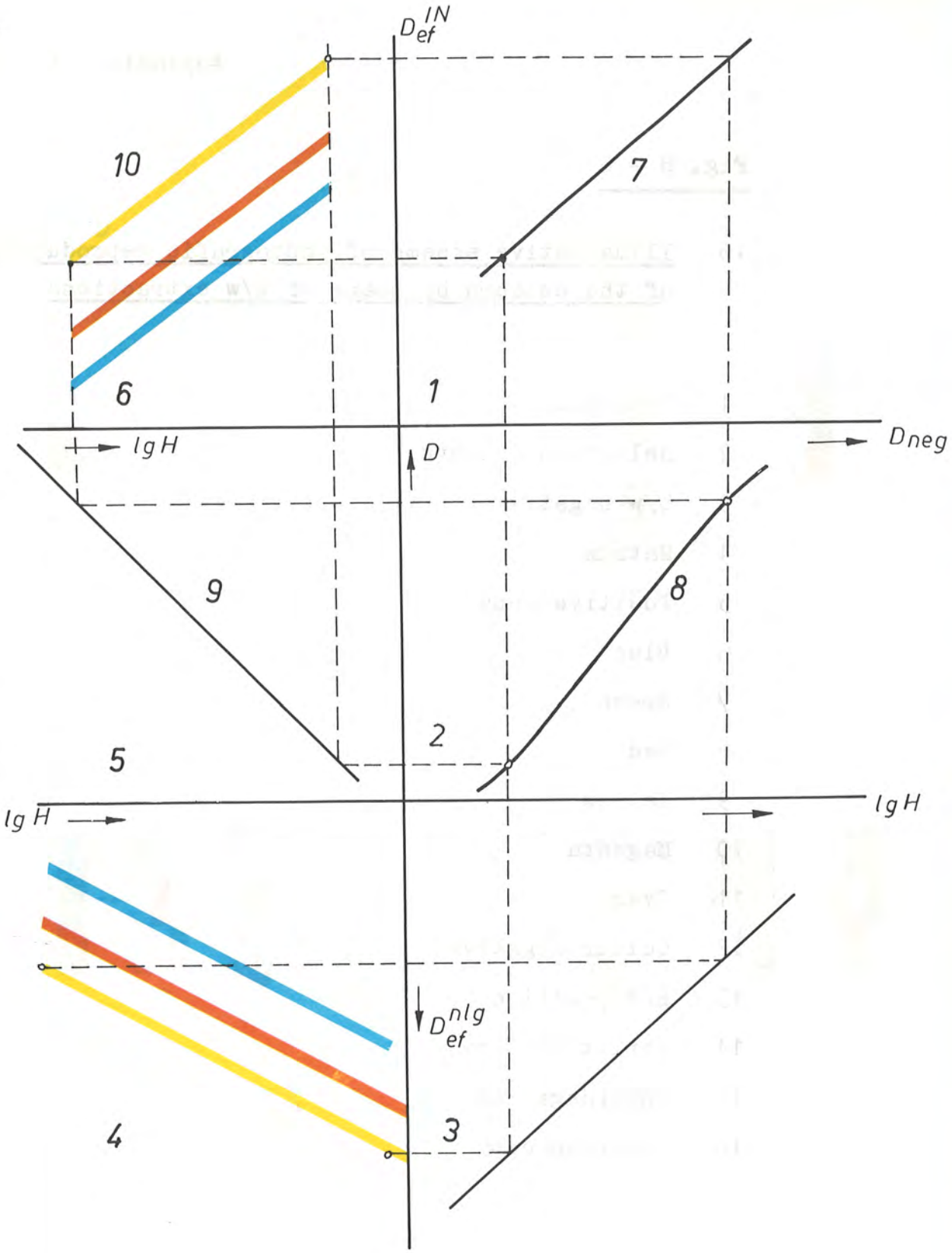


Appendix 3 - 6

Fig. 8 - 6

16 Illustrative scheme of photografic reproduction of the colours by means of b/w extractions

1 Original
2 Selection filters
3 b/w negative
4 Matrix
5 Positive copy
6 Blue
7 Green
8 Red
9 Yellow
10 Magenta
11 Cyan
12 Colour negative
13 B/W positive
14 Strict Filters
15 Internegative
16 Positive copy


D_{ef}^{IN}
10
7
6
1
lg H
D
D_{neg}
9
8
2
5
lg H
lg H
D_{ef}^{nlg}
4
3
11

Appendix 3 - 7

Fig. 8 - 7

11 Illustrative diagram of the reproduction of tones for the process of realisation of colour contretypes by means of b/w separation films

1 Quadrant 1

2 Quadrant 2

3 Quadrant 3

4 Quadrant 4

5 Quadrant 5

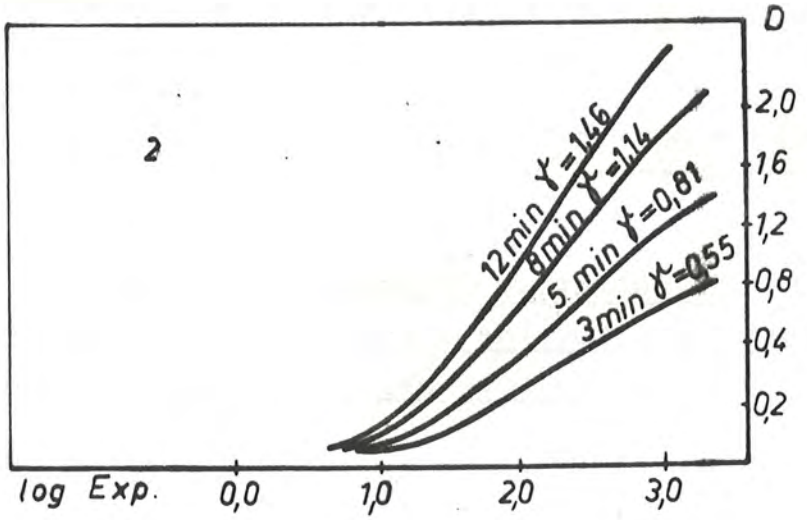
6 Quadrant 6

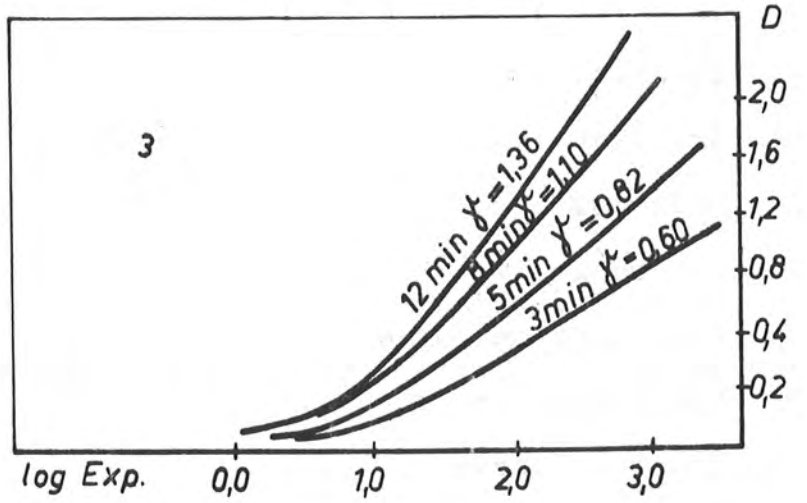
7 Internegative

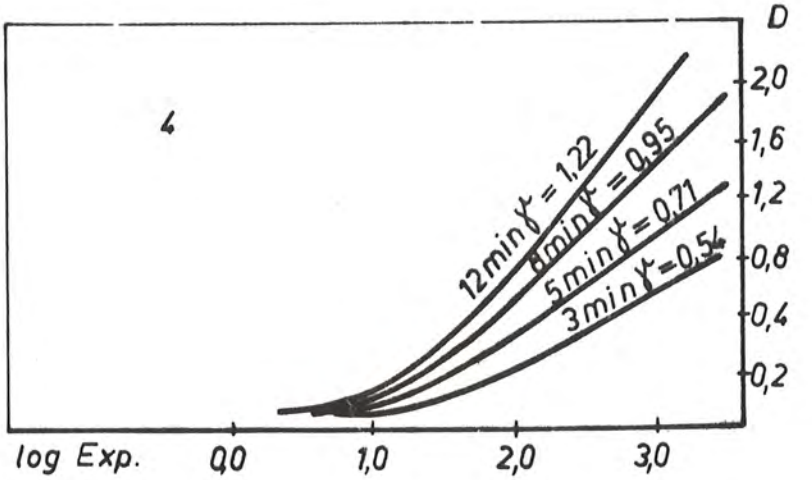
8 Reproduction curve

9 Separation panchro film

10 Transfer curve


D
2
12 min γ = 1,46
8 min γ = 1,14
5 min γ = 0,81
3 min γ = 0,55
2,0
1,6
1,2
0,8
0,4
0,2
log Exp.
0,0
1,0
2,0
3,0


D
3
12 min γ = 1,36
8 min γ = 1,10
5 min γ = 0,82
3 min γ = 0,60
2,0
1,6
1,2
0,8
0,4
0,2
log Exp.
0,0
1,0
2,0
3,0


D
4
12 min γ = 1,22
8 min γ = 0,95
5 min γ = 0,71
3 min γ = 0,54
2,0
1,6
1,2
0,8
0,4
0,2
log Exp.
0,0
1,0
2,0
3,0

1

Appendix 3 - 8

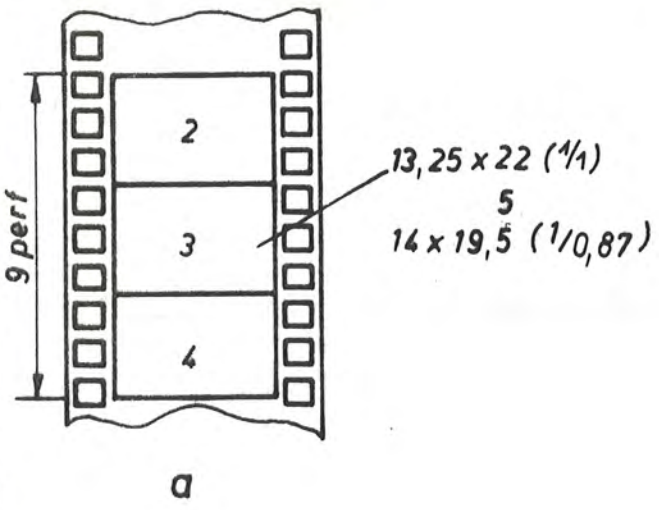
Fig. 8 - 8

1 Adaptation of Eastman Separation panchro film type 5235.

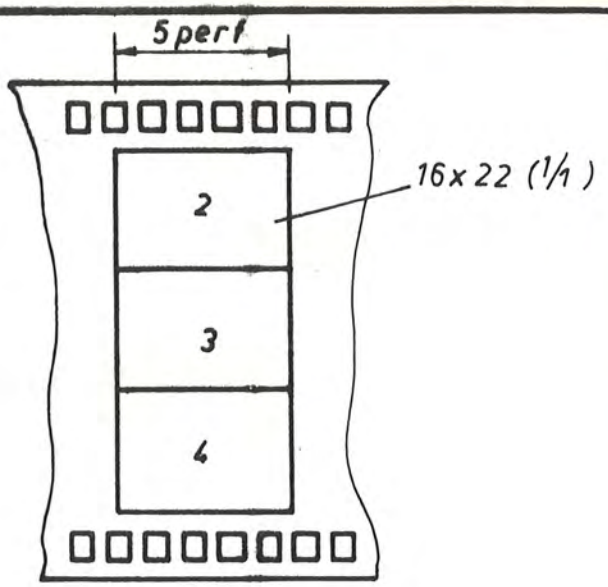
2 Exposure with wratten filter nr 70.
Development in bath D_{76} at 20° C.

3 Exposure with wratten filter nr 98 or 47 B + 2 B.
Development in bath D_{76} at 20° C

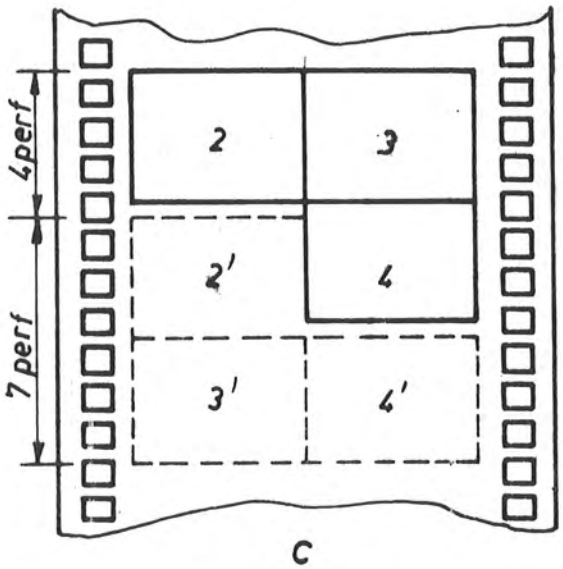
4 Exposure with wratten filter nr 99 or 16 + 61.
Development in bath D_{76} at 20° C.


9 perf
2
3
4
13,25 x 22 (1/1)
5
14 x 19,5 (1/0,87)

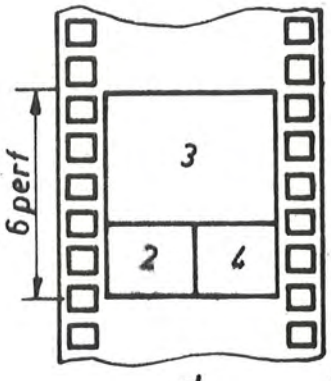
a


5 perf
2
3
4
16 x 22 (1/1)

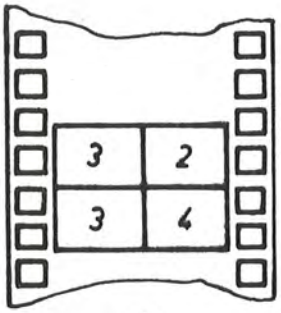
b


4 perf
7 perf
2
3
2'
4
3'
4'

c


6 perf
3
2
4

d


3
2
3
4

e

Appendix 3 - 9

Fig. 8 - 9

1 Possibilities of the disposition of colours on one single film

2 Blue

3 Green

4 Red

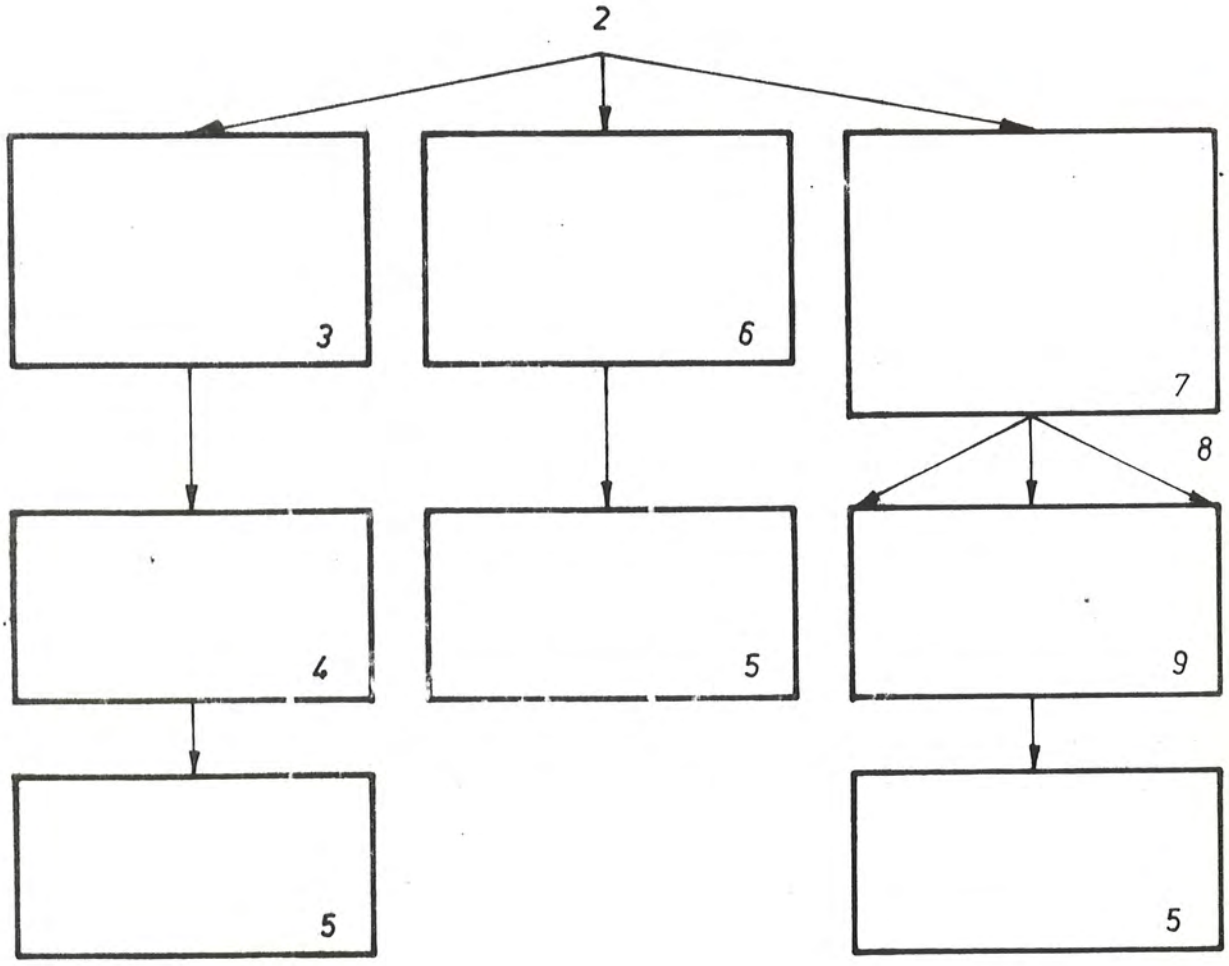
Appendix

to Chapter 4 (9)

fig 9 - 1/2



1



Appendix 4 - 1

Fig 9 - 1

1 Restoration of negative colour images by correcting printing

2 Original colour negative

3 Dup colour positive on intermediate film

4 Dup colour negative on intermediate film

5 Colour copy on positive colour film

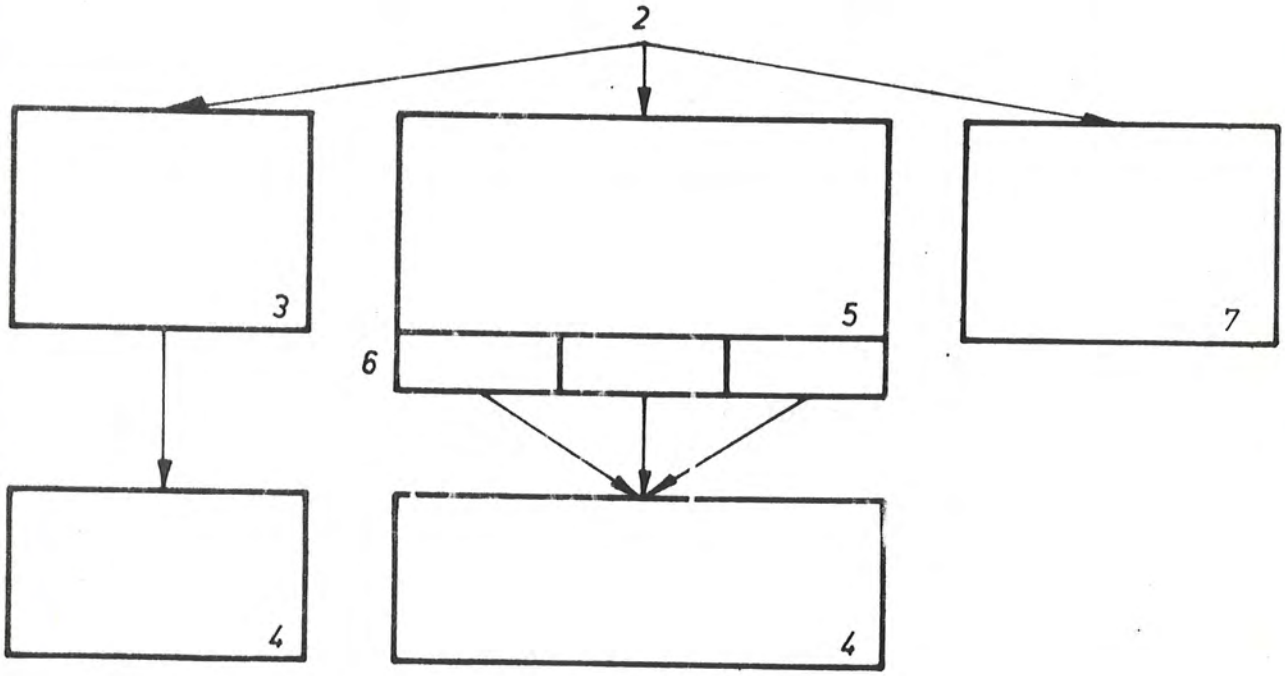
6 Dup colour negative on reversible intermediate film

7 Dup black-and-white positive separation on panchromatic separation film

8 Blue - green - red

9 Dup colour negative on intermediate film

1



a b c

Fig 9 - 2

1 Restoration of positive colour images by correcting printing

2 Original colour positive

3 Colour negative on negative colour film

4 Copy on positive colour film

5 Colour selections on dup panchromatic negative film

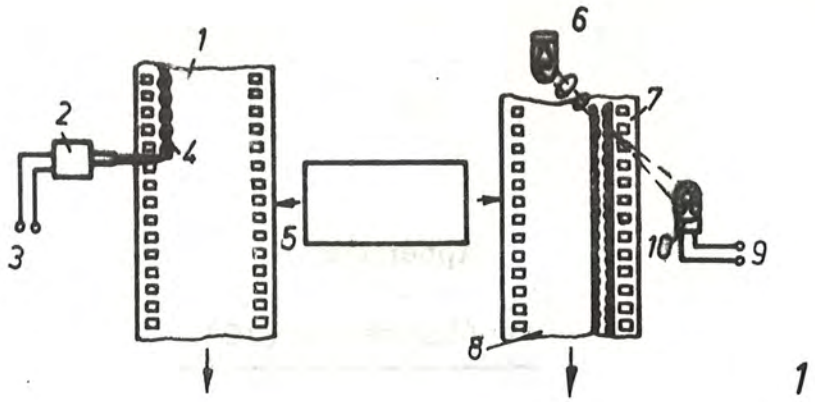
6 Red - green - blue

7 Copy on reversible colour film

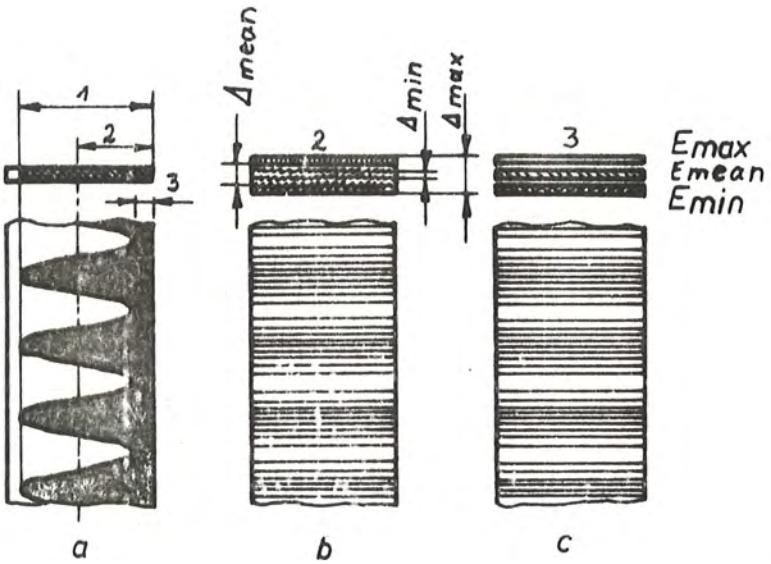
Appendix

to Chapter 5 (10)

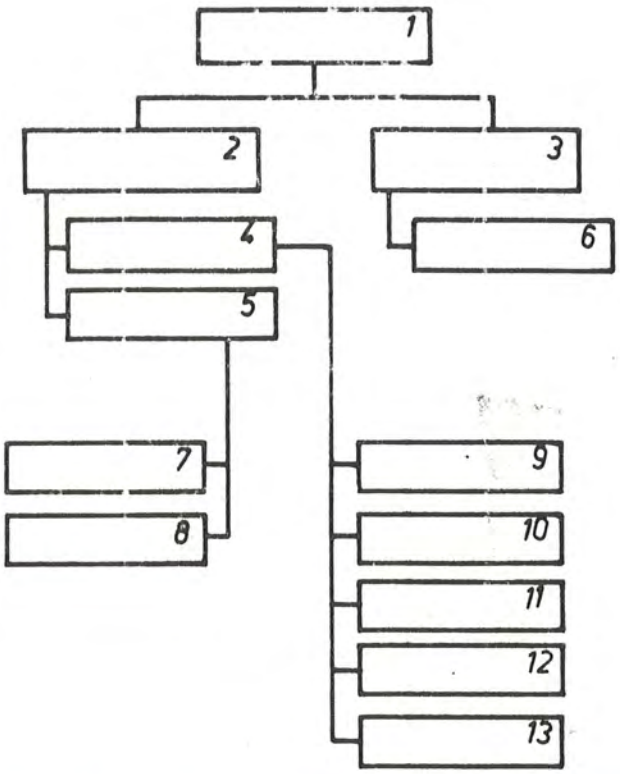
fig 10 - 1/11


1
2
3
4
5
6
7
8
9
10

1


1
2
3
Δmean
Δmin
Δmax
Emax
Emean
Emin
a
b
c

2


1
2
3
4
5
6
7
8
9
10
11
12
13

3

Fig 1 Principles of photographic sound recording and reproduction

1 light sensitive film;
2 light modulator;
3 from recording amplifier;
4 recording beam;
5 sound record development and printing;
6 exciter lamp and optics;
7 scanning beam;
8 film with printed sound record;
9 to sound reproduction amplifier;
10 light sensitive element.

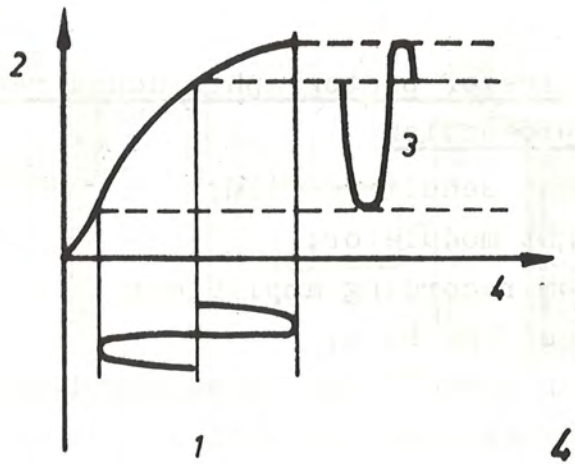
Fig 10 - 2

a variable-area and
b and c variable-density of sound records

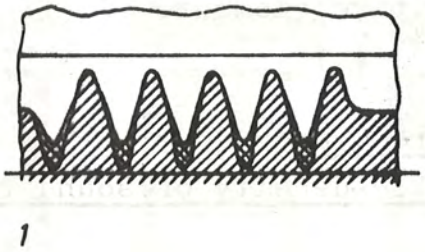
1 maximum
2 mean
3 minimum
4 Δ max Δ mean Δ min
5 E max E mean E min

Fig 3 Classification of light modulators used in sound recording and reproducing equipment

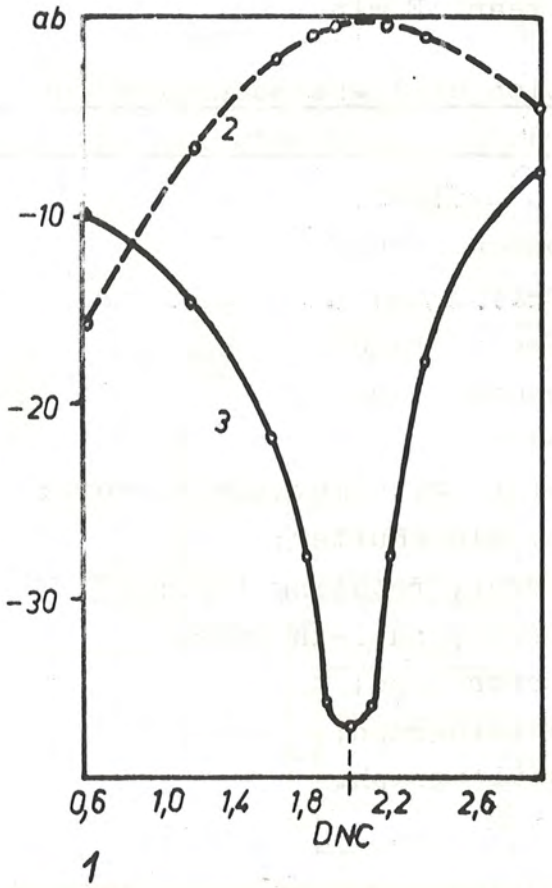
1 light modulators;
2 electromechanical;
3 electro-optical;
4 magneto-electrical;
5 electro-magnetic;
6 Kerr cell;
7 mirror-type with movable mirrors;
8 with movable shutter;
9 coil mirror, rotating type;
10 coil mirror, pull-in type;
11 loop mirror type;
12 tape oscillograph;
13 loop oscillograph.



4



5



6

App 5 fig 10 - 4 - 6

Fig 4 1 Non-linear characteristic of photographic transmission distorting the signal shape

2 Tr

3 $Tr = f(H_N)$

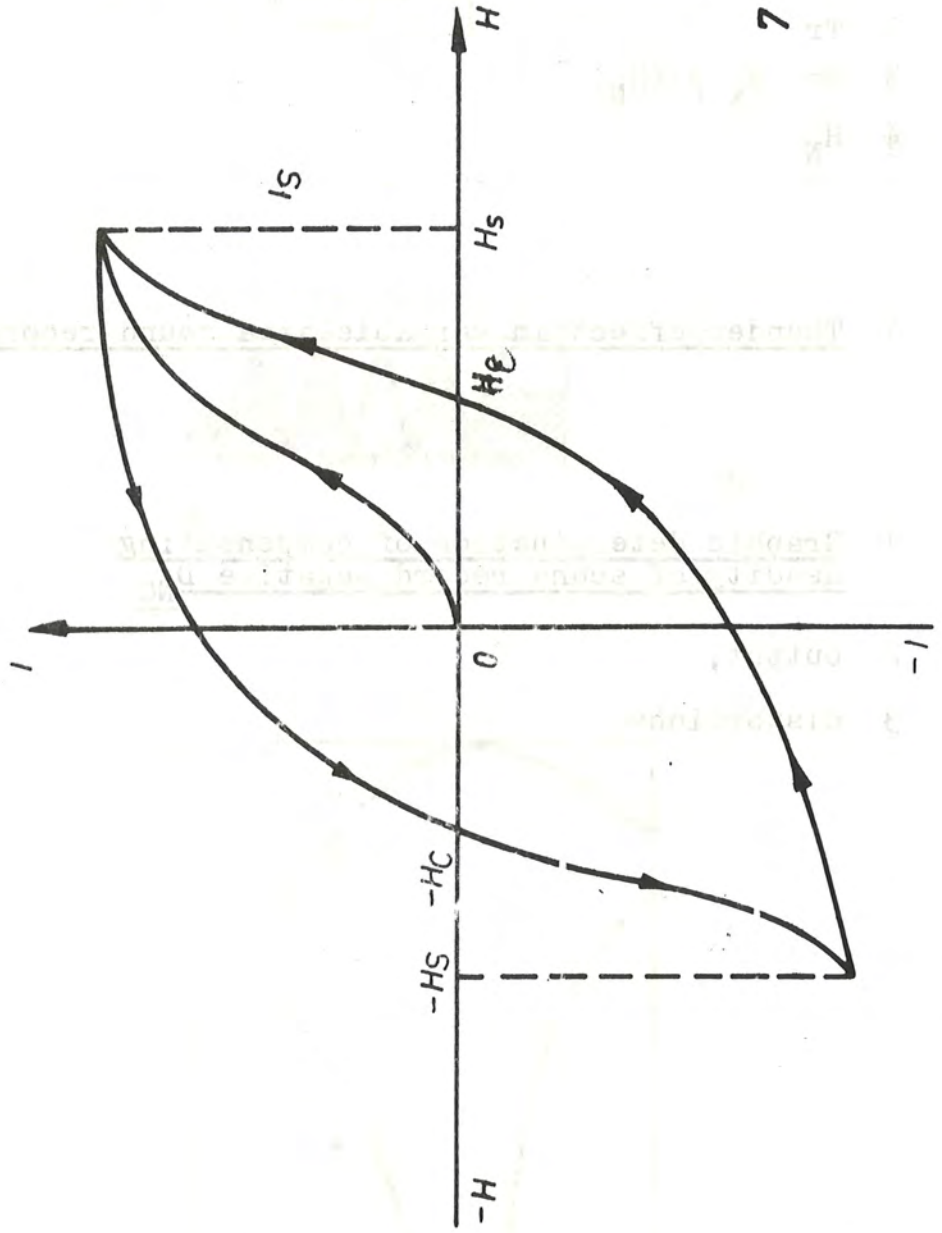
4 H_N

Fig 5 1 Thunder effect in variable-area sound record

Fig 6 1 Graphic determination of compensating density of sound record negative D_{NC}

2 output;

3 distortions.


H
Is
Hs
He
I
0
-I
-Hc
-Hs
-H

App 5 fig 10 - 7

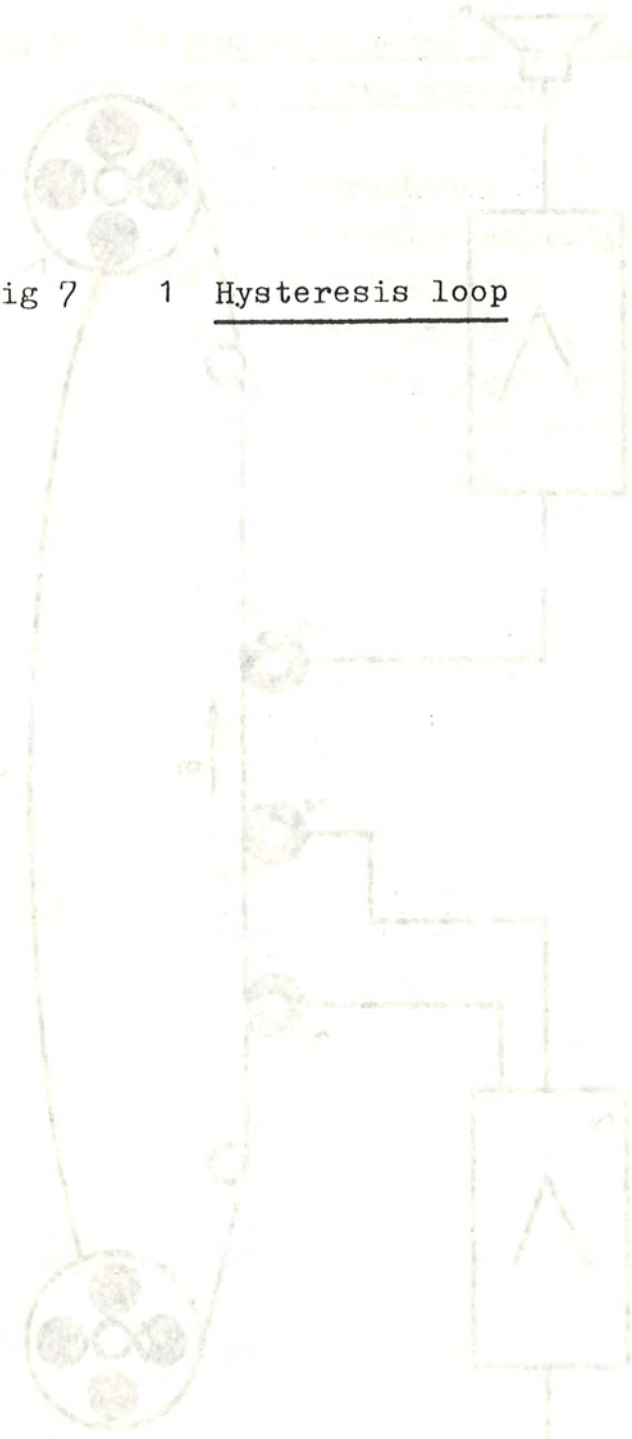
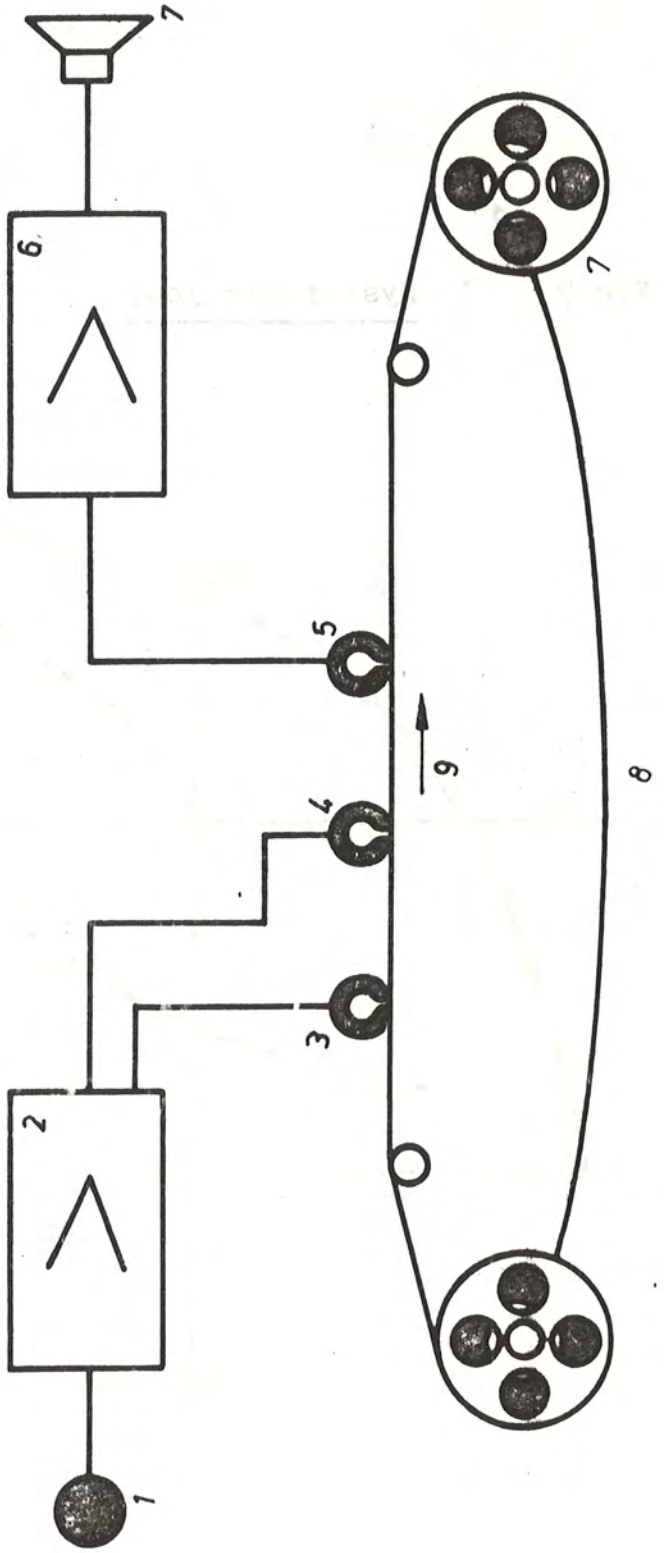


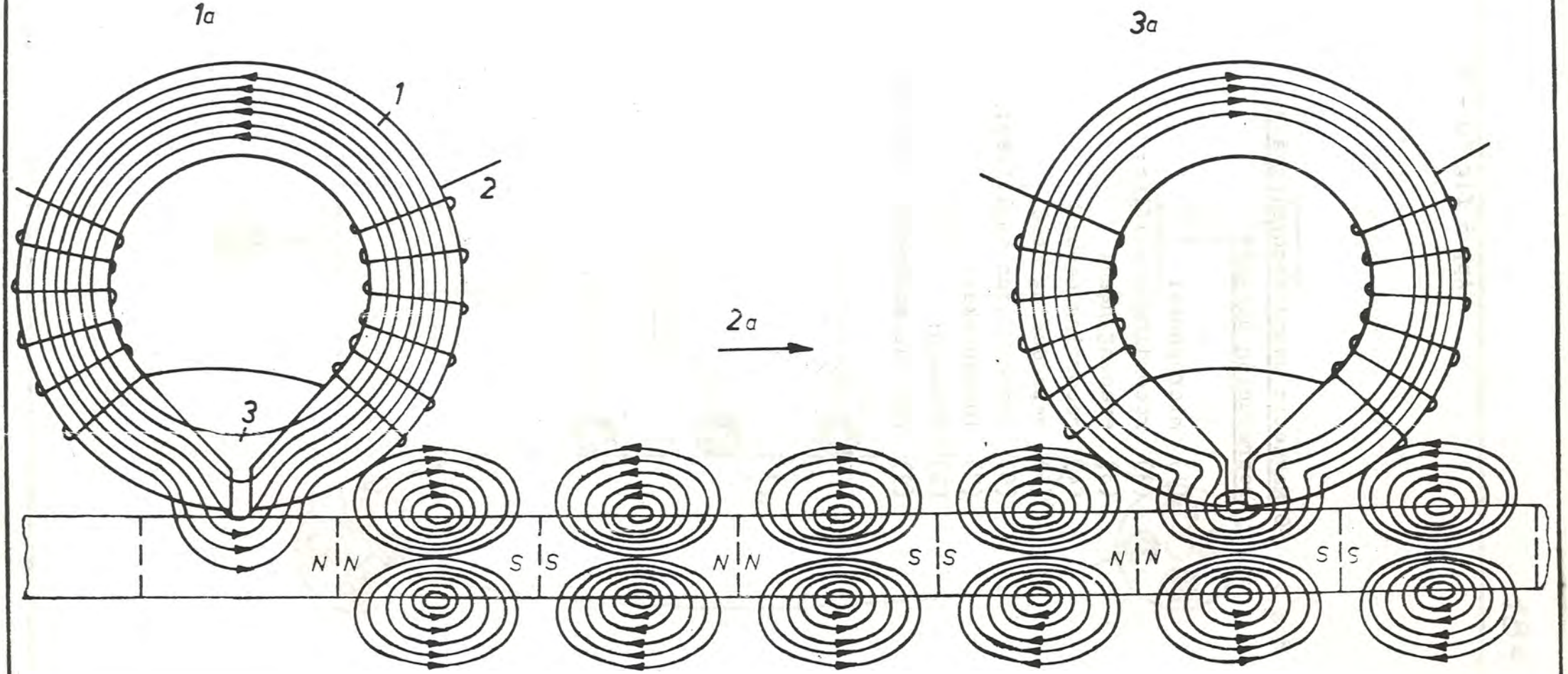
Fig 7 1 Hysteresis loop


7
6
7
5
9
8
4
3
2
1

App 5 fig 10 - 8

Fig 8 10 Magnetic sound recording and reproducing diagram

(1) microphone;
(2) recording amplifier;
(3) erasing head;
(4) recording head;
(5) reproducing head;
(6) reproduction amplifier;
(7) loudspeaker;
(8) Pick-up;
(9) Pick-up movement direction;


1a
3a
1
2
2a
3
N
N
S
S
N
N
S
S
N
N
S
S

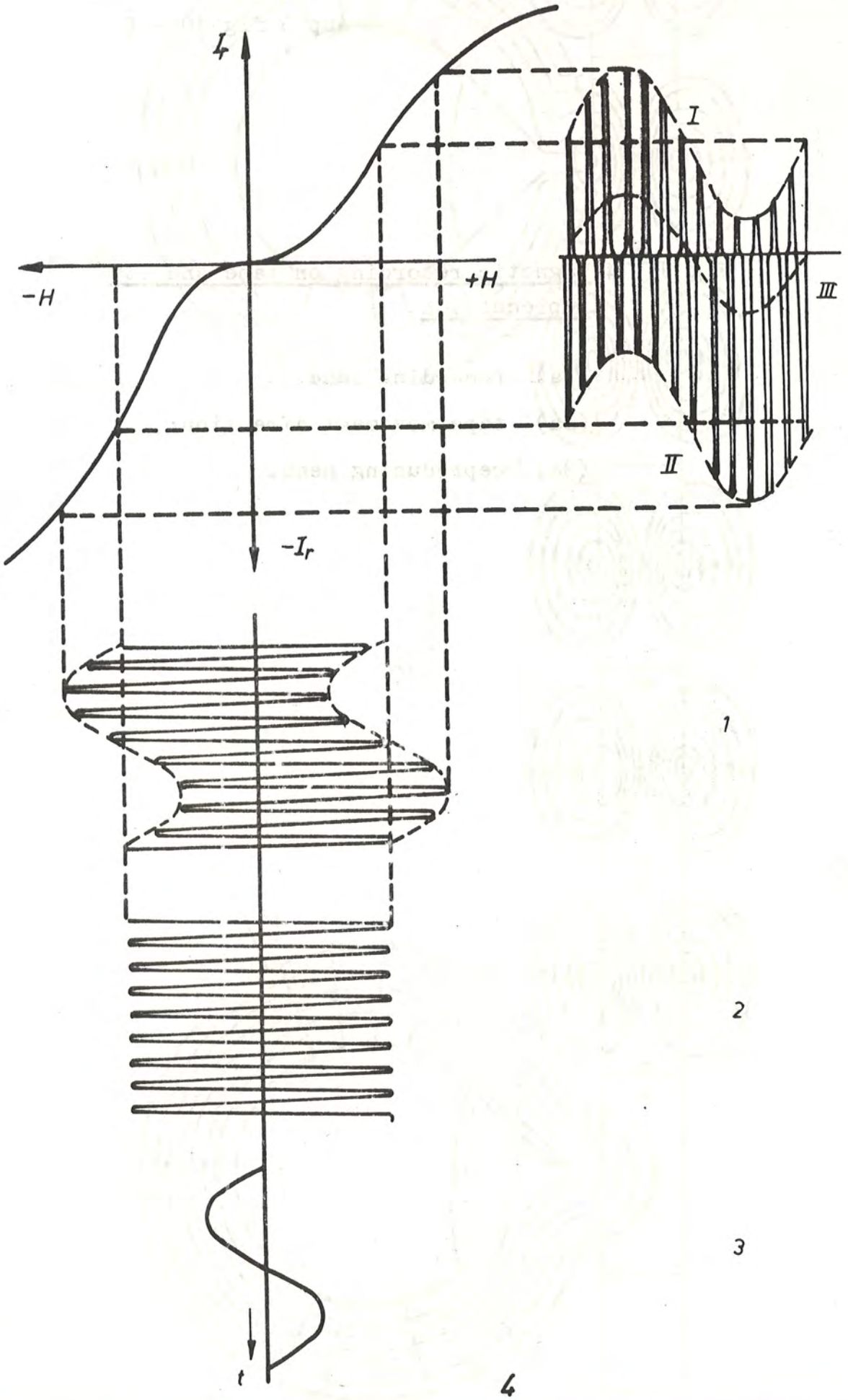
App 5 fig 10 - 9

Fig 9 4 Magnetic recording on tape and its reproduction

(1a) recording head;

(2a) tape movement direction;

(3a) reproducing head.


4
I
III
II
-H
+H
$-I_r$
1
2
3
t
4

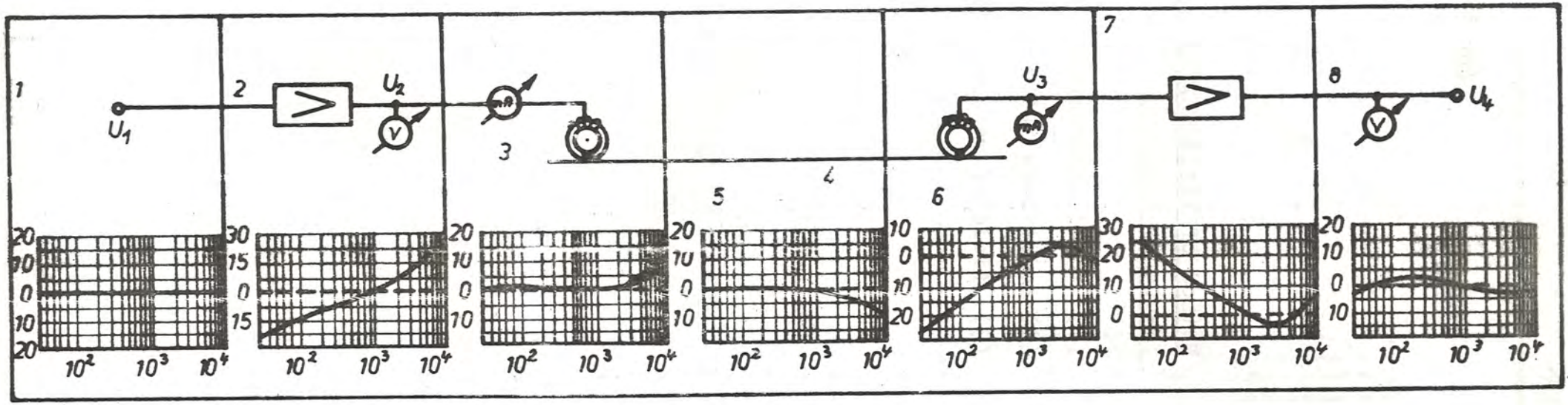
App 5 fig 10 - 10

Fig 10 4 Method of recording with high frequency biasing

(1) total recording field;

(2) additional ultrasonic field;

(3) field of recorded signal.


1
2
3
4
5
6
7
8
U_1
U_2
U_3
U_4
V
mA
20
10
0
10
20
30
15
0
15
20
10
0
10
10
0
10
20
30
20
10
0
10
20
10^2
10^3
10^4

App 5 fig 10 - 11

Fig.11 9 Frequency response of recording/ reproduction channel

(1) input signal

(2) recording amplifier;

(3) recording head;

(4) tape;

(5) magnetization;

(6) reproducing head;

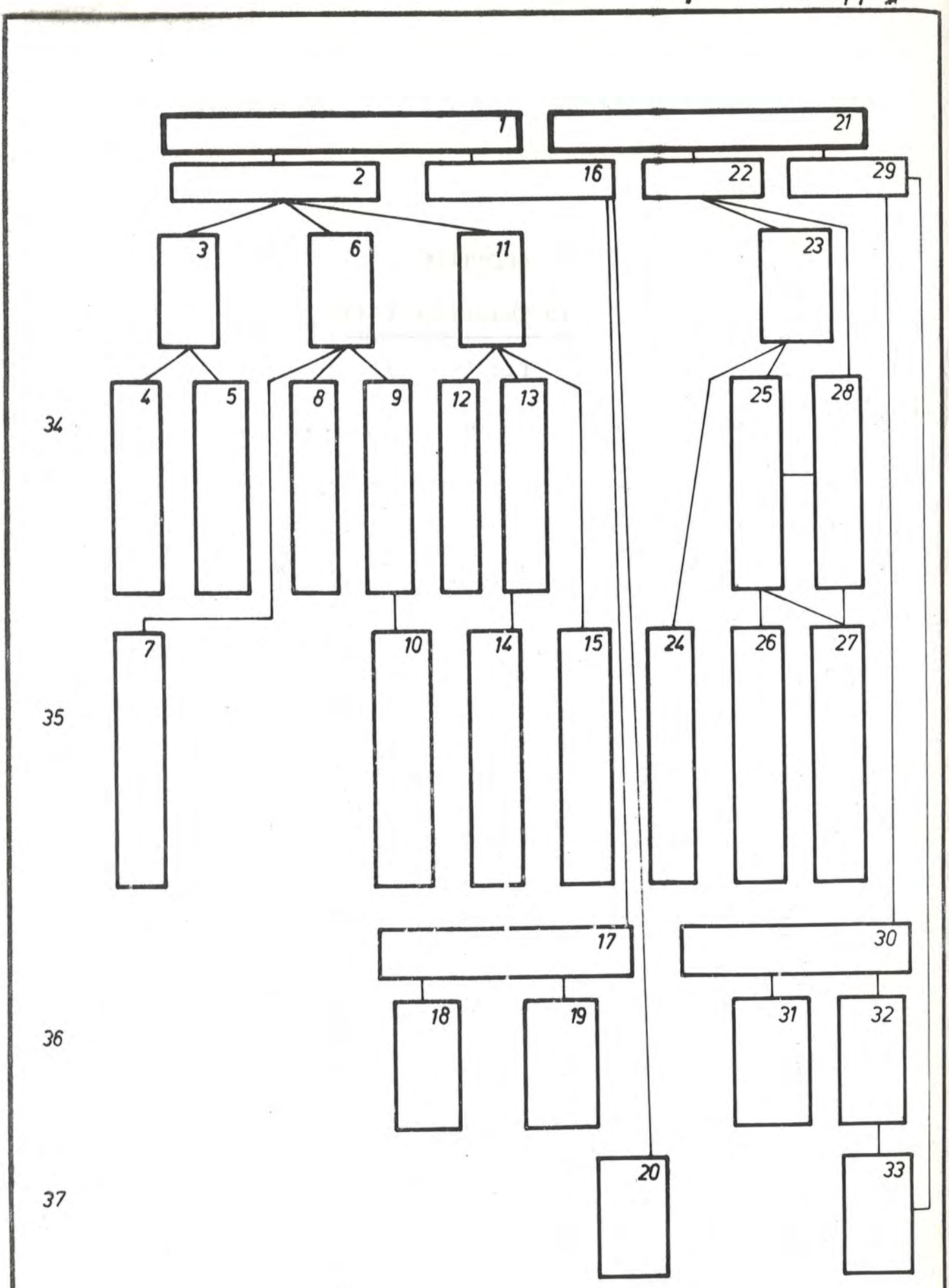
(7) reproduction amplifier;

(8) output signal.

Appendix

to Chapter 6 (11)

fig 11 - 1/14


1
21
2
16
22
29
3
6
11
23
4
5
8
9
12
13
25
28
34
7
10
14
15
24
26
27
35
17
30
18
19
31
32
36
20
33
37
38

Appendix 6 - 1

Fig 11 - 1

38 Basic types of photographic sound records

1 variable-area sound track;

2 single track;
3 unilateral;
4 noise reduction through displacement;
5 noise reduction by shutters;
6 bilateral;
7 bilateral (class "A");
8 centre line displacement;
9 noise reduction by shutters;
10 bilateral (Class "A") with noise reduction shutters;
11 multitrack ("multitooth");
12 by centre line displacement;
13 noise reduction by shutters;
14 multitrack (class "A") with noise reduction by shutters;
15 multitrack (class "A");

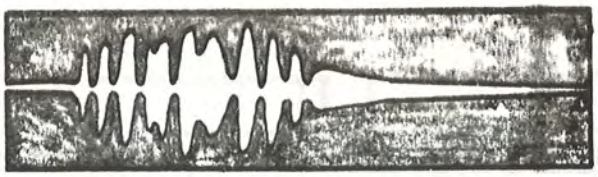
16 multitrack;
17 with control track;
18 with amplitude modulation;
19 with frequency modulation;
20 multichannel stereophonic;

21 variable-density sound

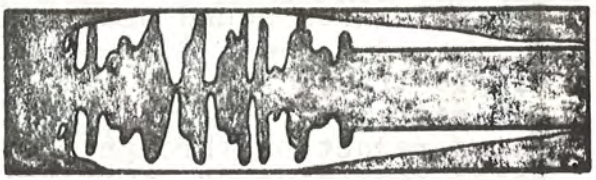
22 single-track;
23 constant area;
24 class "A";
25 by mean density reduction;
26 class "A" with noise reduction;
27 class "A" with controlled area;
28 by controlling background area;

29 multitrack;
30 with control track;
31 with amplitude modulation;
32 with frequency modulation;
33 multichannel stereophonic;

34 methods of sound transmission with noise reduction;
35 methods of sound transmission with push-pull sound records;
36 methods of sound transmission with control track;
37 multichannel sound transmission.



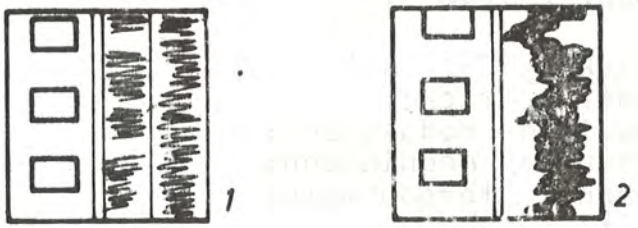
2



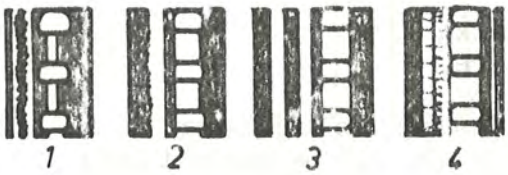
3



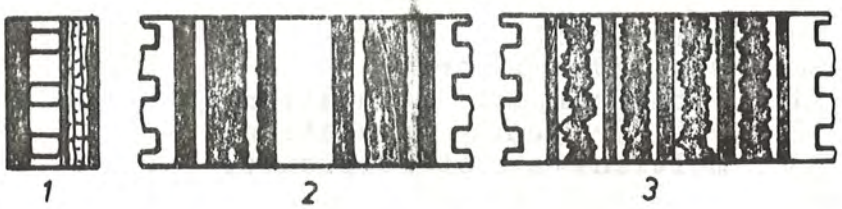
14



5



6



7



8

Fig 11 - 2 Variable-area sound record rendered noiseless through the centre line displacement.

Fig 11 - 3 Double-track variable-area sound record rendered noiseless by special shutters.

Fig 11 - 4 Multitrack (6 tracks) photographic sound record.

Fig 11 - 5 Push-pull photographic sound records

1 variable-density;
2 variable-area.

Fig 11 - 6 Different types of photographic sound records with controlling track.

Fig 11 - 7 Three-channel stereophonic sound records

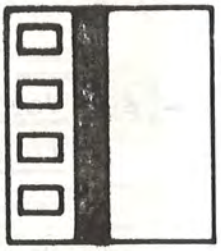
1 - ERPI Movitone;
2 - Bell Telefon Laboratories (3 main and 1 controlling);
3 - Fantasound (3 main and 1 controlling).

Fig 11 - 8 Double-track photographic sound records

1 - bilateral;
2 - unilateral.



1



2



3



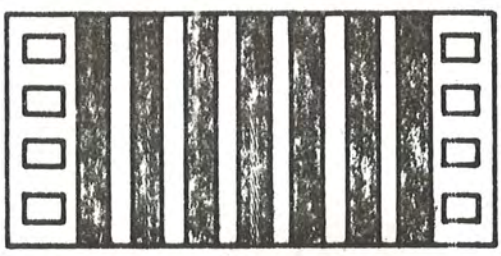
4



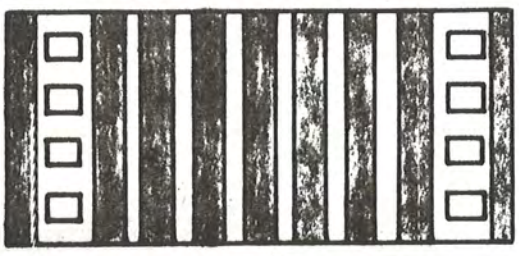
5



6



7



8

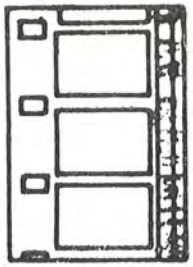
Appendix 6 - 9

Fig 11 - 9 Types of magnetic sound records

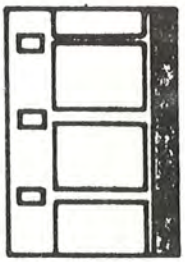
1 on 6.25 mm tape;

2 on 17. 5 mm tape;

3 - 8 on 35. - mm tape.

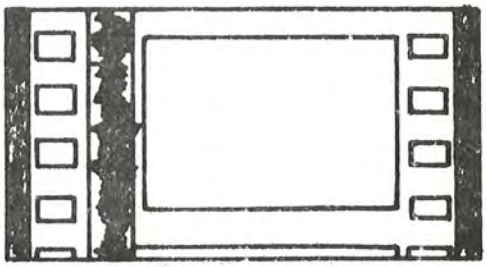


1

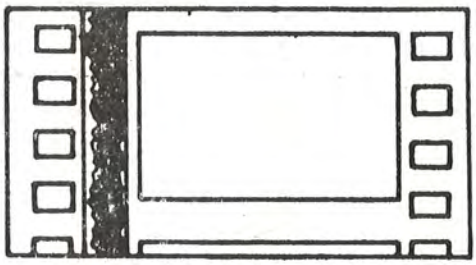


2

10



1

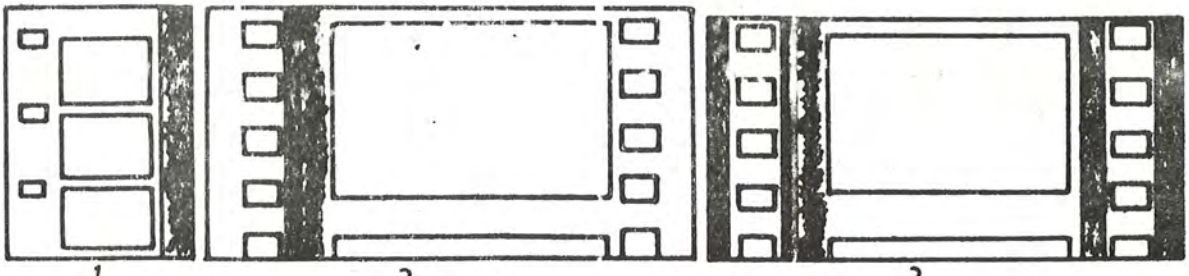


2

11

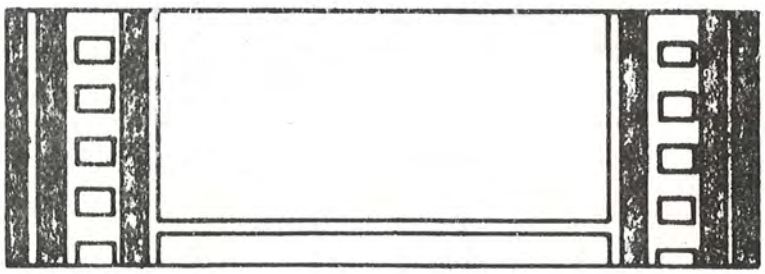


12



1 2 3

13



14

Appendix 6 - 10 - 14

Fig 11 - 10 Sound tracks on 16 mm release prints

1 with a photographic sound record;
2 with a magnetic sound record.

Fig 11 - 11 Sound tracks on 35 mm release prints

1 with 2 magnetic and 1 photographic sound records;
2 with photographic sound record.

Fig 11 - 12 "Cinemascope" release prints with 4 magnetic tracks.

Fig 11 - 13 "Magoptikal" release prints with a magnetic-photographic sound record

1 - on 16 mm film;
2 - on 35 mm film;
3 - on "Cinemascope" motion picture film with 4 tracks.

Fig 11 - 14 70 mm release prints with 6 magnetic tracks.

L i t e r a t u r e

General problems of storing

Kodak, Storage and preservation of motion picture films.

Volkmann, Film Preservation Lagerung, Konservierung und Restaurierung von Kinofilmen (Bericht der Preservation Kommission der FIAF 1969).

Colour couplers

W. Pelz, Mitteilungen aus den Forschungslaboratorien der Agfa-Leverkusen, Bd.III, S. 111-175

Hydrolyse of picture dyes

Sachs u. Barschall, Ber.dtsch.chem.Ges., Bd.35, S.1437 (1902)

Gröger, Pietrzok, Veröffentlichungen der Wiss. Photo-Laboratorien des VEB Filmfabrik Wolfen, Band X, S. 310 - 315 (1965)

Gröger, Veröffentlichungen der Wiss. Photo-Laboratorien des VEB Filmfabrik Wolfen, Band IX, S. 128 - 131 (1961)

Gröger, Dissertation, Berlin (1951)

Mittag, Pietrzok, Veröffentlichungen der Wiss. Photo-Laboratorien des VEB Filmfabrik Wolfen, Bd. X, S. 282 - 299 (1965)

D.C. Hubbel, R.G. McKinney, L.E. West, Photographic Science and Engineering, 11, 195-305 (1967)

P.Z. Adelstein, C.L. Graham, L.E. West, J. SMPTE 79, 1011 - 1018 (1970)

Solovjeva, Levkojev, Arbeiten des NIKFI, Heft 40, S.95-105 (1960)

Instability of Nitratebase

C.L. Hutchinson, L.Ellis, S.A. Ashmore, J.SMPTE 54, 381 - 383 (1950)

H.G. Brown, Brit. Kinemat., 20, 150 - 162 (1952)

J.W. Cummings, A.C. Hutton, H. Silfin, J.SMPTE 54, 268 - 274 (1950)

Standard for the Storage and Handling of Cellulose Nitrate Motion Picture Film, NFPA Nr. 40 (1967)

Effect of nitrogen oxides on the stability of picture dyes

J.H. Carrols, J.M. Calhous, J.SMPTE 64, 501-507 (1955)

Effect of Acetylcellulose on the durability of picture dyes

G.L. Hutchison, L.Ellis, S.A.Ashmore, J.Applied Chem. 8, 24-34 (1958)

J.R. Hill, C.G. Weber, J.SMPTE 27, 677-690 (1936)

C.R. Fordyce, J.SMPTE 51, 331-350 (1948)

Effect of residual hypo

Fridman, Jeremenko, Solovjeva, Alymona, Chem.Industrie sowj., Heft 5, S. 283-285

P. Horovitz, W.R. Weller, J.SMPTE 67, 401-404 (1958)

Ganguin, Photographic Science and Engineering 9, S. 172-179 (1961)

K. Hilbig, Ingenieurarbeit Dtsch.Hochschule f.Filmkunst, 3.6.1968, S.22

Measurement of residual hypo in films

J.I. Crabtree, J.F. Ross, J.SMPTE 14, 419 (1930)

P. Przybylowicz, C.W. Zuehlke, Ballara, Photographic Science and Engineering 2, 148-153 (1958)

C.J.POPE, J. Res.Nat.Bur.Std. C, Vol.67, No.3, July-Sept.

C.D. Anselm, Nicosia, Photographic Science and Engineering 10, 53 (1966)

D.A. Mathey, R.W. Henn, Photographic Science and Engineering 10, 4 (1966)

G.D. Warburton, E.P.Przybylowicz, Photographic Science and Engineering 10, 86-92 (1966)

American National Standard Methode for Determining the Thiosulfate Content of Processed Photographic Film, P H 4.8.1958

American National Standard Specification for Photographic Film vor Archival Records, Silver-Gelatin Type, on Cellulose Ester Base, P H 1, 28 (1969)

Measurement of residual hypo and admissible contents

L.E. West, Image Tech., Nov.-Dec. (1969)

Effect of pH-values on the durability of picture dyes

P. Horovitz, W.R.Weller, J.SMPTE 67, 401-404 (1958)

J.R. Zeman, J.D.Cifford, J.SMPTE 78, 269-273 (1969)

"Der Einfluß des Film-pH-Wertes auf die Haltbarkeit der Bildfarbstoffe für Orwocolor PC 7-Material"; Diplomarbeit Doris Ziegler, 1971, am Leningrader Institut für Filmingenieure, Chem.Technolog. Fakultät

Cleaning of films

D.W. Fassett, F.J. Kolb jun., E.M. Weigel, J.SMPTE 67, 572-589 (1958)

Sound in films

1. V.A. Burgov. "Fundamentals of Sound Recording and Reproduction"
Published by Iskusstvo, Moscow, 1954 (in Russian).

2. Handbook on RTM-KINO, 234-68 g2 V. 95, IRC (in Russian)

3. V.A. Ustinov. "Methods of Increasing the Life Time of Magnetic Tapes". Technika Kino i Televidenija, N5, 1972, pp. 74-81.

4. Yu.M. Orlov. "Dynamic Filter-Noise Suppressor", Technika Kino i Televidenija, N 10, 1974, pp.13-15.

D
4266