AIC

COLOR 89

Volumen I - Invited Lectures

Buenos Aires
Argentina

Proceeding of the 6th Session of the
Association Internationale de la Colour

AIC
COLOR 89

Buenos Aires
Argentina

Volumen I
Invited Lectures

1989

These Proceedings are dedicated to all those devoted to the science of colour. COLOR 89 was one of the many opportunities to exchange experiences on the most important problems confronting colour scientits, technologists and educators at present, as well as to lease information towards the achievements reviewed from various approaches and angles.

Edited by: Grupo Argentino del Color
c/o Sector de Física Industrial - INTI
C.C. 157 - 1650 San Martín (BA)
Argentina

The Congress is auspiced by the Secretary of State of Science and Technology (SECYT) and declared of Municipal Interest by the Council of Buenos Aires and of National Interest by the National Deputy Chamber, organized under the general direction of the AIC Executive Committee by an Organizing Committee whose members are drawn from the "Grupo Argentino del Color". The Secretariat for the Congress is being set up in the Instituto Nacional de Tecnología Industrial (INTI) under the direction of the Chairman of the Organizing Committee, Lic. Roberto Daniel Lozano.

The organizers of COLOR 89 wish to express their sincere thanks to INTI and SECYT for their support to the Congress.

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ACKNOWLEDGEMENTS

To the following institutions, enterprises, organisms and persons, we would like to express our sincere thanks for their support and collaboration in the organization and development of COLOR 89.

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FOREWORD

The Present Proceedings summarizes the advance of the last cuadrienium achieved in the knowledge and in the applications of colour in many different ways, where nature and our daily lives are involved.

The printing was one of the Organizing Committee's responsabilities, but for us, their members, and as citizens of an underdeveloped country which tries to insert it in this fascinating era of fast technological developments; it was a real challenge from the beginning of this project which concludes now after a very hard and conscious experience to endeavor.

Therefore, these Proceedings are not one of the many Scientific and Technological Books which are received from Congresses all around the world, but it is the cristallization of a permanent work along ten years towards this goal: COLOR 89.

We are aware of mistakes and difficulties we had to go through and tried our best to overcome them. A distinguishing feature of this Congress was that plenty of time was devoted, and at the end we expect that most of the attendees will feel that this was an unforgetable meeting, and, for the AIC, a significant precedent so as to give possibilities to other countries like ours, which are employing very hard their time to have a better standard of life.

According to my opinion they deserve an opportunity to demonstrate their ability to succeed in the organization of such important events.

The success of this 6th Session of the AIC-COLOR 89 depended in large measure on the extensive and exceptional assistance from different groups of people, who have collaborated in one or other way. The most relevant are listed in the previous pages, to whom the Organizing Committee is deeply grateful and would like also express their acknowledgement.

We hope that these Books, as part of COLOR 89-Buenos Aires - Argentina, will contribute to a better understanding among all countries, essentially, among people all over the world.

Finally, on behalf of the GAC-Argentine Colour Group- and the COLOR 89's Organizing Committee wishes to thank your kind understanding and hopes you can enjoy your stay which will gather us for the future.

R.D. Lozano
Buenos Aires, April 1989

Opening Session

Opening Session:
From left to right: Dr. Zeida, Dr. Sadosky, Lic. Lozano, Prof. Terstiege.

Panel Discussion:
From left to right: Dr. Sivik (Chairman), Dr. Hard, Dr. Witt, Mr. Hale, Prof. Gerritsen, Dr. Nemcsics, Prof. Indow.

Ministerio de Educación y Justicia
Secretaría de Ciencia y Técnica

DISTINGUIDOS CONGRESALES:

En mi carácter de Secretario de Ciencia y Técnica de la República Argentina, me siento muy honrado en dar la bienvenida al grupo de estudiosos, especialistas científicos e investigadores de renombrada trayectoria que participarán estos días en Buenos Aires en la realización de la 6°Sesión de la AIC - COLOR '89.

Como se aprecia por la estructura del programa, estas sesiones están dirigidas a promover el uso del color en distintas áreas de la industria y el arte vinculadas al tema, así como en todo lo relativo a sus aspectos tecnológicos.

Esta es una oportunidad muy especial de estrechar lazos de auténtica integración y de lograr una apertura hacia un mundo donde la transformación involucra segmentos de cambio.

Por todo ello, les doy la más cordial bienvenida.

DR. MANUEL SADOSKY
SECRETARIO DE CIENCIA Y TECNICA

TRASLATION INTO ENGLISH OF DR.SADOSKY'S LETTER

Distinguished Participants:

As Secretary of State of Science and Technology of the Argentine Republic, I am honored to welcome this distinguished group of studious delegates, scientific specialists as well as investigators of a well known trajectory who will be present during the celebration of the 6th. Session of the Association International de la Couleur -AIC- named Color 89 held in Buenos Aires.

As it can be appreciated in the programme, the Sessions will be directed to promote the use of colour in different topics of the industry and art as well as in the technological fields.

This will be an important opportunity to stretch authentic bonds of integration that will open new frontiers to a world where the transformation involves reliable segments of constant change.

By all these means, I wish to express my sincere and cordial welcome,

Dr. Manuel Sadosky
Secretary of State
of Science and Technology

ADDRESS OF THE PRESIDENT OF THE NATIONAL INSTITUTE OF INDUSTRIAL TECHNOLOGY -INTI- AND SUBSECRETARY OF STATE OF SMALL AND MEDIUM SIZE INDUSTRIES
DR. RUBEN ZEIDA

It is very difficult to say anything after what was said by my young friend, Dr.Sadosky, of whom I was student several years ago, but it is also interesting to be able to add something after his words in this Opening Ceremony.

It is an honor to be here between distinguished delegates from all over the world. I would like to point out that INTI has supported for many years the Argentine Colour Group.

We are happy that during the AIC Meeting held in Berlin and that during the celebration of Montecarlo's Congress the invitation posted by Argentina was accepted, and by consequence Buenos Aires has been elected as venue of the 6th. Session of the AIC COLOR 89.

You will be able to visit our Institute where are the main laboratories dedicated to colour research.

On behalf of INTI's personnel and myself, I would like to express my thanks for coming to this country and, as Dr Sadosky pointed out, the quality of the invited lectures as well as the papers presented will be an important advance towards the technologies applied to colour, so I wish you a good job during the forthcoming days.

Thank you very much, and I hope to meet you in the near future,

Dr. Ruben Zeida
President of INTI
Subsecretary of State
of Small and Medium Size Industries

AIC PRESIDENT'S ADDRESS

Ladies and Gentlemen,

As President of the Association Internationale de la Couleur (AIC) I have the honor and great pleasure to welcome you all to the AIC Congress COLOR 89 in Buenos Aires. This is the sixth Congress of the AIC, the second in America and the first in the southern hemisphere. The previous one were:

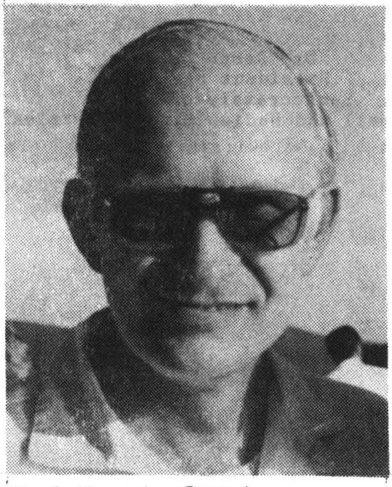
COLOR 69 in Stockholm,	Sweden
COLOR 73 in York,	England
COLOR 77 in Troy,	USA
COLOR 79 in Berlin,	Fed.Rep.of Germany
COLOR 83 in Monte Carlo,	Monaco

Compared with Monaco, we have moved from one of the smallest countries in the world to a country which has over a million times the size and a thousand times the number of inhabitants.

We are happy that the Congrees is so well organized by the argentine member of our Executive Committee, Licenciado Roberto Daniel Lozano from the Instituto Nacional de Tecnologia Industrial (INTI) in Buenos Aires. He is successfully supported by members of the Grupo Argentino del Color whose honorary member I have the privilege to be since 1980.

The Organizing Committee expected 200 participants from 25 countries to take part in COLOR 89, and when I look around I see many globetrotters who attended all the AIC Congresses and did not hesitate to make the long trip down to Argentina to enjoy the city of good air in silverland, even if it is not the Eldorado, the land of gold.

I missing two important faces who were with the AIC from the beginning and served the AIC respectively as Presidents:



Prof. Yves Le Grand

Dr. Janes Bartleson

Prof.Dr.Yves Le Grand,
AIC President from 1970 to 1973
died on January 20th, 1986, 78 years old.

Dr.C.James (Jim) Bartleson,
AIC President from 1978 to 1981
died on August 25th, 1987, 58 years old.

I ask you to join me in standing for a minute of silence in honor of the memory of these distinguished gentlemen.

Since Monte Carlo Congress we are in a position to welcome two new AIC members:

1986 South African Color Science Association (SACSA).
1987 Color Society of Australia (CSA).

We are happy that these new countries are both represented by members of their organizations like Dr. Andy Chalmers of SACSA and Dr. Brian Powell of CSA, who were former observers of AIC.

The AIC now has 21 members and 7 observers.

In the past quadrennium AIC has successfully sponsored interim meetings on special topics:

1986 Ottawa, Canada:	Color in computed generated displays (Canadian Society of Color) with 116 participants.
1987 Florence, Italy:	Color Vision Models (CIE-TC1.5) with 67 participants.
1988 Winterthur, Swizerland:	Color in Design and Art (Winterthur Polytechnic) with 154 participants.

And the Executive Committee has alredy planned meetings for the next quadrennium:

1990 Berlin, Germany:	Instrumentation for Color Measurement
1991 Sydney, Australia:	Illumination for Color Matching
1992 Waterloo, Canada:	Color Vision

The Executive Committee already has an invitation to hold the next AIC Congress COLOR 93 in Budapest and might receive another invitation for COLOR 97 from Japan.

The existing study groups were active in the past quadrennium and most of their chairmanships have changed as at present:

Color Order Systems	under the chairmanship of Nick Hale
Color Education	under the chairmanship of Nancy Howard
Color Dynamics	under the chairmanship of Leo Oberascher

Everybody interested in the subject of the Study Groups should contact the chairperson and give his input to the benefit of the study group.

For a quick distribution of news within its members AIC has published AIC Newsletters. No.4 was published in October 1987. The editing was done by our Vice-President, Dr.A.R.Robertson.

In memory of the late colorimetrist Dr.Deane Brewster Judd the AIC Executive Committe confers the Deane B.Judd-AIC Award on persons in recognition of their wideranging contributions to the science and technology of color.

The previous recipients of Deane B.Judd-AIC Award were:

1975	Dorothy Nickerson
1977	William David Wright
1979	·Gunter Wyszecki
1981	Manfred Richter
1983	David Lewis MacAdam
1985	Dorothy Jameson and Leo M.Hurvich
1987	Robert W.G.Hunt

This year, in Buenos Aires, Tarow Indow will be honored with the 1989 Judd-AIC Award in recognition of his outstanding merit in color science. In particular his work on multidimensional scaling and the examining of the global structure of the Munsell color space by this method, are among the contributions noted here for recognition by the Association Internationale de la Couleur.

Prof.Dr.Tarow Indow started his career at Keio University in 1948 where he obtained his Ph.D. and shortly after became a Professor of Psychology. He was a Research Fellow at Havard University an a visiting Member of the Carnegy Institute of Technology. Back to Japan he was Lecturer at the Tokyo University. In 1977 he became a visiting Professor of Psychology at the University of California, Irvine and 2 years later Professor of Psychology. In addition he is, since 1981, Adjunct Professor at Rensselaer Polytechnic Institute in Troy, NY.

Prof.Indow has published six books in Japanese, more than 100 papers in the Japanese language and 80 papers in the English language. He served and is still serving on many editorial, consulting and advisory boards of scientific journals which include: Perception and Psychophysics, Journal of Mathematical Psychology, Color Research and Application, Acta Chromatica.

From 1969 to 1981 he was on the Executive Committee of the AIC and served as President from 1973 to 1977. His contributions to the science of color have earned him admiration and gratitude from colleagues and associates throughout the international color community. The Executive Committe of the Commission Internationale de la Couleur is therefore pleased to honor Prof.Dr.Tarow Indow with the 1989 Deane B. Judd-AIC Award.

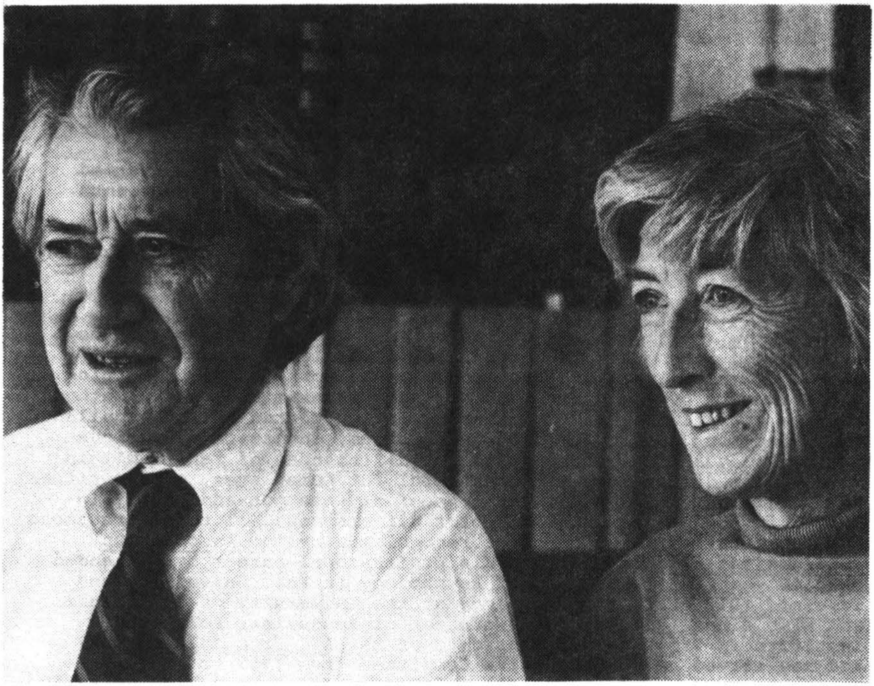
The award consists of a gold medal with a portrait of Deane B. Judd on one side, and on the other the inscription "To honor Tarow Indow 1989 for important work in color science".

The success of AIC work would be impossible without the selfless devotion of all individuals in the AIC, specially the members of our Executive Committee and I wish to convey my thanks to them for making the quadrennium so successful for the AIC; to Dr.Alan Robertson, Vice-President, Dr. Jan Walraven, Secretary, Treasurer, and to the members John Hutchings, Daniel Lozano, Dr.Leo Mori, Prof. Werner Spillmann. I express my personal appreciation for their efforts.

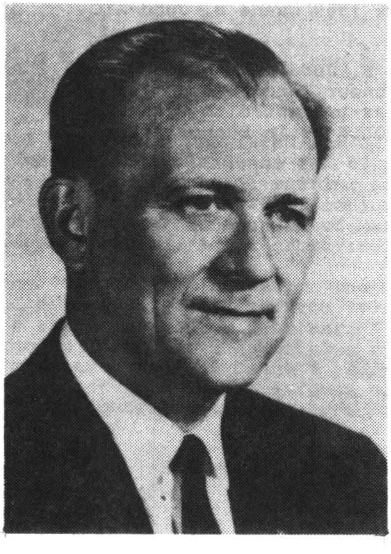
I wish the congress all the success it deserves and hereby open it officially.

Thank you for your attention.

Prof.Dr.Heinz Terstiege
President, AIC



Dorothy Jameson and Leo M. Durvich



David L. Mackdam

Citation for

1989 Deane B. Judd-AIC Award

The Deane B. Judd-AIC Award was instituted in 1975 in honour of the memory of the outstanding colour scientist Deane B. Judd. It is awarded biennially by the Association Internationale de la Couleur (AIC) to recognize and honour persons who have performed work of outstanding merit in colour science. Previous recipients have been Miss Dorothy Nickerson, Professor Dr. William David Wright, Dr. Gunter Wyszecki, Professor Dr. Manfred Richter, Dr. David Lewis MacAdam, Professor Dorothea Jameson/Dr. Leo Hurvich, Professor Dr. Robert W. G. Hunt.

The 1989 Deane B. Judd-AIC Award will be conferred on Prof. Dr. Tarow Indow in recognition of his extensive contributions to the science and technology of colour. In particular his work on the method of multidimensional scaling and his work in which the global structure of the Munsell color space is examined by the method and its variations. His experiments were supported by the excellent technology of Japan to produce color chips. The tests of various methods to quantify perceptual color differences of ranges within which color differences are meaningful for human eyes, of algorithms to define the configuration, the proof of same non-additivity involved in human assessment of color differences. All these are among the contribution noted here for recognition by the Association Internationale de la Couleur. His professional career has extended over 40 years. He was Prof. of Psychology in Keio University and is since 1977 Prof. of Psychology at the University of California and also since 1981 Adjunct Professor of Rensselaer Polytechnic Institute in Troy. He was President of the AIC from 1973 to 1977 and has served on the Executive Committee from 1969 to 1981. His contributions to the science of color have earned him admiration and gratitude of colleagues and associates throughout the international color community. The Executive Committee of the Association Internationale de la Couleur is therefore pleased to honour Prof. Dr. Tarow Indow with the 1989 Deane B. Judd-AIC Award.

The gold medal with a portrait of Deane B. Judd on one side, and on the other side the inscription "To honour Tarow Indow 1989 for important work in colour science" was presented to Prof. Dr. Tarow Indow at the sixth Congress COLOR 89 in Buenos Aires on the 13th of March 1989.

The President:
Prof. Dr. Heinz Terstiege

Prof. Dr. Tarow Indow

Recipient of the 1989 Deane B. Judd-AIC Award

Tarow Indow was born in Tokyo, Japan, just ten days before his birthplace was struck by the historic earthquake in 1923. He spent his student life at Keio University where he received his BA in 1945 with summa cum laufe and Ph.D. in psychology in 1959. For his Ph.D. thesis he was given an annual award of the Keio University.

During his work on the thesis he was given the opportunity of visiting the USA for three months. While staying at Princeton, he was exposed to a newly born idea: the method of multidimensional scaling. Munsell color chips are displayed as a 3-dimensional structure and spacing along each of the three attributes was throughly examined before. The method of multidimensional scaling however can give more quantitative information for the relationship between colors differing in more than one attribute and enables us to construct a configuration of points in an appropriate space according to mutual relationships between objects to be represented as points. Tarow Indow's experiments were supported by the excellent technology of Japan to produce color chips. Through these studies, the condition under which surface colors are embeddable in a threedimensional space has been made explicit in such a way that Euclidian interpoint distances are proportional to perceptual differences between color represented by these points. He tested various methods to quantify perceptual color differences, ranges within which color differences are meaningful for human eyes, and algorithms to define the configuration. He pointed out some anomalies in Munsell Hue Notation and Value Scale and he also showed some non-additivity involved in human assessment of color difference. The same methodology he applied to the OSA Uniform Color Scale.

Prof. Dr. Tarow Indow startet his career at Keio University in 1948 where he obtained his Ph.D. and shortly after became a Professor of Psychology. He was a Research Fellow at Harvard University from 1963 to 1966 and a visiting member of the Carnegy Institute of Technology. Back in Japan he was Lecturer at the Tokyo University. In 1977 he became a visiting Professor of Psychology at the University of California, Irvine, and 2 years later Professor of Pschology. In addition he is since 1981 adjunct Professor at Rensselaer Polytechnic Institute in Troy.

Prof. Indow has published six books in Japanese, more than 100 papers in the Japanese language and 80 papers in the English language. He served and is still serving on many editorial, consulting and advisory boards of scientific journals which include: Perception and Psychophysics, Journal of Mathematical Psychology, Color Research and Application, Acta Chromatica.

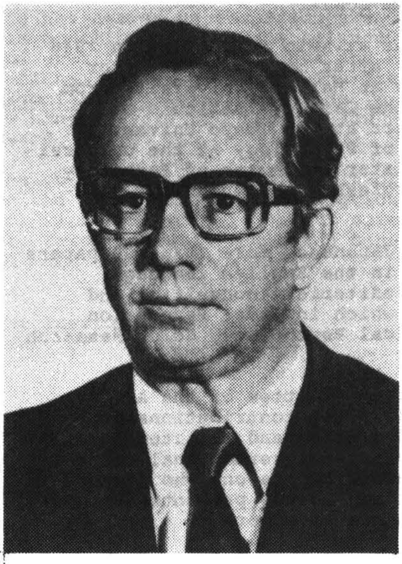
From 1969 to 1981 he was on the Executive Committee of the AIC and served as President from 1973 to 1977. His contributions to the science of color have earned him admiration and gratitude from colleagues and associates throughout the international color community. The 1989 Deane B. Judd-AIC Award honors one who played an eminent role in the science of color and is now presented to one who has contributed immensly to the science of color.

Prof. Dr. Heinz Terstiege
President, AIC

The Recipients of the Deane B. Judd-AIC Award 1975-1981

Dorothy Nickerson (1975)

William David Wright (1977)



Günter Wyszecki (1979)

Manfred Richter (1981)

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COLOUR DIFFERENCES & COLOUR FORMULATION

ARCHITECTURE & DESIGN

EDUCATION & ARCHITECTURE

MEASUREMENTS & INSTRUMENTATION (I)

MEASUREMENTS & INSTRUMENTATION (II)

APPLICATIONS & INSTRUMENTATIONS

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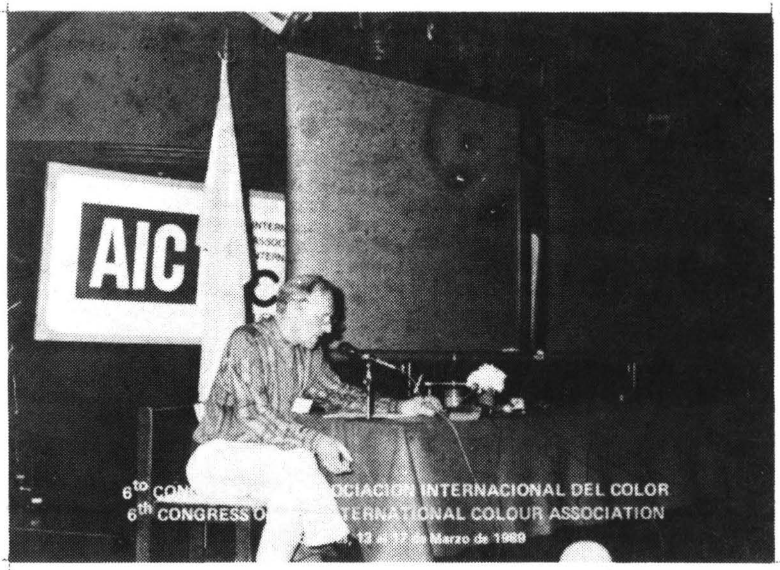
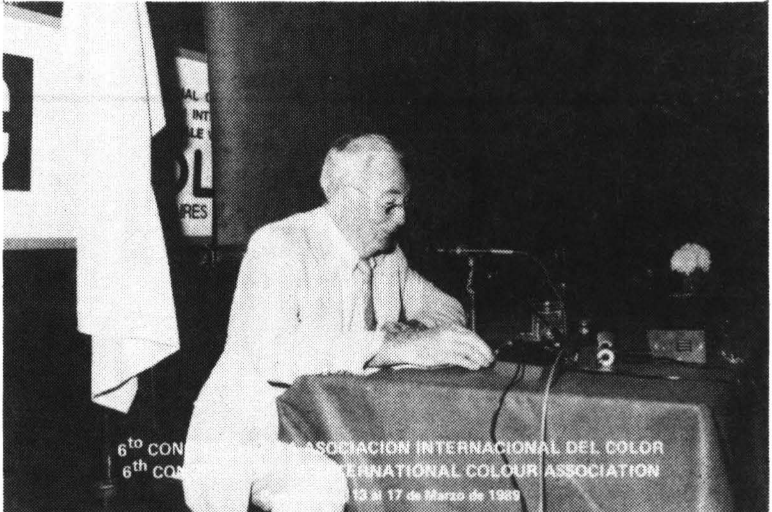
Invited Lectures



Invited Lecture:
Prof. W. Spillmann (Switzerland).



Invited Lecture:
Mr. N. Hale (U.S.A.)

SPILLMANN, Werner

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8401 Winterthur (Switzerland)

COLOUR IN ARCHITECTURE AND INTERIOR DESIGN

Preliminary remark

It is an extraordinary event I think that a design-oriented person has been invited to give the introductory lecture to this scientific forum, the 6th Congress of the International Colour Association AIC in Buenos Aires. Thank your for this honour.

Colour is a phenomenon of our everyday life and an important factor in our environment. For ordinary people colour is first of all a **percept** to be experienced directly by the visual sense. In order to remind us of this fact, my introduction is not intended to be a scientific lecture, but a **colour slide show** offering you the opportunity to meet with colour as a **sensual experience**, maybe even to be touched by this marvellous phenomenon which is so much responsible for the questions whether we can feel well in our environment or not. What I wish to tell you I shall try to express as far as possible by colour pictures. So I hope you will keep in mind when you are going to read this text without the colour illustrations that these sentences are not anything but dry bones deprived of their meat and that English is not my native language.

As an invited introduction should normally be a **general review** offering a kind of survey on a topic I am afraid I will have to mention here among others some aspects I have illustrated, spoken or written about elsewhere before (1).

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Introduction

Colour in everyday life

Colour appears to us in the light of the sky, in the water and on the surface of the earth. Colour attracts our special attention if the colour of a thing is unusual, extraordinary. Colour occurs in living beings like plants and animals. And we meet with different colours in the skin of human beings and their dresses, as well as in their cultural products like art.

Actually, we see colour not only on special occasions, but everywhere we look. And colour is experienced not only by specialists, but by the majority of ordinary people. The sense of colour helps man to find things, to become aware of things which might be important for his **survival**. Colour differences are responsible for the **perception of form**, for the outline and the plasticity of objects. The sense of colour assists in **identifying** things of equal or similar form. The colour we see can give us the information whether a fruit is unripe or mature or wrotten. Or it tells us whether we should buy a piece of meat or if we had better leave it.

Architecture and colour

Man is an unprotected being. He is exposed to space and the forces of nature. He protects his body by some sort of clothes and he builds his shelter in different ways according to where he lives and what material he finds in nature, according to his way of life and the resources he can dispose of.

Nowadays the design of buildings is usually done by a specially trained professional, the architect. Architects devote themselves to a fascinating task charged with great responsibility, that is, to the creation of a suitable **framework for various human activities**. The architect designs architectural space by setting space limitations. But when the architect's conception has been fully realized, space limitations are no more abstract elements as usually in a drawing or in an architectural model of small scale. Built space limitations are made of specific materials which sometimes may show their own texture and typical colour. And sometimes the material has to be covered by protecting coatings or it is covered for other reasons like aesthetic considerations.

The character of a work of architecture is not only defined by shape and size of a building and its rooms, but also by the materials, textures and colours of its surface. **Material, texture and colour**, these very effective **modifiers** of the building structure together with the **light** on the surface or filling the room, influence the **appearance of a building** and its rooms in a crucial way.

As a producer of architecture the architect is primarily interested in the overall building structure. But the users, the people he builds for, experience a building mainly from what they see and what they touch. And their feelings and emotions are affected by visual and tactile perceptions caused by the surface of a building.

Colour is what we see. So, colour is an integral part of architecture.

Colour in the history of European architecture

Extreme tendencies after World War II

Grey buildings spread over large areas in the period after World War II. Grey/white sterility entered schools, working places, appartments and hospitals. At the end of the sixties strong reactions against the sterile urban environment became apparent. In the following years,

superbright colours were occasionally offered as a remedy against an austere environment. In the eighties, there is again a strong trend towards **achromatic, neutral colours.** Looking through architectural magazines of our present time one meets with a lot of examples in **dominating white.**

For better understanding of this attitude towards colour in our time it might be useful to search for the origines of the removal of chromatic colour from architecture.

The **Modern Movement** in the twenties of our century propagated white buildings beaming with pureness and clarity. But already in **Classicism** in the early 19th century we find white buildings. As far as the attitude towards colour is concerned, the puritan thoughts of classicists correspond with the purists' thoughts in modern functionalism. The classicists refer to immaculate ancient marble buildings.

Traditional periods

But today we know that ancient **Greek** temples were dressed in polychromy. And the **Romans** used colour even in an illusionistic way, painting imitations of precious materials and of architectural elements in perspective representation. During the **Middle Ages** polychromatic use of colour was made in churches of the **romanesque** as well as the **gothic** period. And we can find rather chromatic colours in secular buildings of the medieval town as well. For the first time in the history of European architecture a certain trend towards achromatic colour is to be noticed in the **Italian Renaissance.** In the **Baroque** period chromatic colours were used again. Architecture, decoration and the art of painting were combined into an overwhelming integral work of art. More or less chromatic colour participated - richly orchestrated - in this synthesis.

In **Classicism** the chromatic colours of baroque stile had vanished and given way to achromatic colours or to the so-called "Steinsichtigkeit", the trend to allow stones to stay visible. Classicism seems to be the source of the dominant trend towards achromatic colour in the 20th century. But what might be the reason for this irresistable compulsion to remove chromatic colours from architecture which so far had been uncontested in architectural design?

The so-called **French Revolutionary Architecture** around 1790 is characterized by strictly stereometric basic forms. In order to realize the pureness of the stereometric basic forms the architect avoids polychromy as chromatic colour or even polychromy would disturb the perception of the pure abstract plastic form. The idea that the plastic form of an object is more important than its colour - an idea still virulent in our times - starts to have its consequences in architecture from the last decades of the 18th century. But the actual root of disregarding chromatic colour in architecture presumably even goes back to the philosophical preconditions which were responsible for the development of modern sciences.

In the 17th century philisophy started to distinguish between **primary and secondary sensory features.** On the one hand the **quantitative,** measurable characteristics of objects as size, shape and position, on the other hand the **qualitative,** sensory features as for instance colour belonging to the subjective inner reality of man. In consequence, all qualitative features were excluded from the scientific cognitive process in future, or colour which is a percept was mainly reduced in science to its measurable physical stimulus.

On this level of occidental civilization, the ability of percieving qualitative sensory features was disregarded in education and therefore diminished more and more. And the first appearance of the achromatic trend during the Italian Renaissance might be understood in the context of the quite rationally oriented mental attitude after the Middle Ages.

Summary

In this very short survey we have become aware of three important facts:

1. During the entire development of European architecture until the 18th century more or less chromatic colour was an established and essential element of architecture.

2. The mainly rational attitude, for the first time manifest in the Italian Renaissance, and the idea that plastic form is more important than colour, born in the 18th century, led to a trend of achromatic neutrality in architecture and interior design.

3. Emotional undercooling of the built environment after World War II provoked various breakouts into extremely superchromatic colours in the seventies of our century which again brought back a strong trend to the achromatic in the eighties.

In spite of interludes of achromatic abstinence and breakouts into superchromatic colours we can notice today that quite a number of architects take more or less chromatic colour into serious consideration as an important design element of architecture, what I will try to show in the last part of my lecture.

Basic aspects of architectural colour design

Impact on human beings

Lack of stimulation and very strong stimulation are two extreme perception states man sometimes is exposed to. Frederik Vester (2), a biologist, points out the dangerous effects of strong visual stress factors. And Hugo Kükelhaus (3) deals with the development of human sensory organs depending on **rhythmic change in stimulation.** Kükelhaus fights against paralyzing boredom. Vester objects to oppressing visual stress in environments for longer stay.

So, when the architect is confronted with a specific architectural task he should try to feel how far change in stimulation is aspired by the users and what strength of stimulation is compatible with human organism during the specific human activity he is building for. Design which aimes at taking care of the mentioned biological aspects tries to realize **contrast and differentiation** and simultaneously **integration and concord** among various parts. This leads to **continuity in manifoldness or variety in unity,** to a lively **visual order** in the environment.

Man has spent more than 99% of the time of his evolution as a plant-collector or / and a hunter in a predominantly vegetative environment. This determining condition of his existence might be of significance for his **compatibility with chromaticness.** An analysis of the degree of chromaticness of vegetative green shows the nuances in the middle between the most chromatic green and black. More chromatic colours appear in nature only on small dots like flowers and fruits or for a rather short time as in the red sky at sunset. So, colours of moderate chromaticness in environments for long stay as working rooms, living rooms, etc. seem to be more appropriate for human organism than dominating strong and brilliant colours. On the basis of moderate chromaticness, vivid colours can fulfil their function of accentuating single parts and neutral colours can offer welcome refreshing interludes.

Most people have certain colours they **prefer** and others they **reject.** This fact shows that colours are not neutral entities but characteristic beings with specific **emotional expressions and effects.**
Monochromatic rooms of a special hue can be very impressive. But they can easily become oppressive. The well-known colour phenomenon of the negative after-image will make us think about under what conditions one single hue can be used in an environment and when an alternative second hue has to be offered as well. Sometimes, the addition of an achromatic colour like grey or white can already have a positive effect. It was left to Johann Wolfgang

Goethe (4) to focus interest into the psychological aspect of colour. He had a series of successors among painters like Wassily Kandinsky as well as authors writing about colour psychology like Heinrich Frieling (5). In his book "Licht und Farbe" Eckart Heimendahl (6) offers a very worthy and critical survey on colour psychology until 1960, including early experimental research and current colour test methods. Much research in the impact of colour and light on human beings must have been done since worldwide.

Those designers who would like to learn more about the impact of colour and light on human beings might find books like the ones on this topic by Faber Birren (7) or "The Psychology of Colour and Design" (1974) by Deborah T. Sharpe (8) or "Colour and Light in Man-Made Environment" (1987) by Frank und Rudolf Mahnke (9) useful. In the first chapter the last two authors give an interesting short report on research concerning the problem of sense stimulation, as well as unity and complexitiy balance, a fundamental aspect of environmental design I mentioned at the beginning of this passage.

Another approach of research work was reported by Christina Burton (10) at the 1988 AIC Symposium on Environmental Colour Design at the Winterthur Polytechnic: "Post Occupancy Evaluation" (POE). The primary focus of a POE is the impact of a real and complex environment on the different user-categories. A POE aims at getting immediate feed back to a project and information for future projects. I am convinced that the more these methods will be developed and refined the more the practicing designer will get research results relevant to his work.

Building colour in its context

Every building is part of given natural or built surroundings, its context. Any given context has its own colour-character. Buildings as a consequence of their visual appearance in the context can show various relations to their surroundings:

Camouflage is well known from animals. The object tries to melt visually with the background. For buildings this relation is not very usual except in war times or other extraordinary occasions.

Subordination is a natural consequence in those cases when the building material is directly taken from the surroundings. But subordination might become a rather questionable relation as soon as a metal facade of a building dresses in a green similar to the vegetation surrounding it.

Buildings usually belong to an object category different from vegetation. This difference can be symbolized by a contrast in hue. Nevertheless, the building colour can appear clearly bound with the surroundings by a similarity in nuance (similar chromaticness, blackness, whiteness). So, the house would appear different in kind but equal in importance what could be called **equal ordination.**

Sometimes, houses are beaming out of the landscape. They appear to be more important than the surroundings, superior to the context. This relation could be called **superordination.** This effect needs not necessarily being caused by higher chromaticness, but it works already when the object shows less blackness than the surroundings.

Maximal chromaticness combined with characteristic hue contrast can lead to **isolation** of the building in a context. Isolation in a more discrete manner can also be effected by pure white in contrast with vegetable green or earth colour.

So, when choosing the main colour of a building one decides at the same time about its importance, its significance in the context, as colour relations express spontaneously specific object relations.

The contextual colour relation need not be constant. It can vary during the course of the seasons, but also as a consequence of the viewing situation.

While in **landscape** a building is in a **context of different object category**, in **townscape** it is among other buildings, among **elements of similar object category**. We usually admire the continuity of colour in traditional settlements. This positive feature is mostly not a result of aesthetic considerations of their builders, but many times just a positive issue of their restricted means, a local building material. Since the development of railway transportation which brought other materials to a place and since the inexpensive production of high-chromatic pigments we have been confronted with much more complex problems in keeping a certain **colour continunity** in an urban environment.

We might welcome a special **accentuation** of a single building as soon as it is of a certain importance for the public as the cathedral in the context of the houses of Siena or the buildings of the Swedish parliament in Stockholm or maybe the swimming "teatro del mondo" by Aldo Rossi in Venice. But there is always the question of when accentuation is **justified** and when isolating marking of a single element is **appropriate** in the social context.

Jean Philippe and Dominique Lenclos (11) in "Les couleurs de la France" (1982), Michael Lancaster (12) in "Britain in View. Colour and the Landscape" (1984), Martina Düttmann (13) et al. in "Farbe im Stadtbild" (1980) and the team of authors called Gruppo Colorscape (14) in "I piani del colore" (1987) deal with the context of landscape and townscape.

Colour and architectural gestalt

Why do we speak about polychromy as we see for instance in some traditional Mediterranean settlements how impressing **monochromatic white architecture** can be? We welcome the fact that all the surface of a house is covered by the same colour, because we see that it is concieved as a **homogeneous plastic structure**. The overall monochrome coating therefore looks quite natural. And the direct sunlight together with the blue Mediterranean sea and sky produces a fascinating play of fine white shades. But how attractive would the same structure appear under an average Middle European grey sky? For the famous 19th century architect Gottfried Semper, the frequent condition of diffuse daylight in Middle Europe was an important argument for polychromy in architecture.

Monochrome coating does not always look so convincing if we understand that the various parts of a structure are of different origin. Monochromy on heterogeneous structure does not look so natural as on homogeneous ones. One has experienced that nature many times makes a colour difference between elements of different kinds, for instance between branches and foliage. So, **heterogeneous structure** can be another cause for **polychromy**.

Furthermore, it is quite usual in traditional as well as in modern architecture that linear frames or networks and filling planes are presented in a distinct colour contrast, even when made of the same material as it can happen in wooden houses. When even different materials are used, a differentiation seems quite normal and a hue contrast in a linear metal network makes the appearance of a wall colour more attractive.

Multimembered structures even call for **distinct colour differentation**, for **meaningful accentuation** and for **visual ordering** of the built environment, because sensible colour differentiation can really help to make complex structures and functional connections more understandable, as we can see for instance in an anatomic model.

Polychromatic solutions require clear design directions:
- Which is the main colour?
- What are accompanying colours?
- Which single part or colour plays the role of accentuation?
- Where could achromatic interludes be offered?

Until now, we have only seen examples where one colour covered a whole plastic or constructive part. And we have found colour changes exclusively along lines where two different parts met. This way of colour change can make clear how a heterogeneous structure is composed. This relation could be called **"congruence"** of colour pattern with building structure.

There are also buildings where we find a repetition of colour change even on the same plane. For an orthodox understanding of colour in architecture this attitude might already exceed the tolerance. Nevertheless, we know that stripes on the same plastic form have a long tradition as we previously saw on the pillars in the cathedral of Siena. And stripes on the same plastic form are not at all unnatural. A tiger for instance without stripes is no more a tiger. His colour pattern is an essential feature of his appearance.

Very often in nature the same **plastic form** is combined with **various colour patterns** as can be seen in seasnale shells. Both, plastic form and colour pattern together make what is called (in German) the Gestalt of an object. So, the integration of building structure and its colour pattern could be called **architectural gestalt.**

These examples make us think about further possibilities of relations between building structure and colour pattern apart from congruence.

A **non-congruent colour pattern** can be **strongly related** to the building structure and try to enrich the complexity of an architectural gestalt like in a baroque trompe-l'oeuil facade. An analogous tight relation between colour pattern and essential points of a plastic form is used in face paintings of native people. It intensifies the expression of a face. There are also colour patterns which aim at a more **independent relation,** at a dialogue of two autonomous partners, the plastic form and the colour pattern. Sometimes a colour pattern can predominate the visual impression of the building structure and thus dissolve it. We can find this degree of **dissolution** of a plastic form even in nature, for instance in the irregular yellow stripes on a black poison frog.

Anyway, the more a colour pattern emancipates from its building structure, the more a **high artistic sensibility and ability** is urgently required. And we may freely admit that in most building tasks of every day life the relation of congruence of colour pattern with building structure will more easily lead to a convincing architectural gestalt.

Tom Poster (15) in "Colour Outside" (1982), Daniel Boulogne (16) in "Les raisons de la couleur" (1983) and Heinz Krewinkel (17) in "Baugestaltung mit Farbe" (1985) offer interesting material concerning the aspect of colour and architectural gestalt.

<u>Colour in environmental design today</u>

The trend to the achromatic

The recently inaugurated International Design Center in New York reflects the strong trend to achromatic architecture typical again for the eighties. **Monochromy** sometimes can make the **legibility** of an interior space more difficult especially if elements in the foreground blend with the background as a consequence of an absence of contrast. Sufficient lightness contrast can avoid this blending effect. It accentuates the difference in depth, gives a feeling of here and there and offeres more stimulation even in an achromatic environment.

A monochromatic structure needs not necessarily give a diffuse impression, a fact which is proved enough by the admirable buildings by **Richard Meier,** such as the Malibu and the Westchester House (1984-86). He succeeds in creating monochromatic white structures which offer a **contrastful appearance** and invite to enter the building and to enjoy the interplay of the formal elements and the lookthroughs when walking through the interior space, where the white colour enters a dialogue with the warm colour of the floor and the cool colours we see through the windows.

Various chromatic tendencies

Peter Eisenman includes red elements in the achromatic structure of his fire house (1984-87) and **yellow, red** and **blue** elements in his project for Falk House (1970). He thus reminds us of the colour repertory used by the Dutch painter **Piet Mondrian** who reduced pictorial painting to basic formal elements such as straight black lines and rectangular planes, as well as the classical primary colours before 1920 and by this gave rise to the so-called **Stijl movement**.

Theo van Doesburg introduced the strongly coloured plate as a space-determining element in three dimensional design. And Gerrit Thomas Rietfeld created his famous Schroeder House in Utrecht in 1924. As far as the colour repertory ist concerned, the Stijl has kept its influence until the present day as might be illustrated by the railway station in Zurich Airport or by the project for a villa in town by **Antoine Grumbach** which he designed in 1985 for the 1987 International Building Exhibition in Berlin.

A tendency towards more **subdued chromaticness** can be found in another project for the International Building Exhibition in Berlin. It is by **Kollhoff and Ovaska,** made in 1984. These colours recall us the palette of the young Le Corbusier, used in a building of the famous Weissenhofsiedlung in Stuttgart for the 1927 Werkbund Exhibition. When still using his original name Jeanneret, **Le Corbusier** developed the so-called **Purism** in the early twenties, a post-cubistic manner of painting. Le Corbusier used the same palette as in his pictures for adding **low chromatic elements** to the well-known **white architecture** of the Modern Movement as can be seen in his project for the Cook House in 1926.

Michael Graves, architect/painter, makes creative use of a rich **medium chromatic palette** in his paintings as well as in his architecture, for instance in his Snyderman House, 1972. In interior design he enriches the dominating white structure with fresh chromatic elements. The design for the central telephone exchange in Triest by **Celli & Tognon** in the early eighties demonstrates how a predominantly achromatic interior can be activated by chromatic objects in an effective way although strong primary colours are avoided.

Norman Foster in his Renault Centre at Swindon makes sophisticated use of a bright yellow for his elegant main support structure and of the dark grey for the metal elements holding the glass front behind it. When accentuating constructive elements in a white or other achromatic context, in the eighties we can find a tendency towards using less chromatic colours than the strong primaries.

One can also find examples today where a **soft chromatic touch** is added to the predominant white colour as in the IBM offices in Stockholm by **Rosenberg & Stal,** 1984-85. It cannot be overlooked that in our days several designers like to try how low a contrast can be, without loosing its necessary distinctness.

After all, I wish to express that I also know to appreciate the charm of certain monochromatic design solutions. One feels that monochromy in these cases is not the consequence of lacking creativity or chromatic imagination but a conscious design decision, as polychromy could distract our attention from the subtle interplay of the formal elements or fine reflexions on blank metal surface. But sometimes grey monochromy can really look drab and become depressing. It seems that during the whole design process one never paid attention to the question how an elaborated structure would appear to the users' eye and what room atmosphere would result, while good illumination and competent use of colour can change an atmosphere distinctly, as can be seen in an interior by **Richard Rogers,** painted by Ben Johnson.

Towards a new colour culture?

Several famous architects are making conscious use of colour today, as did **James Stirling** in his Clore Gallery, an extension of the Tate Gallery in London, 1987, or **Aldo Rossi** in his dwelling houses in Berlin, 1987. Again we can see that good colour design in architecture is not done by a dogmatic decision only in favour of strict achromatism or of overwhelming superchromatism. Good colour design often performs a wise **interplay** between more or less **chromatic and achromatic elements.** Architectural colour design is also not done by adding a nice accessory at the end of the architectural design process. **Colour** is an integral part of the **architectural design process** as an early sketch by Rossi demonstrates. Rossi does not concieve a building as an abstract structure. He renders account of a building's colour appearance during the architectural design process.

The philosophical distinction between primary and secondary sensory features in the 17th century was an essential precondition for the development of modern natural sciences. The consequent separation of abstract plastic form and colour was not at all advantageous for design, as for environmental design the integration of form and colour, the **architectural gestalt,** is so essential. Several architects have started to regain a new understanding for what we called architectural gestalt. This might be shown by some architectural illustrations by **Oswald Mathias Ungers,** by **Charles Moore** (1985) and by **Paolo Portoghesi** (1982).

It might also be interesting in this context to mention that a **new interest for decorative patterns** has recently woken up among architects:
Cesar Pelli's Herring Hall in Huston (1984) shows what modest measures in surface design can add a **fine stimulation** to a simple facade. **Wilhelm Holzbauer** includes a fine diagonal pattern in his design of 1985. He certainly remembers the condemnment of any ornament by his compatriot **Adolf Loos** in "Ornament, a crime" (1908) but he doesn't feel obliged to this dogma anymore.

Such decorative attitude looks back to a long tradition, exemplified by the Isfahan mosque of the 15th century. We might be astonished to find architectural decoration reminding us of textile patterns. It was Gottfried Semper who in his important publication "Der Stil" made clear that textile techniques were used for building initial architecture what might be visualized by a royal residence in the Kongo.

A certain tendency to **activate a surface by discrete stimuli** is characteristic for our eighties. And the colour of a simple building material like brick enters an interesting dialogue with a consciously set contrasting hue as it is the case in the psychiatric hospital by **Ganz & Rolfes** in Berlin, 1987.

Dialogues between contrasting hues are also used in interior design and can result in an attractive appearance: Two Italian designs by **Toni Cordero** and **Ettore Sottsass** in the eighties. These hue contrasts need not at all be complementary whatever concepts of complementarity you might have in mind. And even intermediate hues may be offered for linking the red/brown exhibits with the contrasting yellowgreen in the Biedermeier Exhibition in Vienna in 1988.

Even smooth analogous hue contrasts can have an agreeable effect especially if the eye is offered achromatic interludes as well. And again we can notice that in up-to-date design there is a tendency towards an **interplay of soft colours.** This tendency is sometimes even manifest in fine colour texture technique. Other special techniques like "stucco antico" are applied in the eighties to avoid a totally uniform colour surface which lacks the agreeable mini-stimulation.

Fritz Fuchs, a German/Swedish painter has developed a special technique of transparent layers on concrete or wood which leaves visible the specific surface characteristics of the building material, but at the same time offering a **tender tinge** of chromatic colours as well. A **precious surface treatment** can also be found in the building of the Popular Bank in Verona, 1978 by **Carlo Scarpa.** And some designs make explicit use of precious materials like marble.

This tendency reminds us of Mies van der Rohe's use of marble in the German pavillion for the 1929 Barcelona Exhibition. Tendencies towards **colours refinement** can also be noticed in present day object design. While a set of eight clear colours on chairs still somehow recall the colour gamut around 1970, the discrete colour chord of a chair designed in 1985 is more typical for the eighties. The same tendency towards colour refinement can also be found in designs for tables, lamps, home textiles, pottery and ceramic tiles.

If speaking about colour refinement I cannot but mention the work of the German colorist **Paul Meyer-Speer** who in 1927/28 realized a colour desing for the cathedral in Mainz which really adds a further dimension to the building structure and so bringing forward an impressive and emotionally touching architectural gestalt. Excuse my confronting you now with a photo of a humble savoy cabbage. But I must confess that I see here analogous visual qualities which could also give inspiration to subtle refined colour sequences in future environmental desing.

How much **illumination** can **change the appearance** of a building is illustrated by two slides taken from the "Tower of Winds" in Yokohama by **Toyo Ito**, realized in 1987. The illumination of an interior influences its first impression which mostly determines a prejudice or an unconscious feeling towards the room in a positive or negative way. The **brightes area** usually attracts our **attention** and thus directs it or distracts it from important elements. In case brightness differences are very low, everything seems to have the same importance or nothing appears of special importance. On the other hand, it does not need very strong brightness differences as shown in the previous slides, **slight brightness contrasts** when **distinct enough** are sufficient to avoid eyes lingering around, to render the room elements some kind of **visual hierarchy**.

A new trend are ceilings with mirror effects. The question avises in what situations this attention catching or distracting effect might fit with the specific activity in the interior. Other interesting **visual effects** which offer **change** when the observer is **moving** through a room are realized by the famous South American artist **Cruz-Dièz**.

Fascinating coloured light effects can be found in interiors of our days as well as in medieval cathedrals. **Colour and light**, light and colour are important **space modifying design means**. They are worth being studied furtheron and being used in **creative** ways and **sophisticated** manners for inspiring, stimulating or restful human environments.

Charles Jencks (18) in "Current Architecture" (1982), Heinrich Klotz (19) in "Postmodern Visions" (1985), Josef Kleihues (20) "Internationale Bauaustellung in Berlin 1987" (1986) and the Italian/English magazine (21) "domus", a monthly review of architecture, interiors, design and art give fascinating information of present-day tendencies in environmental design.

Within AIC I think we should deal more with the question: "Who needs to know what about colour?" a title for a paper once proposed by Anders Hard as far as I am informed. But for professionals responsible for environmental design it is not at all enough to know more about colour. The main problem for them is the development of colour perception, of **colour sensitivity**, of **visual awareness** and consciousness in real environments, what I try to aim at in my Winterthur Colour Courses for architects. Here I see another noble task for the **AIC Study Group on Colour Education**, indeed.

There is no doubt that the interest for **colour as a visual phenomenon** and an **aesthetic means for environmental design** has grown considerably during the last few years. My call for the **1988** AIC Symposium on Colour in Environmental Design at Winterthur Polytechnic had an **astonishing** response. The great majority of participants came from beyond AIC: Architects, **interior** and industrial designers, colour consultants, perception psychologists and colour **researchers** from 24 countries, including Australia, Japan, Korea, India and the USA met in **Switzerland** for exchanging ideas and experience and leaving after a week with the wish to be **informed** about future meetings on this topic. And we understood that the **AIC Study Group on Environmental Colour Design** ECD will have to play an important role in this worldwide **process** of growing interest in environmental colour design.

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COLOR ORDER SYSTEMS AND COLOR NOTATIONS

I am not going to speak today about the same old color order systems you have been hearing about for years, except by occasional references when appropriate. The various systems such as Ostwald, Munsell, DIN, NCS and so forth have long been with us and we have seen their very useful color atlases. Similarly we have heard endlessly about CIE and its various transformations into more useable uniform color scales. The AIC, since our last quadrennial meeting in Monte Carlo, has published through its Color Order System Study Group an extensive bibliography covering all systems represented by comprehensive atlases, and a variety of books describe CIE and its relatives.

The Forsius Symposium in 1983 in Kungalv, Sweden was perhaps the first major conference on color order systems. It was most extensive and intensive. A variety of papers enumerated and described such systems and their related color notations from Leonardo da Vinci to the present century, which certainly contributed its share. We also heard of new systems from Messrs. Albert-Vanel of France, Green-Armytage of Australia, Hunt and Pointer of the U.K., Passigli of Italy, Spillmann of Switzerland and Simon of the U.S. Each System was described as to its basis -- psychological, physiological, psychophysical or other and some authors touched upon preferred applications of their systems. The general tenor was that most systems were appropriate to a wide spectrum of uses.

Yet of all these color order systems, old and new, only a few have been produced in the form of colored materials in commercial quantities and achieved the wide distribution indicative of broad application. On the other hand there are more pragmatic systems which, while less elegant in theory, have achieved worldwide usage in international and national commerce.

There are several ways to classify color order systems. One is to distinguish between those for which sets of color samples are available, and those without colors. Another is to separate those based on hue, lightness and saturation from those who accompany lightness with opponent hue parameters. Still another approach is to differentiate those which are transformations of CIE tristimulus values from those which are not. Some of the features that characterize these classifications influence the uses to which systems can be put.

How are color order systems used today?
Systems used for teaching color in a broad sense in our educational systems need to have actual color samples; people need to see the colors as the instructor talks about them. Color education also seems to work best with the color attributes of hue, lightness and saturation, especially when accompanied with color scales that illustrate these dimensions as part of a total three-dimensional color universe. Munsell seems to work well for color education, as well as NCS.

Industrial color quality control is more and more a function of instrumental color measurement. Systems such as Hunter and CIELAB work well here; they appear as a readout in most instruments, and their approximations to uniform visual color spacing provide a good starting point for color tolerance specification. The OSA-UCS might work as well or better, its visual spacing is more uniform than any of the others and its notation system is similar to Hunter and CIELAB. However, we will never know until the instrument manufacturers provide it as an instrument readout option.

Today I would like to speak about some new systems that I hope will be of interest, and to describe and illustrate some "commercial" systems. By "commercial" I mean those systems which first and foremost stress their application to specific commercial and industrial color problems, as opposed to some color order systems whose proponents exclaim them to address all of the world's color applications.

The demarcation between general or universal color systems and atlases and those which profess to be task-specific is not too clear. The designer of a color system does so with one or more color problems in mind. Historically, one was chiefly concerned with teaching art and color, others were addressing design applications, still others looked at industrial uses. Still another addresses the basic human condition, being based on the so-called psychological color primaries, although they appear somewhat elusive. However, once the development work is done and the atlas published there arises a tendency to suggest that there are many other uses for it. Nevertheless some systems have been so successful in the field for which they were designed that other applications are trivial.

The technical color literature has not been too kind to the commercial systems, hardly giving them a mention, despite the fact that the color charts or other forms of display compare quite favorably to the universal systems in color gamut, cost and color matching accuracy. And in terms of usefulness to the commercial and industrial world these commercial systems are ahead by several orders of magnitude. We should at least acknowledge how well they have served us in solving the problems for which they were designed.

Twenty years ago and earlier color atlases with suitable notations were often used in lieu of color measuring instruments. Atlases were much, much less expensive than instruments, instruments had limited accuracy and reproducibility and were not too versatile, limiting the size and other characteristics of the specimens they could satisfactorily measure. Thus there are numerous records of colors being notated in terms of Ridway and Munsell notations, especially for biological specimens. Other color atlases were similarly employed.

This is much less the case at this time. While instruments have become much better in all respects, color atlases retain all of their historic limitations. Atlas costs vary widely without apparent reasons. Tolerances have barely improved and are seldom published; one that is published has not improved in almost fifty years, despite the improvements brought about by computer color matching. If atlas manufacturers have studied color change with ageing they have been reticent in telling us about it. Meanwhile commercial and industrial product color quality control requirements have tightened importantly, so that visual matching to a color in an atlas is neither good enough nor fast enough.

Instruments continue to provide improved accuracy and repeatability and are now commonplace industrial color quality control tools. They make provisions for a variety of specimen sizes, shapes, textures and other characteristics. They can measure accurately such optically complex products as orange juice, human teeth, gemstones and cathode ray tubes. A new retroreflectometer can measure highway paint stripes while moving at 50 KPH. New families of portable instruments are making their appearance, powered by vehicle or self-contained batteries.

As instruments improve, the applications for color atlases decrease in scope and change in character. Color collections work best when designed for a specific purpose and limited in application to this purpose. The application must be of sufficient scope to provide a market for the atlas that will permit production anc sale at a price low enough to be widely affordable. There are some historical examples and we are seeing more today.

Who buys the color systems and how do they use them?

A major market for books illustrating color order systems is the field of design, in which I include designers of structures (architects), products, packages and graphics. How well does the systematic nature of the color collection serve designers? For example, the color collections with the widest distribution among designers are probably Munsell and NCS; when it was still available, the Ostwald System (Color Harmony Manual) as published by the Container Corporation of America was very popular with designers.

However, I do not interpret the purchase of a color book as meaning that the designer is making good use of the particular system illustrated by that book. Designers need large number of colors to work with, they need them well distributed throughout the color space and they need to have additional samples available, individually, and preferably in a larger size than the color chips in the books. Munsell and NCS (and formerly Ostwald) meet this requirement, and I believe this is a major factor in the sale of such color systems to this market.

To illustrate the point I provide several examples. A major U.S manufacturer of cosmetics, very well-known for their packaging, regularly provided copies of the Munsell System to all members of the package design staff; this involved twenty or thirty sets of these books. Colors for packages were selected from these books and ordered in larger size for making dummy packages and for use as standards for purchasing. I talked with these designers and visited them in their studios and know that they made little or no use of the Munsell System as such; they only wanted a large color collection from which to select their color scheme.

Recently members of an ISO committee, many of whom are here today, heard talks during the course of a committee meeting from an architect and a product designer who used the Natural Colour System in their work. However, they failed to tell us just how they used the NCS, and when they replied to questions after their talks it was clear that their use of NCS was less as a color order system than as a comprehensive collection of colors from which to choose. These examples do not reflect discredit upon these color systems, they simply show that good designers don't need such systems in their color work. They know how to select color schemes for their uses. They know as much as we do about such things as constant hue, which isn't too much considering that each system has a somewhat different version of constant hue.

A few minutes ago I mentioned that there are color systems which are low on theory but high on practical usage. I want to return to this and talk about color selection and usage in paint and printing ink. The annual value of products colored with paint and ink probably exceeds the value of all other colored products. How are most of these colors selected and specified? Not with any color order system that we discuss in AIC or CIE, ASTM, DIN, BSI or any of the color groups we know. How could this have happened when these groups are the repositories of so much color knowledge?

Let us consider paint used for architectural purposes, i.e., painting buildings. Before World War II there were few if any paint stores, as we know them today, at least in the United States. Most paint was used in and around the home, and it was purchased in hardware stores which also sold other home maintenance items.

There were no in-store colorant mixture systems, the paint was stocked usually in three different sizes and in perhaps ten different colors. It was no accident that most homes were painted white on the outside, or that the wood shutters on the windows were green; green was the color for shutters and every store had it. When you said you wanted a quart of paint for your shutters, a can of exterior green appeared on the counter before you. Barns were red, and many of them still are.

In the early 1940's, to the best of my knowledge, the first colorant mixture system made its appearance, the Martin-Senour Nu-Hue System, designed by Carl E. Foss. By the intermixing of eight or ten colorants with a can of white, any of 1,000 different colors could be produced. This technology rapidly spread worldwide and revolutionized the marketing of paint. It also increased the sales volume, because with this wealth of colors available for both interiors and exteriors, the home owner frequently repainted an area simply to have a new color, not because the old finish had deteriorated. This is the same Carl Foss who, thirty years later, designed the procedure by which the OSA-UCS color order system samples the color space.

Another example of a commercially successful color system is the industry-specific Pantone ®* Matching System, introduced in the U.S. about twenty-five years ago for use in the graphic arts field. Prior to this time each ink manufacturer published its own color chart, displaying a small number of colors representing inks stocked by its local supply house, and sometimes simple (e.g., 1 to 1) intermixes. Because thecolors offered were too few in number, and usually printed on only one paper substrate, graphic designers and others who specify colors for printing applications were frustrated, to say the least.

The alternative to accepting what was offered was to specify the color by use of a color sample and to tell the printer to match it. Whether this was accomplished by the ink supplier or the printer, th custom color match was costly, the process often slow and the result sometimes less than satisfactory.

Pantone mixed about 500 different colors using eight chromatic inks, a black and a transparent white, published the color charts on two different paper substrates, along with the mixing formulas, and licensed ink manufacturers to provide these

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* Pantone, Inc.'s check-standard trademark.

colors mixed to their specifications. The colors were not mixed according to classic concepts, nor were the colors spaced by reference to a system based on theoretical premises. Scales displaying the outside gamut of the colorants were interspersed with those resulting from mixing non-adjacent hues, in both cases let down with black and white. Some grayed colors included three chromatics, such as red, blue and yellow, insuring that the visual relationship between colors would change importantly from one light source to another. The ageing characteristics of the different colors were vastly different. Colors were identified by a three-digit number, not related to visual or instrumental color attributes.

Pantone was not trying to address a broad spectrum of color problems in a variety of colored media. They had identified an important problem and tried to provide a solution. The problem was that ink manufacturers were not providing enough colors and neither local ink houses or printers were very good at mixing colors to order. The solution was to provide a large number of ink colors, with simple mixing formulas readily mixed from a base set of inks that, eventually, almost all ink manufacturers provided. This simple solution proved to be very successful for ink manufacturers because more colored inks, which are more expensive, were specified. Printers like it because it allows them to offer a wide color selection without having to mix the colors by eye. Customers welcome the versatility of many colors from which to choose.

This ink mixing system has now spread worldwide, the color selection has been increased and the same firm is now offering comparable color series in coatings and fabrics. The quantity and value of the sets of color charts sold annually from this one manufacturer probably exceeds the total sales of all scientifically based color order systems. More importantly, this and similar systems in the paint industry have promoted increased use of color in the graphic arts and coatings field to make the world more colorful for all of us.

The success of these commercial paint and ink colorant mixture systems makes a point. It is that success follows development of appropriate color concepts and providing the colors at a price and in a format that the customer will accept. Costs for ink and paint increased initially to amortize the cost of these color systems. But the increase in sales which soon followed more than overcame these startup costs. Manufacturers of color order systems should not think their products necessarily follow different principles of economics.

Now let us turn to what is new, or almost so, in the area of color order systems. There is one from America and one from Europe.

Recently introduced in North America, and perhaps elsewhere, is a color order system with color atlas, called Colorcurve System. It is clearly aimed at the design field, in its broadest sense -- designers of buildings, interiors, packages and products. It was designed by well-known color scientist Ralph Stanziola and was first described at the color meetings held in Toronto in 1986.

Colorcurve is described as a color communication system, as has been the case with most color order systems, providing a way for the color specifier (designer) to communicate accurate color information to a manufacturer of color products. This concept is hardly new. But what appears to be new is a concerted effort to involve both specifier and manufacturer in employing the same system. Its success may be determined by how well this is achieved.

Colorcurve has color aimpoints specified in CIELAB notations and purports to match these points within one color difference unit. While its current physical manifestation encompasses the colorant gamut of coating materials, its concept allows gamut extensions with improved colorants, or if produced in high gloss finish. The color space is sampled in scales with rather uniform visual spacing on charts of constant lightness (L*) at eighteen levels from L* values of 30 to 95.

The sampling scheme is keyed to the distribution of colors used by designers; that is, there are more colors in the near-gray regions than in the vivid regions, and the constant lightness charts appear at closer L* intervals in the lighter regions. Tailoring the color selection to design requirements has resulted in 2,400 different colors in matte finish, and they are also available in formats other than that described. Cost is modest for a color atlas of this size; it appears to be well designed and competently produced. As with the earlier-described paint and ink mixture systems, it is task-specific, aimed toward a major area of color usage and marketed with equal emphasis on the designers and producers of colored products.

The Eurocolor System is exemplified by an atlas of color chips 30 mm x 30 mm, mounted on 25 charts for a total of about 1,000 colors. The colors are denominated in a modified CIELAB notation and appear on 25 charts of constant hue. The modification converts the CIELAB hue angle of 360 degrees into hue steps totaling 1,000 for the entire hue circle. Charts are available at hue intervals of 50 units (0, 50, 100, etc.) beginning at CIELAB a*+, or red. The 20 charts so defined are augmented in the red-to-yellow region by intermediate charts at hue position 25, 75, 125, 175 and 225.

The complete Eurocolor notation includes a three-digit hue notation, followed by a two digit lightness notation equal to CIELAB L* and a two-digit chroma figure equal to CIELAB chroma, thus 250.80.70 would define a vivid yellow. The data are computed for CIE Illuminant D_{65} and the CIE 10 degree Observer. Literature on the Eurocolor System states that the aim in production was to match the nominal notation positions to within one CIELAB color difference unit. No measurement data are provided. Colors are in matte finish and are said to encompass the color gamut of permanent pigments most often used in the coating industry.

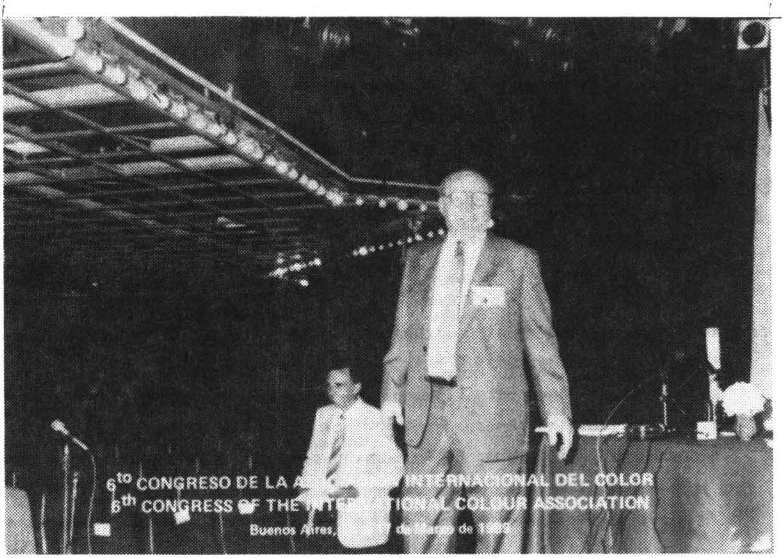
The Eurocolor atlas would seem to be a useful addition to this field. It provides a needed representation of the increasingly popular CIELAB system which appears as readout in almost all color measuring instruments. Its conformance to its nominal positions is as good as others and better than some atlases. Eurocolor seems aimed at the design market although its limited gamut matte finish would seem to confine it to interior design, as opposed to exterior building design and product and package design work. The collection is also available in other formats such as fan decks which are more readily portable.

It is helpful to have a color atlas in a system whose attributes are available on colorimeters and spectrophotometers. Other uniform spacing systems appear on instruments, and other color atlases are available, but this seems to be the first time an atlas has been produced to illustrate a uniform spacing color order system. On the other hand, the recently introduced Minolta spectrophotometer has a Munsell notation readout and it is accurate, as opposed to the conversion available earlier on Minolta tristimulus colorimeters. However, I doubt that many designers will be interested in such matters as they have little use for instrumental measurements.

The Forsius Symposium not only enumerated the many color order systems in history, but also provided current system designers an opportunity to describe and illustrate new systems. However, very few of these numerous systems have been exemplified in commercial quantities to permit widespread usage. Those which have been produced have enjoyed modest success at most.

Most of the systems produced in the past have been designed and marketed for universal application. More recently in the two major color using industries, paint and ink, task-specific systems have been quite successful.

With the advent of improved instrumentation, the market for color order systems may be shrinking in scope, especially for universal systems and particularly so for those with high prices. We now have two new color collections, one illustrating the CIE-recommended CIELAB system and the second exemplifying a new task-specific system for designers. Over the next few years we will see how they prosper.



Invited Lecture:
Prof. F.T. Simon (U.S.A.), (Chairman: Lic. A. A. Alvarez, Argentina).

Invited Lecture:
Dr. R. Gundlach (F.R.G.), (Chairman Dr. G. Gevtler, F.R.G.).

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COLOR MATCHING

Introduction

Color matching in its purest sense is a visual process involving the judgement of human beings. When instruments and computers are brought to bear on the problem of color matching, the thing that is accomplished must be called color formulation (also properly called match prediction) which is a mathematical process used to generate one or more recipes for applying colorants to objects with the hope that the resulting material will be a match for a standard or "aim." Then it is a judgement call to decide whether the pair of colored objects look alike. The major difference between color matching done visually and with the modern instrumentation is that the computer method is faster and can be programmed to consider various factors that would have to be learned through many years of experience. Both methods are not absolutely accurate and depend on an iterative approach to achieve acceptable matches. Furthermore, the visual and instrumental methods share certain principles which are worth repeating here.

Color matching is done in paint, plastics, printing ink and textiles. Color formulation to some degree has revolutionized the way in which color matching is now done in those industries because of the efficiency of the process and the much larger amount of information which can be at the disposal of the color matcher so that a better decision can be made. During the past three decades a substantial amount of technological development has taken place. The lower cost of color formulation has encouraged the interest of instrument makers to improve their product. The boom in digital computers has fostered the introduction of better, faster, and cheaper processors, operating systems, and peripherals. And all of this has been brought together in modern color formulation systems that could only be imagined a few years ago.

General guiding principles for color matching

Color matching for object colors is based on the principle that mixtures of two or more colorants can achieve colors that cannot be obtained when single colorants are used alone. This means that the effect of the colorants is combined to give colors that partake of each colorant in the mixture. In this way an artist can create what he sees or imagines and the industrial colorist can duplicate a customers sample.

No matter whether the task is to create colors that are a mental image or to duplicate colors provided by others, there are a few "rules" that should be followed:

a. The first principle at all times is <u>know your colorants</u>.

b. The total color gamut that can be achieved by a group of colorants must be understood by some sort of display. This can be done with all available colorants laid out on an artist's palette. The industrial colorist should have a collection of all of the available colorants in material that will be used to achieve matches.

c. The group of colorants must be compatible with each other

d. It is necessary to understand the "build-up" of individual colorants as their concentration is increased.

e. It is helpful to make samples of all colorants in a group at several concentrations in order to learn whether they show hue or chroma changes.

f. If at all possible, a color match should be based upon on one or more colorants that are closest to the desired color, rather than using only high chroma primaries such as yellow, cyan, and magenta or red, yellow and blue.

g. For a match under one light, limit the number of colorants to three; add black and/or white in the case of pigments.

h. When the color match must be made in two or more conditions of lighting, more than three colorants should be provided to control the appearance under other illumination environments.

Visual color matching is an iterative process which requires that the colorist first select specific colorants from his supply and then make an estimate of the proportion of colorants to be mixed to achieve the desired effect. A trial is then made and this is followed by a correction of additions and/or changes to original estimate. In todays modern factory most color matching is done by quantitative means using an instrument and a computer to calculate a desirable recipe or formula. Although the visual estimate substitutes experience for computation, good practise dictates that the number of colorants be constrained and adjustments are made to the original recipe rather than increase the number of colorants because the trial "looks like it needs ....". and add a colorant. It is better to start over with another set of colorants because it is not possible to repeat a random selection at a later time. This principle follows for instrumental shade matching.

Many criteria, both visual and instrumental, are used to determine what is a satisfactory color match. Probably the most important factor in determining whether a color matches another one is the surrounding in which the color is viewed. This means that proper consideration must be given to the lighting and the other colored areas that are around the color to be matched. It is a general principle that the criticality of any color match is inversely proportional to the size of the object; that is, large areas require closer matches than small areas. This means that the matcher can take liberties with some color matches but is affected by all of the other colors that surround a particular area of a complicated design. In the effort to duplicate a color, the industrial colorist can take no chances and will follow the rule that the customer sets the tolerances for color matches and build such tolerances into computer pass-fail programs.

Methods of Color Matching

Visual color matching is still widely practised in applications that cannot justify the expenditure or in cases where the optical properties of the material are sufficiently complicated to defy current instrumental measurement. The technique is arduous and can be accomplished with considerable experience and has always been regarded as a great skill. In general what is required is the ability to visualize how much of one or more colorants must used together to achieve a first trial. Then it is the task of the colorist to estimate how much of each of the colorants in that trial needs to be changed in order to match the "aim" closely enough. Hopefully as the color matching progresses, smaller and smaller additions have to be made and eventually a match is obtained. Familiarity with how a particular group of colorants behaves is helpful. It is also a great aid to any color matching if a file is available of previously matched samples with their formulas. Since color matching is time-consuming and sometimes tedious, all kinds of material help is considered appropriate to the task.

Instrumental methods are used in a large segment of the color application industries. All of these methods require a spectrophotometer, a computer, and computer programs to perform the necessary computations. This application of technology one of continuing development over the past three decades. Where it is appropriate, the task of trial-and-error color matching by the experienced eye is reduced to making measurements and "pushing a few buttons". The description of the instrumental technique is given below. However all of the aforesaid "rules" for visual matching apply to instrumental methods taking into consideration that an instrument does not "see" color but merely measures the spectral characteristics of the samples presented to it.

The features of any instrumental method are characterized by the component parts:

a) the mathematics and user interface of the computer program

b) the type of spectrophotometer used to measure samples

c) the type of computer used to perform the calculations and the peripherals used to obtain output of data

Two major mathematical procedures are in widespread commercial use to do the calculations necessary for color formulation. These are generally termed: a) the tristimulus method and b) the least squares method. Several alternative mathematical approaches such as linear programming have been recommended in the literature. The details of the two methods are described very well in two substantial references (1,2) as well as many others. However for the purpose of completing this paper, a brief desciption is given below of the basic mathematics of the so-called single constant method.

The differences in the two methods is illustrated in the Figures 1 and 2. The concept of tristimulus matching fundamentally means that three colorants can be mixed together to achieve a specific situation where the tristimulus values, CIE X,Y, and Z, of a sample will equal the tristimulus values of a standard. This implies specific conditions of illumination and observation. This is to say that:

T (standard) = T (sample)

where:

T represents CIE X, Y, and Z values

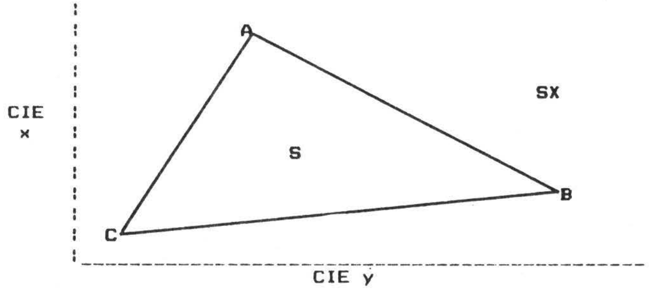

Fig. 1 To illustrate the principle of tristimulus formulation
S is a sample to be matched.
A, B C are three primary colorants
SX is a sample outside the gamut of A, B, C

Although straight lines are used to show the boundary of all mixtures of the example colorants, this is rarely true in the CIE chromaticity diagram. The sample, SX, cannot be matched with these colorants and a tristimulus program would find this by calculating substantial negative values for one of the components which indicates the impossibility of obtaining a match.

The least squares method approaches color formulation by fitting the spectral curve of the sample to be matched. It is different in that the objective is purely physical and works best if the colorants used in the mixture are the same as those in the standard. In any case the calculations tend to minimize the differences in reflectance between the mixture and the standard. This can be simply stated as:

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1. Kuehni, R. (1975) *Computer Colorant Formulation* D.C. Heath, New York
2. Allen, E.M. (1980) *Colorant Formulation and Shading*, Chapter 7 in *Optical Radiation Measurements*, Volume 2, F. Grum and C.J. Bartleson, Eds., Academic Press, New York

$$\Delta \beta(\lambda) \rightarrow \text{MIN}$$

Figure 2 shows an example of a mixture of two colorants, a green and an orange which are used to match the curve of a green standard. The method is not limited to a small number of colorants nor is it restricted to minimizing reflectance data differences in the visible range of the spectrum; it can be used for matching spectral curves in the near infra-red region.

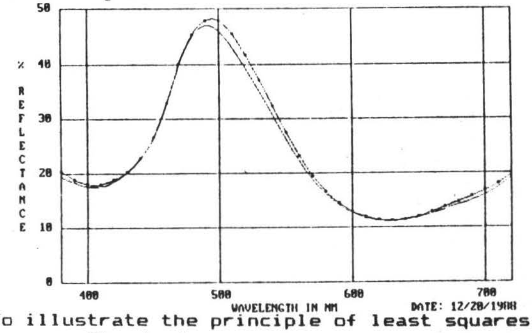

Fig. 2 To illustrate the principle of least squares formulation
——— Standard green
■-■-■-■ Green + orange mixture

Techniques for formulation

The first step before any computer formulation can be done is to prepare a set of samples of the colorants which are to be used. The number of samples needed depends upon the type of standards that will be matched and the sophistication of the computer program which is used to do the calculations. In the simplest instance, tristimulus color formulation can be accomplished with only three colorants at a single, intermediate concentration. An example of the method is given by Stearns (Ref. 3) who shows how the calculations can be done with a hand-held calculator. This method has also been programmed in the BASIC language for easier use. The procedure is sound and has been generalized and greatly improved to fit a variety of industrial applications. Table I shows several ways in which a simple program must be expanded to provide the flexibilty found in commercial formulation packages.

Samples	Minimum program	Commercial programs
Matching standard	One	A number can be queued
Substrate	One	Many
Colorants-number	Three	As many as appropriate
-levels	One	Min-3; Max-8; Usual-6

Table I. Comparison of a simple tristimulus formulation program with commercially available programs

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3. Stearns, E.I. (1969) *The Practise of Absorption Spectrophotometry*, pp 252-269. Wiley-Interscience. New York

It should also be noted that this simple example is for single-constant applications whereas programs intended for paint and plastics industries treat the absorption and scattering of the colorants separately; i.e., by the two-constant method. Commercial programs use some of the same mathematics as a kernel but elaborate it with routines which improve the matching capability of the system as well as making the input of instrument data much easier and automatic.

Minimum program

The steps in the construction of a single-constant tristimulus program are given here to illustrate how data are manipulated to obtain recipes. The basic input to any program is the reflection (or transmission) measurment made on a spectrophotometer. For the present example, reflectance data will be used; these data are retained for color difference calculations but are also converted through the Kubelka-Munk equation to what is given the designation of F to show that the scattering is assumed to be constant. This is done for each wavelength throughout the visible spectrum.

$$F(\lambda) = (1 - \beta(\lambda))^2 / (2 * \beta(\lambda)) = K/S \qquad \text{Equation 1}$$

where: $\beta(\lambda)$ = reflectance factor (0 to 1)

If the substrate data are designated as FS then these data are subtracted, wavelength-by-wavelength, from F's for the match standard and each of the colorants. The corrected F's for the colorants are converted to absorbencies, A, with the input concentration for each colorant:

$$A(\lambda) = (F(\lambda) - FS(\lambda))/c \qquad \text{Equation 2}$$

In computer programs the criterion for determining whether a satisfactory match is obtained is naturally a numerical one. The number which is calculated is color difference which is developed below. However, the fundamental thesis for establishing whether two colors match is to calculate their tristimulus values, X, Y, and Z for a particular illuminant. If these are equal, a sample matches a standard. Written in shorthand, this can be stated:

$$T(\text{standard}) = T(\text{predicted match}) \qquad \text{Equation 3}$$

where T = X,Y,Z

This criterion would be met for a "perfect" match, but practicality allows for slightly less than "perfect" so a color difference formula is used for this judgement. In either case, the tristimulus data are necessary so these are calculated for the standard at this time.

$$T(\text{std}) = \sum_{\lambda} [\bar{t} * P(\lambda) * \beta(\lambda)] \qquad \text{Equation 4}$$

where:

T= X,Y,Z CIE tristimulus values

$\bar{t} = \bar{x}, \bar{y}, \bar{z}$ color matching functions at each λ

$P(\lambda)$= Spectral power distribution of illuminant

$\beta(\lambda)$= Reflectance of standard

The approach that is used to compute a formula which will match the standard with the given colorants is iterative and is based on the computation of the concentration of each colorant from a set of differential equations that relate concentration to tristimulus value. These equations are developed from several relationships. In the first place, the relationship of concentration and the function of reflectance, F, is:

$$F(\lambda) = A(\lambda)\ c \qquad \text{Equation 5}$$

where:
c = the concentration of a colorant

In order to establish a connection between tristimulus, T, and concentration, some partial differential equations are developed for a local region of color space. For that the derivative of β with respect to function of reflectance, F is needed; that is, $d\beta/dF$, which will be designated as D:

$$D = (2 * \beta(\lambda)*\beta(\lambda))/(\beta(\lambda)*\beta(\lambda) - 1) \qquad \text{Equation 6}$$

This leads to the matrix of differentials, $\delta T/\delta c$, called Q, which has subscripts i for tristimulus values and j for colorants. This is calculated for all measured wavelengths ($\sum_{\lambda}$ is implied):

$$Q = \sum_i \sum_j [\bar{t}(i) * F(j) * P * D] \qquad \text{Equation 7}$$

The analogous function is also need for the standard (summed for all measured wavelengths):

$$QS = \sum_i [t(i) * (F(std)-F(sub)) * P * D] \qquad \text{Equation 8}$$

The matrix Q is then inverted and the following matrix equation is valid:

$$c_a = Q^{-1}\ QS \qquad \text{Equation 9}$$

where:
c_a is approximate concentration for the 3 colorants

A set of concentrations are calculated from this equation which is first multiplied by the A's and then summed at all wavelengths for the respective colorants. The result is a spectral function curve for the approximate formula, called F_a:

$$F_a = \sum\sum_{j\lambda} [F(j,\lambda) * c_a(j)] \qquad \text{Equation 10}$$

Since reflectance is needed to calculate color differences, it is derived from F_a by the inverse of the function and is calculated for the entire spectral range.

$$\beta_a = (1 + F_a - (F_a * F_a + 2 * F_a * F_a)^{1/2}$$ Equation 11

Then the tristimulus values for the approximation can be calculated with Equation 4 by substituting β_a for β which gives an equivalent set of tristimulus values, T_a. A color difference computation is then made to determine how close an approximation to a match has been computed. The common color difference equation used to evaluate that was given by the CIE in 1976. The required data are the ΔL*, Δa*, and Δb* between the standard and the predicted approximation. This results in a ΔE from the following equation:

$$\Delta E = (\Delta L*^2 + \Delta a*^2 + \Delta b*^2)^{1/2}$$ Equation 12

The value of ΔE indicates whether the approximation is reasonably close to the standard. It is general practice to consider that when a $\Delta E < 0.25$ is obtained, the calculated formula will give a match that is close enough to the standard when examined in the light that is described by the term P in Equation 4. When $\Delta E > 0.25$, a further step is taken in the computation to improve the formula. This is done by calculating a difference in concentration of the colorants from a difference between tristimulus values T and T_a. Equation 9 is used to calculate a difference in concentration, Δc, according to:

$$\Delta c = Q^{-1} * (T - T_a)$$ Equation 13

where:
Δ c = the difference in concentration of the colorants

When c_a and Δ c are added together algebraically, a new set of c_a's are obtained; these are then multiplied by the A's for each colorant as in Equation 10. The steps of Equation 10 through 13 give an iterative method whereby closer approximate formulas can be calculated until the criterion $\Delta E < 0.25$ is met. Once ΔE is low enough for the first illuminant designated as P, then the color difference is calculated for a second and even a third illuminant using Equation 4, except that the values of P are changed in accordance with the spectral power distribution for the other illuminants. The difference between ΔE calculated for the first illuminant and the others is called "metameric index" and gives some idea of the relative appearance between standard and approximation. It is desirable to minimize these values and this can be done by changing the selection of colorants. One of the advantages of commercial formulation programs is that larger fields of colorants can be input initially and the better sets of three colorants are selected combinatorially; the computer does all of the work!

Metamerism and extensions to the three-colorant tristimulus method

Unless complete spectral matches are obtained by using the same colorants that are in the standard, any match prediction may be a compromise as to matching in a second and third illuminant beyond the primary one chosen for the formula calculation. Some colorants behave quite differently than others under various lighting conditions, so special information is needed to make a decision on behavior of the match under other illuminants; these data are called metameric indices and are given for at least two other illuminants. Furthermore, with the selection of certain colorant combinations, the effect of metamerism can be greatly reduced. Allen (Ref. 3) suggests that a 4-colorant tristimulus formulation method using the tristimulus X value for the second illuminant is a logical extension of the usual 3-colorant algorithm. This is most appropriate in metameric matching when daylight is the primary formulation illuminant and incandescent light is the second illuminant. This same idea can be extended to a 5-colorant scheme when a third illuminant is to be considered.

An alternative may be that fewer colorants than three could effect a reasonable match for certain standards. 2- and 1- colorant formulas can be calculated by the least squares method according to Allen and can be necessary to match bright colors. Some tristimulus programs proceed with the same method as with three colorants but ignore small amounts of one colorant which may be left from the output.

The generality is true in some cases that more colorants rather than fewer colorants reduces metamerism. But more colorants can lead to control problems in production environments so spectrophotometric curves of the predicted matches can be more informative than simple metameric index numbers. The two sets of data given below show that with the proper choice of colorants the spectral curves of the predicted matches will be closer together and result in lower metameric indices for daylight-to-incandescent light as well as daylight-to-fluorescent light.

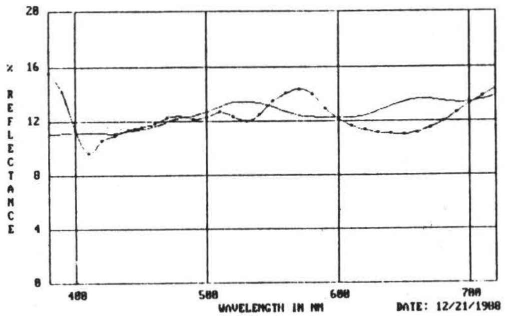

Fig. 3 Spectral curve of recipe for Light Gray
——— Standard Light Gray
■-■-■-■ Yellow + orange + blue mixture
Metameric indices: Daylight → Incandescent = 1.3
Daylight → Fluorescent = 1.0

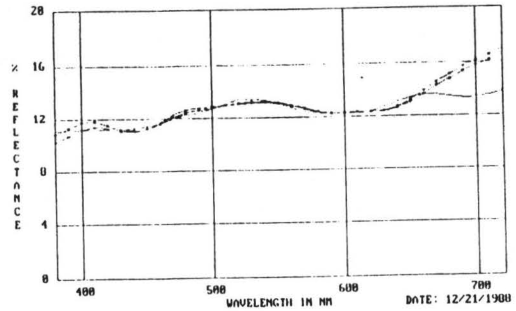

Fig. 4 Spectral curves for Light Gray with two other combinations
——— Standard Light Gray
■-■-■-■ Blue + gray + orange mixture
×-×-×-× Green + gray + orange mixture
Metameric indices: Daylight → Incandescent = 0.1
Daylight → Fluorescent = 0.2

The addition of a fourth colorant to the 3-colorant combination shown in Figure 3 reduces the metamerism as suggested before. When the calculated metameric indices are not within established criteria, 4-colorant recipes should be calculated with the program. However, if the selection of the field is adequate, 3-colorant formulas as in Figure 4 would be advised.

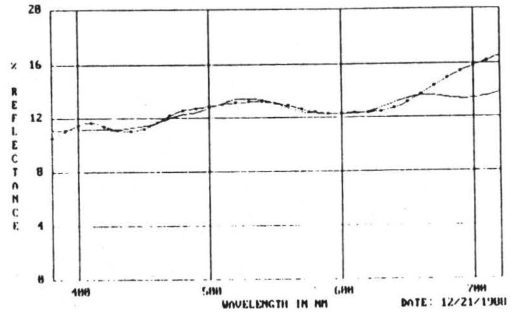

Fig. 5 Spectral curves for Light Gray with a four-colorant combination
——— Standard Light Gray
■-■-■-■ Yellow + orange + blue + navy mixture
Metameric indices: Daylight → Incandescent = 0.2
Daylight → Fluorescent = 0.5

Color correction

Up to this point all of the "matching" has been numerical; that is, by calculation with by a computer. Actually, the computations have only led to a formula which must be proven by making a trial. When an actual sample has been prepared the moment of truth has arrived and all of the interactions among colorants and substrate as well as any errors in preparation of the input data come together.

With a trial in hand the goodness of the match can be determined either by visual estimate or by measurement with an instrument and calculation of a numerical color difference between trial and standard with the 1976 CIEL*a*b* color difference formula. In either case, a judgement must be made as to whether an acceptable match has been achieved. If an improvement in the match is required this can be done with another computer program which uses much of the same mathematics that was given above. In principle two formulations are obtained, one for the standard and another for the trial sample. Since the amount of each colorant is known for the trial, correction factors can be calculated:

$$cf = c_t/c_s$$

where:

cf = correction factor for each colorant

c_t = computed concentration of colorants in trial

c_s = computed conc. of colorants in standard

The values of c_s should be known from previous computations but can be recalculated if the standard is remeasured at the time of the correction. Alternatively, the necessary spectral data could be retrieved from a file record that was stored when the original formulation was done. The correction factors can now be applied to the newly calculated concentrations of the colorants to give an improved formula which should be a closer match to the standard:

$$c_n = c_i/cf$$

where:

c_n = new concentrations for each colorant

c_i = actual conc. of colorants used in trial

Thus, repeated trials can lead to samples which should be closer and closer matches to the standard based on the iterative loop used and can achieve an acceptable match to a standard.

One of the greatest problems which interferes with proper convergence to an acceptable match is the lack of reproducibilty of preparing the trials. At each juncture in the process, the variability of sample preparation is a statistic that is incorporated into predicting an accurate color correction. The mathematics of the computation is correct and the problem of sample preparation must be addressed. Some colorists prefer to do the correction step visually feeling that they can intelligently compensate for the errors that are inherent in the process.

<u>Primary data for formulation</u>

All computer-based formulation systems have special programs that allow for entry of the primary colorant data into the computer files that are data bases for the formulation and correction programs. Along with the reflection data, concentrations, and colorant name other useful information can be retained in the data base for future use. Examples are maximum and minimum useful concentrations, strength factors, date material was stored, surface reflection, etc. The type of data associated with the colorant may be just as important to the user as the data used by the formulation program and can be used in conjunction with other color-oriented computer programs.

In addition to the simplified means to build the data base, these programs usually have means to analyze the validity of the information that is stored. A certain amount of subjectivity is involved in determining whether the basic colorant data stored in the computer are correct. The most critical test for making this evaluation is to observe whether the predicted recipes lead to good color matches. If unacceptable matches are found with specific colorants, these should be checked and perhaps the concentration ladder should be made again and entered into the computer to replace questionable primary data. This is time consuming, so most data should tested before it produces dubious formulas.

The easiest test to make is a qualitative examination of the measured spectral data for all concentrations of the colorants prepared as primaries. A typical set is shown in Figure 6. The criteria for checking spectral curves for a concentration ladder is to look for duplications or cross-overs of several reflection curves. Cross-overs are expected, however, for yellow and orange colorants since some of them increase in opacity with increasing concentration which leads to lower reflectances in the 600 to 700 nanometer region.

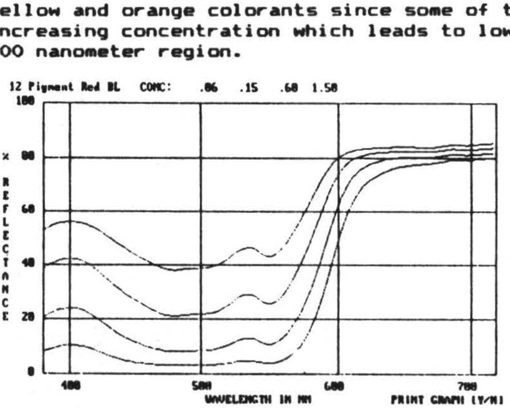

Fig. 6 Spectral reflectance data for various concentrations of Pigment Red BL

Another simple test is to examine the consistency of the concentration ladder. This can be demonstrated with a plot of absorbency versus concentration for each colorant. The graph in Figure 7 shows a case where the indicated amount of colorant in the nominal .15 and 1.50 levels are suspect, based on a straight line drawn through points for the other levels and the substrate. This preliminary indication is not proof positive that the nominal concentrations are incorrect but suggest that an intermediate concentration should be prepared to support the hypothesis. Such data quickly show the way to possible problems.

The function that is used to describe absorbency is termed integrated or summed K/S. This function is used to appreciate the entire spectral curve rather than data based on reflectance only the maximum absorption. The function is:

$$\text{Sum } K/S = \sum_{\lambda} K/S(\lambda)$$

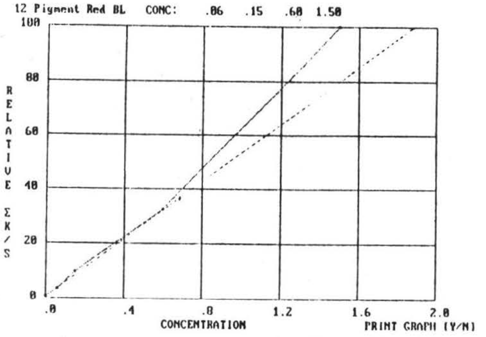

Fig. 7 Absorbency versus concentration for Pigment Red BL

Enhancements to Computer Output

Computer technology has advanced yearly and the formulation systems have kept pace with it. Increased speed, storage capacity and ergonomic hardware have been made available to the user because of the fierce competitive nature of the computer industry. In addition, software developments in the area of graphics, color displays, and color printers have provided new and more useful information which can aid in the interpretation of formulation and correction output data. Color is used in many of the video monitors to aid in the interpretation of the input and help to minimize interpretation of output data.

One of the features that has been of interest to the author is the use of color graphics to simulate the results of the formulation computation on a color video monitor screen. In this way it is possible to visually compare the results to the standard and make visual judgements about the

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4. Lucas, J.M. (1987) *Accurate Representation of Surface Colors on a Video Display Unit*, PhD Dissertation, Clemson University, Clemson, SC

closeness of the match (Ref. 4). The change of the color under different lighting conditions is also simulated which provides a visual impression of the fact of metamerism. A parallel development to the formulation display is the simulation of samples presented to the computer for batch correction. In this instance a display shows colored patches to simulate the batch and standard colors with a third patch which represents the calculated corrected batch. The color of the third patch can be manipulated by changing the concentration of the ingredients in the formula along with the formula to show the effect of corrections that do not need to give an exact match for the standard.

A few of the vendors of commercial formulation systems offer video devices which accomplish what Lucas' work demonstrated but this approach seems to be only a beginning. Unfortunately, inexpensive printers have not been developed yet to make a respectable paper copy of the simulated color display.

What if you get poor formulas?

Certainly you have a problem but the blame cannot be placed on the "dumb" computer, particularly if you sometimes get reasonable formulas. The fault most likely lies in the preparation of the trials. Consequently, a duplicate trial should be prepared with the same formula and the two samples compared to each other by calculating their color difference after measuremnt. If the two differ by more than 3 CIE L*a*b* ΔE units, more care must be taken with the sample preparation. On the other hand, if a specific formula can be duplicated, then suspicion must be cast in the direction of the primaries. If a few concentrations are duplicated for one primary colorant and the results are better, the entire set of primaries must be scrutinized using the methods described above. The third most likely cause of poor formulas is unreliable measurements with the spectrophotometer. It is good practise to average two or more measurements of all samples rather than depend upon one measurement. One safeguard that I use is to always calculate a Munsell notation (Ref. 5) for every standard as it is measured for the match prediction program. When questions arise about the formula, a visual check of the calculated Munsell notation against a sample in the Book, will quickly reveal bad measurements. Finally, there are interactions between colorants as they are applied. This factor is more prevalent in dyes that are exhausted from a solution and there is no better answer to this problem than to do a color correction of the initial trial which gives compensating factors as is described above.

Acknowledgement

The author appreciates the loan by Gardner Laboratory, Pacific Scientific Company of a spectrophotometer called The Color Machine® to make the measurements shown in the illustrations. All calculations were done on an IBM PS/2 computer with specialized software.

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5. Simon, Frederick T. & Judith A. Frost, (1987) "A New Method for the Conversion of CIE Colorimetric Data to Munsell Notations", *Color Research and Application* 12, p.256-260

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PHOTOLUMINESCENCE OF SURFACE COLORS

Introduction

Each material with a temperature above the absolute zero point, e.g. with room temperature (T= 300 K) emits electromagnetic radiation. If this system is an ideal absorber like a black body it is also an ideal radiator, and the spectral distribution of the emitted radiation is given by Planck's formula

$$M_\lambda(\lambda,T)= \frac{c_1}{\lambda^5(e^{c_2/\lambda T}-1)} \qquad (1)$$

wherein M_λ is the spectral radiant exitance defined as the spectral radiant power emitted from the surface per unit area. The unit is watts per squaremeter and meter. c_1 and c_2 are the Planckian radiation constants. At 300 K the maximum of emission is in the FIR near 10 µm. If there is no difference in temperature to the surroundings, absorption and emission are in balance and the material can not be discriminated from others by its own emission and cannot be seen in the dark.

Radiation energy emitted by an external source of higher temperature which is incident to this material will be absorbed and increases the heat content or enthalpy of the system. With the increased temperature the emission of electromagnetic radiation increases and the maximum of emission shifts to shorter wavelengths but will remain in the IR. Only if the temperature of the material exceeds 1000 K then it can be seen first in the dark as a glowing and later with increasing temperature as an incandescent object. The color of the emitted light will change from red over yellow towards white and blue-white.

Beside this thermal emission of radiation or incandescence there is often another effect of emission, called luminescence. Luminescence in general is the emission of electromagnetic radiation from a substance as a result of any non-thermal process. Luminescence is produced when atoms, molecules or crystals are excited and then decay to their ground state. Because the lifetime of excited states lasts at least 10^{-9}s, the emission can only start after this time as the earliest. Luminescence can be triggered e.g. by absorbed ionizing or optical radiation, cathode rays, and chemical or biochemical processes especially oxidation. Here, in connection with the luminescence of surface colors, we are mainly interested in photoluminescence. With photoluminescence the excitation is caused by optical radiation e.g. of daylight.

This delimitation of photoluminescence against thermal radiation is not the only criterion for luminescence. There are some light effects which are not luminescence. The Raman effect for instance, is not a resonance but a scattering effect. The Cerenkov effect, a bluish light emitted by a beam of high-energy particles passing through a transparent medium, is caused by emission of surplus energy. Here the velocity of the particles is higher than the velocity of light in that medium. The delay of both effects is about 10^{-14} s and so in the order of the period of one oscillation of light waves. Therefore, these effects can not be absorption-emission effects like luminescence with a delay of 10^{-8}s .

Photoluminescence is a generic term for fluorescence, phosphorescence, and other similar processes. Is there after excitation and internal conversion a direct decay to the ground state within 10^{-9} to 10^{-7}s, the process of emission is called fluorescence. On the other hand an intersystem crossing after excitation leads to a rather stable triplet state and the emission is delayed at least for 10^{-2}s, usually much longer. This persistence is called phosphorescence. Beside these both processes other effects like delayed fluorescence, trapping of luminous electrons at defects and quenching effects may occur. Because normally there is no information on the very type of photoluminescence with a specimen, it is better to call it photoluminescence or short luminescence in general, even if it can be assumed to be fluorescence. Another reason is that all instrumentation in colorimetry of luminescent colors cannot discriminate between fluorescence and phosphorescence. Therefore, with colorimetric equipment only luminescence is measured.

The next question is, which systems are predisposed to luminescence? In general one can say that all systems with insulated optically active electrons (luminous electrons) are candidates for this effect. That involves that the probabilitiy for losses by thermal vibrations or photochemical reactions is low and decreases with decreasing temperature. This is likely e.g. for gases by limited density, large rigid molecules and oxides of rare earth elements with deep insulated transitions.

Photoluminescence is widespread in nature. Only the often investigated fluorescence of chlorophyll in leaves may be mentioned here. In science and industry beside photoluminescence with gas discharge processes, photoluminescent materials are used e.g. as quantum detectors, laser dyes, and phosphors in fluorescent lamps, for TV- screens and displays.

Here, we are mainly interested in the photoluminescence of surface colors which can cause two conspicuous sensations:

- Extraordinary brilliance of chromatic colors
- Whiteness

The appearance of color with opaque specimens in general is the result of selective reflection. If daylight e.g. is incident on a nonluminescent orange sample, about 90% of the longer wavelength portion of the light is reflected and can be seen as an orange color. The shorter wavelength portion including the uv-radiation of the daylight is absorbed and dissipated as heat. With a luminescent orange sample the amount of reflection will be the same but the absorbed radiation is converted with an efficiency of about 70% into a yellow-orange lightband of about 50 nm bandwidth. This emission due to luminescence overlaps the reflection in this range. The sum of both can exceed 250% of the ideal white. Here the orange color seen is so unnatural and conspicuous in its extraordinary brilliance that it is widely applied as a safety and warning color. Although the worldwide production of daylight luminescent pigments can be neglected compared to the production of other pigments, due to international and national regulations and recommendations in the field of safety in traffic, business and also leisure, the correct measurement of the daylight color of luminescent materials is very important.

The sensation of whiteness is perceived with colors of dominant wavelengths of approximately 470 nm to 570 nm, low purity, and high luminous reflectance. Within this restricted color gamut blueness in general is preferred to lightness. Whether a greener or redder tint of the blueness is preferred can depend on the origin of the observer. The problem of measuring whiteness is closely connected to the production and restoration of whiteness with papers, plastics, fabrics, textiles, and detergents. Here the absence of bluish- whiteness means with organic compounds yellowness which is a synonym for degradation. So up to the first decades of our century whiteness was enhanced by bleaching in sunlight and bluing by dyes. Today fluorescent whitening agents (FWA's) are used. FWA's are luminescent dyes which mainly absorb in the uv-range and emit in the visible range at about 430 nm. These organic compounds are instable against uv- radiation and environmental influences. To measure the whiteness of materials fitted with FWA's is the main task in luminescence colorimetry due to its industrial importance.

For both types of luminescent pigments it is necessary to measure the relevant optical properties of the resulting luminescent systems in which they are imbedded with regard to color or whiteness.

Opaque luminescent systems

Daylight luminescent dyes are organic dyes. Their luminescence is directly associated with the individual molecules. So if they will luminesce efficiently, they must be dissolved in rather low concentration in a suitable solvent which causes no quenching effects and will protect the molecules against environmental influences. In order to get a pigment the solvent must be a solid. These requirements are met by organic resins which themselves must show less degradation in the dark and by exposure to daylight. The resins are pulverized and classified by air. A rather small size distribution with a maximum of 6 to 7 µm is typical. Due to the resin as solid solvent the luminescent pigments are amorphous and transparent. So they must be dispersed in a binder in rather high concentration and coated in a rather thick layer of about 300 µm wet thickness. The transparent luminescent coating must usually be applied above a white reflector which may be a white primer. To improve the lightfastness the layer will be overcoated with a clear layer containing an uv-absorber. In luminescence colorimetry always the complete luminescent system is measured. It can contain more than one luminescent component even if only a single pigment is used. Those mixtures will cause cascade effects by optical coupling of emission and absorption within the layer.

FWA's or optical brighteners are seldom used in such complex systems as daylight luminescent pigments. Commonly they are directly adsorbed by fibres of papers or fabrics. Therefore the fastness against environmental influences is often poor and also the lightfastness can not be improved by an uv-absorber.

Color measurement of luminescent surface colors

The color of luminescent surfaces can be measured in principle in the same way as that of nonluminescent colors if the luminescence is excited and evaluated correctly. That means that during measurement the spectral irradiance distribution on the surface of the sample must comply with the spectral irradiance distribution of the illuminant wanted with the tristimulus values e.g. standard illuminant D65.

A simple way would be to use a source of standard illuminant D65, and an absolute measuring tristimulus colorimeter containing the measuring geometry wanted. The geometry should be 45/0 or reverse and no integrating sphere to avoid the wellknown errors due to a feedback of the luminescence on the irradiance of sample and reference. This simple measurement is not possible due to the facts, that firstly there is no source recommended for standard illuminant D65 and secondly quasi absolute measuring colorimeter heads are very expensive and usually not designed for measurements of surface colors.

Instead of standard illuminant D65 only a close simulation of D65 can be used in combination with a spectrometer. The sum of spectral reflection and emission due to luminescence is measured against a white reflecting diffuser and then the tristimulus values for D65 are calculated in the usual way. With this so-called one-monochromator method mainly errors by the poor simulation of D65 occur which can be corrected approximately.

The best but most time-consuming and expensive way is to apply the so-called two- monochromator method. Here the luminescent specimen is irradiated monochromatically through the first monochromator and the reflected und luminesced radiation is analyzed through the second monochromator. With this method tristimulus values can be calculated for every illuminance wanted.

This short introduction to measuring methods suggest that the measurement of luminescent surface colors mainly is a problem of reflection spectrometry with correct excited and evaluated specimen. Characteristic properties of the specimens must be measured spectrometrically and estimated colorimetrically.

Spectral characteristic of luminescent surface colors

In colorimetry the adequate spectral quantity which characterizes an opaque diffuse reflecting material is the *spectral radiance factor*

$$\beta_S(\lambda) = \frac{[L_\lambda]_S}{[L_\lambda]_W} \tag{2}$$

which is defined by the radiance of the specimen per unit waveband at wavelength λ divided by the radiance of a perfect white reflecting diffuser per unit waveband at wavelength λ identically irradiated and viewed. It must be cleary stated that the spectral radiance factor of a non-ideal reflecting and diffusing material always depends on the geometrical conditions of irradiation and viewing. The spectral radiance factor is not intrinsic to a real material beside a perfect reflecting one.

With a luminescent opaque diffuse reflecting material beside reflection diffuse emission occurs. Because the human eye is not able to discriminate diffuse reflected from diffuse emitted light, the luminesced radiation is treated like the reflected one. So a *total spectral radiance factor*

$$[\beta_T(\lambda)]_N = \beta_S(\lambda) + [\beta_L(\lambda)]_N \qquad (3)$$

is defined which is the sum of two portions. $\beta_S(\lambda)$ is the *reflected radiance factor* and $\beta_L(\lambda)$ *the luminesced* or *luminescent radiance factor.* The latter depends on the spectral irradiance distribution (S.I.D.) on the sample and so also the total spectral radiance factor which indicates the subscript N.

As already mentioned above, the total spectral radiance factor can be measured directly with a simulator e.g. for standard illuminant D65. As analyzer a one-monochromator spectrometer can be used. This kind of measurement is performed in the so-called reverse mode which means polychromatic irradiation of the specimen and reference and monochromatic observation (P/M-mode). Due to bad S.I.D. conditions usually corrections of the readings are necessary and can be performed by several published methods e.g. after Alman, and Billmeyer(1979).

Much better than direct measurement, it is to calculate the total spectral radiance factor for each S.I.D. wanted from the results of a two-monochromator measurement, where the luminescent specimen and the reference are irradiated and viewed monochromatically (M/M-mode). With this method all relevant information on a luminescent system, especially on three basic quantities can be obtained.

These three intrinsic quantities which describe the relevant optical properties of an opaque luminescent system completely are in the revised notation by Gundlach (1986):

Firstly, the *external spectral radiant efficiency* or *spectral radiant yield*

$$q(\mu) = \frac{M(\mu)}{E_\mu} \qquad (4)$$

It is defined as a ratio of emitted to absorbed energy. $M(\mu)$, the radiant exitance is the surface density of the exitant radiation due to luminescence. This is caused by E_μ, the spectral concentration of the surface density of the incident radiation per unit waveband at wavelength μ in the range of excitation.

Secondly, the *spectral luminescence distribution factor*

$$\varepsilon_\mu(\lambda) = \frac{[M_\lambda]_L}{\int_\lambda [M_\lambda]_L d\lambda} \qquad (5)$$

which is defined as the spectral concentration of the surface density of the luminesced radiation per unit waveband at wavelength λ divided by the integral of the luminesced radiation which is equal to $M(\mu)$ in Eq.(4). The spectral luminescence distribution always depends on the wavelength of excitation μ. The integration of $\varepsilon_\mu(\lambda)$ over the wavelengths of emission gives the unit.

Thirdly, the *diffuse spectral reflectance*

$$\rho(\lambda) = \frac{[M_\lambda]_S}{E_\lambda} \tag{6}$$

defined as the ratio of the spectral radiant exitance due to reflection to the incident spectral irradiance of the specimen. This quantity is also known as *true spectral reflectance* of a sample.

If these basic quantities are known, the reflected and luminesced spectral radiance factor can be calculated.

The *reflected radiance factor* indicated by the subscript S

$$\beta_S(\lambda) = \frac{\pi^{-1} E_\lambda \rho_S(\lambda)}{\pi^{-1} E_\lambda \rho_W(\lambda)} \tag{7}$$

is calculated from the true spectral reflectance of the specimen S and the reference W as the ratio of spectral radiances generated by identical conditions of irradiation and viewing.

From the spectral radiant yield (Eq.4) and the spectral luminescence distribution factor (Eq.5) the *luminesced radiance factor*

$$[\beta_L(\lambda)]_N = \frac{\pi^{-1} \int_\mu [E_\mu]_N q(\mu) \varepsilon_\mu(\lambda) d\mu}{\pi^{-1} [E_\lambda]_N \rho_W(\lambda)} \tag{8}$$

can be calculated for a given S.I.D. denoted N. E_μ and E_λ are the irradiances of the wanted S.I.D. at the wavelength of excitation μ respectively of viewing λ.

With the definition of a *luminesced spectral radiance factor* a problem can arise. The law of Stokes generally predicts a wavelength shift between excitation and emission. If the specimen is excited by a S.I.D. which causes relatively little or no irradiance on the reference in the emission range of the specimen then by dividing through zero irradance the *luminesced spectral radiance factor* must increase ad infinitum per definition. An experiment can show that this can not be true. If a red luminescent specimen is excited by a low pressure sodium lamp then only a rather week orange-red luminescence can be seen beside the yellow-white reflection of the reference. To measure such a combination with a one-monochromator set up an auxiliary measurement with a standard lamp is necessary or an absolute detector must be used. The discrepancy is caused by the definition of a "*spectral*" luminesced radiance factor which can, but must not exist for each wavelength of emission. To avoid such problems by exciting chromatic luminescent specimen with non-continuous radiation sources like daylight type metal-halide lamps or FWA's with mere uv- radiation, it is always better not to define "spectral ratios" in the first step of luminescence colorimetry. It is always possible to perform all calculations with *radiances* in place of *radiance factors*, the integration steps included (Gundlach 1986). Here, for convenience we will stay with the spectral radiance factor.

For those which are interested in colorant formulation it is useful to split up the total spectral radiance factor into reflected and luminesced component. As shown, it is easy to do this with the two-monochromator method but it causes problems with one-monochromator measurements. Here the quantities can only be measured or calculated approximately from special one-monochromator measurements performimg luminescence weakening, luminescence killing, and measuring of the so-called *conventional reflectance* by monochromatic irradiation and polychromatic viewing of the specimen (M/P-mode). All these methods are wellknown for years and already described in books and state-of-the-art reports.

The reflection spectrometry of luminescent materials with references up to 1980 is discussed by Mielenz (1982) and up to 1979 by Grum, and Bartleson (1980). An actual survey of methods on measuring the color of opaque luminescent materials is given by McKinnon (1987).

Topics in luminescence colorimetry during the last decade

Blaise (1980) discussed the wellknown methods and problems of luminescence colorimetry and proposed an adjustment method to overcome the difficulties in practical realization of a sufficient spectral irradiance distribution (S.I.D.) corresponding to standard illuminant D65. As a primary source he proposed a short- arc xenon lamp which is optimal due to its sufficient content of uv- radiation. To get a first approximation to D65 a specially designed correction filter is used with this lamp. It is assumed that there are only small differences between the S.I.D. caused by the filtered xenon lamp and that of D65. So his conception is to correct the influence of those small differences by using additional sources of limited bandwidth. He recommended the use of seven correction sources over the visible range. These bandpass- sources should be realized by the original xenon lamp in combination with interference bandpasses.

The wanted S.I.D. of D65 is made up by a linear combinatiom of the S.I.D.s of these eight filtered xenon sources. This requires to find the coefficients for the linear combination of the resulting eight equations by mathematical treatment. Different algorithms can be used. The basic requirement is that the measurement with the special designed correction filter is the main measurement and must give the largest coefficient compared to the seven correction measurements in restricted ranges.

This proposed adjustment method was tested by Billmeyer, and Yuan Chen (1984). The results obtained were compared with results from other measurements. It was found, that the adjustment method reduced significantly the measured color difference of an orange specimen from 20.8, obtained with a poor simulator, to 1.2 CIELAB units with seven correction measurements but only four or three already gave acceptable results. Billmeyer and Yuan Chen stated that the most serious disadvantage of this method is its complexity and time-consuming nature.

Clarke, and McKinnon (1982) suggested another way to overcome the difficulties with standard illuminant D65. They propose to use interior daylight ID65 in industrial colorimetry of luminescent materials. This illuminant was already presented by Clarke on the 19th CIE- meeting in Kyoto (1979). It represents exterior daylight D65 attenuated by average window glas. The advantage of this illuminant will be, that for general industrial colorimetry a stable simple multicomponent filtered tungsten-halogen lamp is available. Because chromatic luminescent materials are overlayed commonly with uv- absorber it can be expected, that the missing uv- content of ID65 will cause no large errors. On the other hand measurements of FWA's will be more critical due to less excitation. To assess this the authors chose a Ciba-Geigy White Tile No 9 to be colorimetrically representative of a high-quality white paper. By own experience, this cannot be confirmed because measurements of optical brightened papers show that the curves of spectral quantum yields differs significantly from the relative stable Ciba-Geigy tiles just below 350 nm.

McKinnon (1983) described in detail the NPL luminescence spectrometer designed for two- monochromator measurements of opaque samples. To avoid the troublesome interactions of the passbands of the two monochromators, which causes the so-called bandwidth or slitwidth problem, the slits of the second or analyzing monochromator were maladjusted so that a trapezoidal passband was obtained which includes completely the ideal triangular shaped slitwidth-function of the first monochromator. Therefore no corrections with regard to the bandwidth problem were necessary. The idea was first published by Clarke (1975).

The bandwidth problems were also discussed by Minato, Nanjo, and Nayatani (1979). The authors defined it as a problem of the second or analyzing monochromator. The correction is done by the so-called *effective wavelength width* ΔM_{eff}. With equal bandwidth settings the effective wavelength width is estimated to be 3/2 the bandwidth of the second monochromator. The Japanese two-monochromator set up is using triangular shaped slit functions with both monochromators whereby the bandwidth of the analyzing monochromator is set much larger than those of the first one. A separation of reflected and luminesced component in the overlapping range is performed by Lagrangian interpolation of the emission curve.

Minato, Nanjo, and Nayatani (1983) described in detail the possible influence of polarization on the results of two-monochromator measurements of luminescent materials. With the Japanese two-monochromator set up the spectrometric errors in the reflected radiance factor are estimated to be not less than 1% at some wavelengths. On the other hand, the errors of the luminesced radiance factor are relativily small. The colorimetric errors are small at all and less than 1 CIELUV unit what can be accepted.

In 1985, Minato, Nanjo, and Nayatani (1985) published a paper on the two-monochromator method which was already published partly in Japanese in 1981. In the paper again the rather complex theory of the two-monochromator method including the influence of the slit-function and the estimation of accuracy were given. The latter is reduced to the estimation of the accuracy in calculating the total spectral radiance factor for available xenon- and tungsten-halogen-sources with known S.I.D.s. A set of chromatic luminescent specimens from green to red were measured with the Japanese two- monochromator set up and with the real sources too. The results obtained show that both methods are in very good agreement. The measured color differences are always below 1 CIELUV unit with the tungsten- halogen lamp and up to 1.4 with the xenon lamp. It can be expected that the accuracy in estimating the total spectral radiance factor for any radiation sources will be about 1%.

Gundlach, Mäder, and Hammer (1985) reported at the AIC Congress Color 85 in Monte Carlo on an internal intercomparison with glossy and non-glossy sets of luminescent and non-luminescent achromatic and chromatic specimen. The sets were measured with the two- monochromator set up of BAM in the consequent matrix mode and also with the sophisticated multichannel D65-simulator of BAM. It was pointed out that it should be possible to obtain color differences of less than 1 CIELAB unit when comparing both quite different methods. With the knowledge of today we can say that this statement is still valid because larger differences are mostly due to changes in the optical properties of the specimen e.g. decrease or increase (!) of the external quantum efficiency caused by degradation together with darkening or bleaching effects.

Gundlach (1985/86) described in German the theory of the consequent matrix version of the two-monochromator method for the colorimetry of opaque luminescent specimens as it is performed with the computer controlled two-monochromator spectrometer of BAM. With this automatic device all readings are done generally with stepwidths equal to bandwidths in a two- dimensional matrix of 10 (facultative 5) nm distance from 300 nm to 800 nm at the most. Because the bandwidth settings of both monochromators are constant and generally equal the wellknown bandwidth problem arises. It is caused by the fact that with equal wavelength settings the reflected portion is passing two monochromators with triangle shaped slit-functions, the luminesced portion only one. With constant excitation wavelength setting, three signals of the reflected component are obtained by stepping the analyzing wavelength. It is easy to show that under ideal conditions (no slope of the overall instrumental function) the three readings are theoretically constant and have a ratio of

$$1/6 : 2/3 : 1/6$$

The factor 2/3 is already known by its reverse ratio 3/2 defined by Minato et al.(1979) as *effective wavelength width* ΔM_{eff} with equal bandwidth settings of both monochromators. There the factor is seen to be a correction of the luminescent portion. This view does not match with the theory reported here.

Due to the slope of the reflection curve of the specimen and the transmission function of the instrument the factors 1/6 can change but the factor 2/3 remains constant if there is no unsteadiness in the range of twice the bandwidth. Apart from this the sum of the three readings always give the unit which corresponds with the complete signal. The splitting of the reflected signal causes a threefold diagonal in the matrix which is superimposed to the luminesced signal in the overlapping range. Nevertheless, it could be shown that in this range which may extend 100 nm if more than one luminescent compound is present, a definite splitting of the reflected and luminesced portion is possible without any interpolation only by halving the bandwidth of the exciting monochromator.

If the readings in the overlapping range are indicated by the subscript T and the readings with halve the bandwidth marked by ° additionally, then the reflection value R_S and the luminescence value R_L at equal wavelength settings is given in an abridged notation by

$$R_S = 24 R_T^{\circ} - 6 R_T \tag{9}$$

$$R_L = 5 R_T - 16 R_T^{\circ} \tag{10}$$

Because with bandwidth equal to stepwidth setting a threefold diagonal appears the readings at ± one stepwidth must also be corrected. If these readings are indicated by ± in brackets the purified readings of mere luminescence are

$$R_L(\pm) = R_T(\pm) - 1/12\,[R_S - R_S(\pm)] \tag{11}$$

R_S again is the reading at equal wavelength settings.

With the consequent matrix method it is useful to define a spectral quantity

$$\vartheta(\mu,\lambda) = q(\mu)\,\varepsilon_\mu(\lambda) \tag{12}$$

called *bispectral transition factor* which is as an intrinsic quantity of an opaque luminescent system as the true reflectance is. The bispectral transition factor is the product of the spectral radiant yield defined in Eq.(4) and the spectral luminescence distribution factor defined in Eq.(5). The bispectral transition factor describes the energie transition per unit waveband at a wavelength μ in the range of exitation to a wavelength λ in the range of luminescence. The bispectral transition factor is closely related to the *bispectral luminescent radiance factor*

$$\beta_{L\lambda}(\mu) = \left[\frac{\partial(\beta_L(\mu))}{\partial\lambda}\right]_\lambda \tag{13}$$

defined by Clarke (1975). In his words the bispectral luminescent radiance factor is the radiance per unit waveband at wavelength λ due to luminescence of the sample when irradiated at wavelength μ divided by the radiance of a perfect reflecting diffuser identically irradiated (at wavelength μ). By this definition the quantity is not intrinsic to the luminescent system because the factor depends on the geometrical conditions of irradiation and viewing contrary to the bispectral transition factor.

Grum (1982) discussed the need for luminescent standards. He stated that stability is the most important quality before absolute calibration, which is not required for industrial use. Stable opaque materials for front-surface irradiation are needed to create sets of FWA standards and chromatic luminescent standards too. Eight years later we can state that the requirements of the late Dr. Franc Grum are as actual as before. Up to now we have no stable sets of luminescent specimen for calibration purposes. Especially with the possibility of modern instruments to regulate the uv- content of their radiation sources for compensating ageing effects, it is necessary to control the S.I.D. as well in the exciting as in the evaluating range. That means that for FWA's the S.I.D. must be controlled between 300 nm and at least 450 nm. For chromatic luminescent specimen the range may start with 350 nm (due to the uv- absorber) but will go up to 780 nm. Another important demand to luminescence standards is that the characterictic spectral quantities, esspecially the spectral radiant yields, closely meet those of the samples to be measured. Here can be confirmed again that by experience the rather stable Ciba- Geigy plastics have due to their stability quite other excitation curves than optical brightened papers or textiles. We would like to have sets of stable blue-white luminescent materials with excitation curves like the theoretical ones published in CIE Publication No 51 and supplemented by green to red luminescent standards. The chromatic luminescent standards may meet requirements of international safety colors. To realize such defined colors knowledge in colorant formulation of luminescent materials is needed.

Döring (1986) confirmed that colorant formulation for luminescent colors is much more difficult than for nonluminescent ones because reflection, emission and e.g. quenching effects must be taken in account. So he proposed a simplified match formulation which tries to minimize the differences in integral tristimulus values and not in spectral quantities. He showed that very sufficient results were obtained around an initial color.

Bonham (1986) investigated anew the well-established Kubelka-Munk theory with regard to colorant formulation of chromatic luminescent and nonluminescent dyes in paper. Beside K and S, the absorptic respectively the scattering coefficient of the classical K-M theory the quantum yields of the luminescent systems are needed. For convenience of mathematical treatment it is assumed that absorption and emission do not overlap (and that the emission spectra do not depend on the wavelength of ecxitation). Nevertheless, as the author stated the extended theory has already led to a practical color-prediction system.

Billmeyer (1988) published the results of a CIE intercomparison of measurements of the (total) spectral radiance factor of luminescent specimen. Five sets of seven luminescent specimen with two white and five chromatic colors were measured with D65 simulators by four laboratories. The results were corrected in view of standard illuminant D65. It is surprising to read that the results of the only two- monochromator- measurement could not be included into the mean due to quite different results compared to the others. Unfortunately no analysis of the reasons for the discrepancies is given. The mean of the measured color differences is about 3 CIELAB units what seems to be the state-of-the-art. The mean of the results of a Japanese intercomparison is somewhat lower. It is assumed that the level of 1 CIELAB unit level can only be reached in standardizing laboratories.

Conclusion

In the last decade problems dealing with the two- monochromator method were recognized, understood and clearly stated. Several proposals were made to overcome them. This method will become in future the standard method for certifying sets of luminescent standards which are needed in industrial colorimetry of luminescent materials.

In industry measurements of luminescent materials will be performed in near future only with one- monochromator instruments or tristimulus colorimeters. The progress of the last decade shows that the results can be improved by corrections but only approximate results will be obtained. This is because all correction methods predict the independence of the luminesced radiation by the wavelength of excitation which is not given. The best way of correction will be to calibrate a spectrometer with a certified luminescent working standard as it must be already done with a tristimulus colorimeter. This is necessary in particular with modern instruments which allow to regulate the uv-content of their radiation sources.

Because there will be a need for certified luminescent standards the development of stable luminescent systems must be forced. This can only be done in close collaboration of manufacturers of luminescent pigments and standardizing laboratories.

New problems in colorimetry of luminescent and also nonluminescent specimens have already arisen by exciting specimens with short-time high-energy sources like xenon flashs. Unusual triplet states may cause unusual absorptions and emissions. Array detectors, used in modern spectrometers may cause additional problems by delay times. So in future there will be work enough in the field of photoluminescence of surface colors and their measurement.

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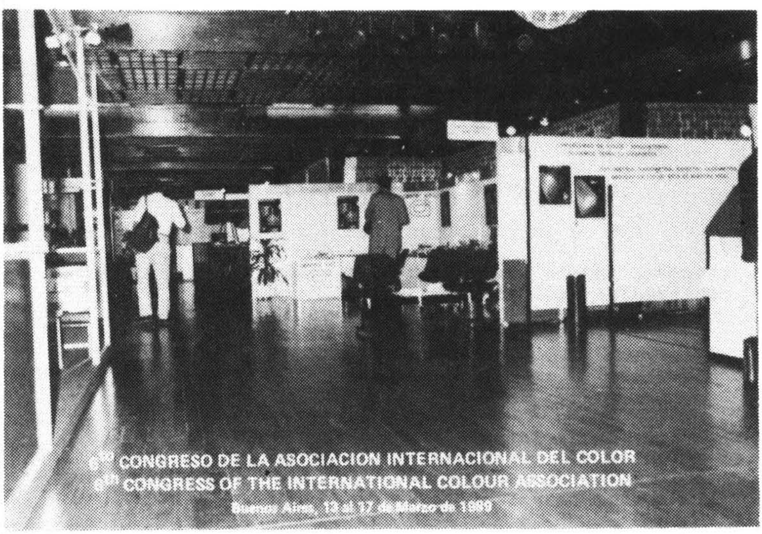
Invited Lecture:
Mr. J. Gluskey (Argentina).



Expocolor 89:
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COLOUR IN ARCHITECTURE IN LATINAMERICA

Those who remember the neoplasticists statement schemes, with Stijil's Group in front, and, of course, Mondrian, should take into consideration his objective position of obtaining an architecture, which should be the synthesis of the three visual arts: the architecture, the paiting and the sculpture.

For the same reason, the purity of the shapes, would only express the concrete, and faces, in some way, the physical constants of the world, where it results impossible to exclude the light.

Architecture it is not like a painting, an art of the colour. Form Lascaux to nowadays, the painting is defined by the colour and the architecture. It is the art of the space.

The painting can be analyzed according to different chromatic components and supply valid distinctions capable to fulfill ourselves in the 4th. century period or in those unconventionalists of the 20th. century. The architecture does not have any approximation that starts from colour.

Space art as from the rite or from the demarcation as Fosfles desires and as it is no extended vision has been obtained with the same generosity, as painting was treated, because the painting is the art of colour, has not impede us from analyzing its space.

What does hinder us to analyze colour in the architecture not having to remote the great civilizations we have at hand where numerous examples of potential architecture in its urbean insertion are in colour?

In Buenos Aires -the so called "Boca"-, expression of famous leashholds who defined substantial areas of the city from the 19th. century -or those recycled at San Telmo-, representative of a certain intelectual class covered by a post-mortem aestheticism are characterized by an urban scene where you can appreciate the lack of prejudices in the use of colour, not taking into account the numerous structures created by the modern industry: deposits, destilleries, supermarkets or big living complexes, where colour is used to increase its language.

We believe this is a prejuice, Though the full aknoledgement that architecture is one of the visual arts, their traditional analysis tends, dangerously, to reduce it to its functional concept.

It is not ths aim of this paper to analyze the arguments against or in favour of the rationalism and architectural functionalism. But it is convenient to remember that, Loor, Bahrens, Pere, Gropius and Le Corbusier (Rational-functional thought), as Wright (organic), assured their independence from the past forms of building, considering tha building elements, not as an end, but as a way to harmonize the technical aesthetics.

There is a certain marginated factor of colour in architecture. It is the spontaneous architecture. The architecture with no architects, that replies to the complex strengths or powers, to echonomical factors: political, ethnic, historic or magic. Is there, where man does what has at hand, covering his necessities and adds his creative and poetic impulse.

We think that it is unnecessary to clear up that we understand, the meaning of architecture is that "thing" that adds artificial pictoric elements to its structures: painting or vitraux designed by great artists, ceramics, mosaics, etc. The architecture merges its components with colour and adapts it as a part of an aesthetic expression. The synthesis of the three arts looked by the neo-pasticists, will not result from the addition of the paintings and sculptures, but from the integral concept of space form and colour.

So, it is very interesting to refer, particularly, to the work of two latinamerican architectures, where the colour has an essential role in its designs. One of them is the Mexican teacher/ guide Luis Barragan and the other is the Brazilian Eolor Maia.

Luis Barragan, born in 1902, is a respected and recognized figure in his country. The architectural elements covered up by Barragan are deeply rooted in the cultural and religious traditions of his country. His micro-compositions, his poetic landscape paints, take care, primarily, of the sky brigthness, the strenght of the solar rays and the use, for socio-echonomical reasons, of simple materials and elemental constructive techniques, which saves the emotion present in the ancient culture.

Several circumstances have contributed that Barragan developed this poetic world in his practice. The fundamental is the impact of the metaphysical paints of De Chirico, Matias Goeritz's (with whom he worked in the creation of the Torres de la Ciudad, which are risen as symbols in the north access of the Capital) sculptures, his journey to Europa and Marroco at the end of the 20's which showed him the spaces and the magic treatment of gardens and water fountais of Alhambra, and particularly, the so-called "ranchos" and monastery made by the popular mexican architecture. These backgrounds integrated show, through his works, the continuity of a architectural tradition which includes colour as one of the most relevant elements.

His own home is an example of this poetry, going around it, catching the spaces in its balconies, its gardens, its interior its envolving chromatism, is like going through a tri-dimensional space on one of the italian metaphysic paintings.

Barragan's architecture cannot be understood through representations (plants or sights). It is a simple but refined architecture, where it is impossible to detect any kind of rules nor generalizing systems, each work has its complete identity. The value of the empty spaces as negative volumens, have so much weight as what it is built. Upon the creation of these elements, the use of colour, has an fundamental objective as it is expressed by Barragan: "Man should be in peace with himself".

The first step of his work is developed in Guadalajara, where he reveals his fascination for the mediterranean architecture. From this moment, 1927, onwards, there are a number of residences that explains the application os his sensitive use of colour through the gardens and yards.

In 1940 he starts as a landscape painter. His more relevant work is "El Pedregal", a natural and wild landscape, with volcanic formations and strange vegetation, transforming a park into a residential area "to reconcile man with nature".

Paths and stairs curved into the rock, swiming pools with moving waters, and stoned walls with a carefully selected colour give the impression that both, architecture and nature, are designed simultaneously.

"Las Arboledas" (1958-61), "Los Clubes" (1963-64), and "San Cristobal" (1967-68) have a common factor: the creation of suitable spaces for equestrian activities, with residential sub-divisions for stables, horse-riders, swiming pools and ponds. The continuous presence of water, allows him the use of its surface as a mirror of nature and of the built parts, as well as the sound produced by the running waters.

Barragan works with the conviction that "the architecture function should be used to solve material's problems not forgeting the spiritual necessities of mankind".

Barragan most ambitious project was the creation of a town's micro-model which he knew from childhood. His own testimony reveals his spirit in the search of the emotions: "My childhood memories, are related with the rancho that my family owned in La Manzanilla, it was a town with hills, settled up by houses with tiles in its roofs and enormous eaves that served as protection against the heavy rainings of that zone, for pedestrians. Even earth colour was interesant. In this town the system for water distribution were made with big excavated tree trunks like spouts, mounted on hooks of about 5 meters high, which passed over the houses. This aqueduct passed through the town reaching the yards, where the water was collected in big stone fountains. In the yards were the stables, cow and chicken, all together. Outside, in the street there were iron rings to tie up horses. The trunks covered with rust and dripping water all over the town, gave a colour and a scenery of a fairy tale. No photographs, only located in the memory"

Other latinoamerican example is the work done by Eolo Maia from Minas Gerais, who discovered the architecture and started to feel it on the Ouro Preto streets. The old city, beautiful, with its spaces, its colours, and its characters, influenced his childhood and took him to the Architecture School of Minas Gerais, where he obtained, in 1971, his master degree.

He is a partisan of the architecture. This Eolo Maia's characterization is originated upon his radical nonconformity and his heroic and cheerful belligerency, synthesis of his thoughts and his worries upon the social situation. Evidently, he fights through the architecture, for a more human and more worthy life. But he does not believe that to confirm these values, he must first to deny them, using an esterile violence. The only way to fight for freedom is to practice it.

More than a century ago. Einstein wrote to his friend Freud, that the intelectuals do not practice a direct influence over the history, because the power usually belongs to the violent and irresponsable people. Fortunately, in the architecture, it happens in another way for the authors, no matter how difficult the situation could be, they have a cultural continuity, they live with it and enrich it through their work last longer than tyranies.

Eolo Maia considers his way through the Architecture School as a period of academic and ridiculuos learning. Courses, with some rare exemptions, were completely out of the Brazilian reality. The certificate helped him to put him into proffesional practice, but he already breathed it, sweated it and lived with it.

In a business, like his, creativity is essential, and demands to be corageous, to be in love with your job, to be anxious for adventures and the unknown.

Eolo states: "Reason is static, adventure is dynamic". When he was asked to give the names of three architects who have influenced him, he listed Oscar Niemeyer, Louis Khan and Gaudi.

Naturally he only knew Niemeyer. He was fascinated by the work of Pampulha, the different quartier that dreamed Juscelino Kubischek for Belo Horizonte, the capital of its State. With Pampulha reacting against the functionalism, Niemeyer inaugurated the Brazilian architecture on a free and creative style which today is distinguishable and finished with the construction of Brasilia, the Federal District, projected by Lucio Costa.

Curiously, though the exuberance of his temper, Eolo maintains a rigorous artistic and ideological unity on his ideas, founded upon the landscape observance, surroundings, the urban developments and the country's heritage. And it is here where he rescues the culture of colour, so present in his compatriots.

The new Brazilian generation make architecture facing each subject as a unique and non-repeatible situation, investigating tenacitily the possibilities of dialectic interaction between shapes and ideas. The proposals of his productions have constant demands of his aesthetic values, incorporating the culture ambiance to the architecture, though the production is a carefully craftsmanship work process. These young architects work in small offices, with low echonomical means and always threathened by the inflation and debts, and one of the less used elements, is colour.

This group is formed by Maria Josefina Vasconcellos, Sylvio Emrich de Podesta, Marcio Lima, Flavio Grillo and others, which, sometime, work individually or, in other opportunities, in groups.

Eolo's first work is Marco Tadeu's residence in 1966-67. With a defined brute rationalist character, but already in Renam Alvin's and Sollero's, in 1971, the spatial organization shows a theoretical especulation which is opposed purpously to plants and walls.

The volumetric and chromatic treatment of walls, vertical circulating areas and installations ideas which recognizes antecedents in the Archigram (Peter Cook) English group proposals, and the thoughts and designs of the Pop-Art painters, which also are born in London and dialogue with the architects of the Contemporary Art Institute. There, the english theorist Lawrence Alloway (today lives in New York) set the term "Pop-Art", which obviously means Popular Art.

On more recent projects we can appreciate that the volumetric conformation is simplified, and the walls treatment with vivid colours applied on full smooth surfaces, emphatizes the architecture character as scenery of the landscape.

Upon social buildings, it is really outstanding, how he can innovate new proposals and experiments new formal codes through the emphasis of wall colouring, taking into consideration the limited echonomical situation. On other programmes ellaborated later, it is important to mention the Barco do Sul joint ownership, projected in 1976-77 with Marcio Lima. In this building, the spatial researches, formal and constructive, begun from the construction of Tingua, reaches a synthesis particularly important. The expresion is brutalist, but the volumetric treatment implies a direct revalorization of the curved forms characteristic of the Minas' Churches, particularly that of the Rosario, in Ouro Preto.

The Hotel Verdes Mares, projected by Eolo in 1976-77, represents a clair reference to the famous teacher of northamerican architecture, Louis Kahn, proposals, so much in special terms, as in the constructive language; though colour compensates certain external monumentality, which results from the implanted volumen in function of the available area dimensions.

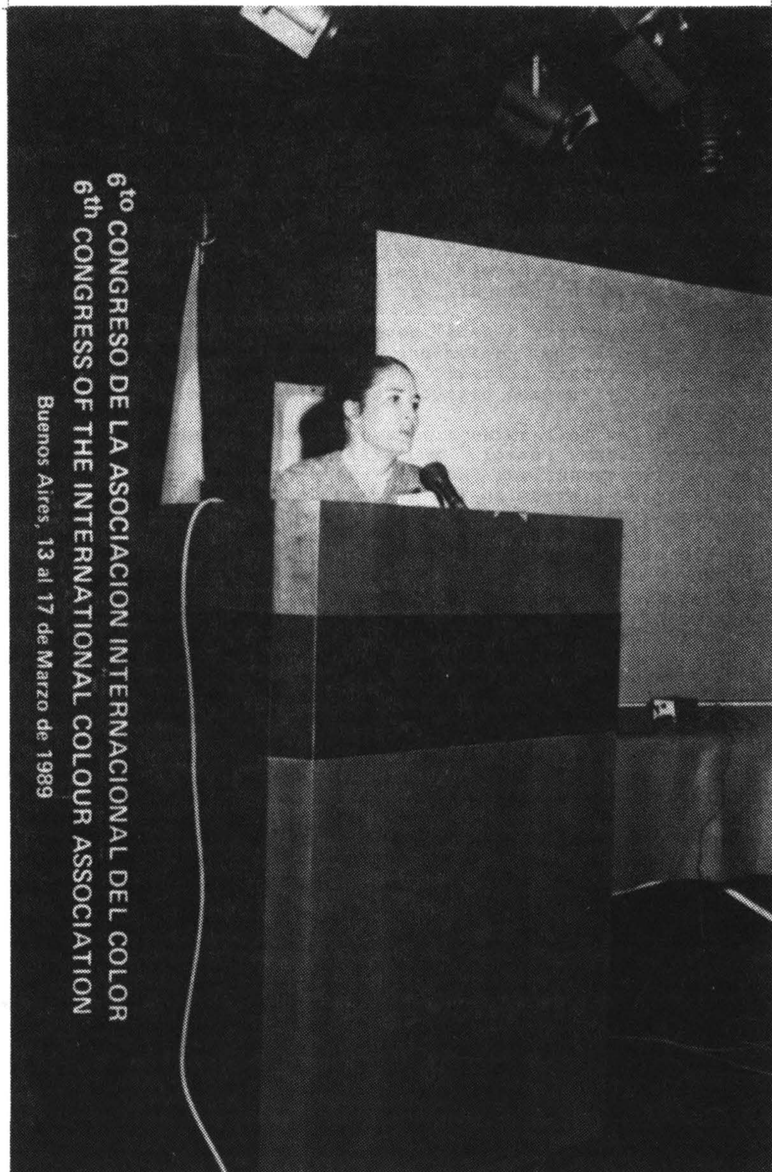
Perhaps, the more characteristic of the Maia's thoughts and style, will be the restoration of the ranch Pe de Morro, in Ouro Branco and that of the near Santana Chapel.

In this region, he explains, there are several historic farms. The majority belongs to the 18th. century. At the foot of the Ouro Branco hills passed the royal road which connected Ouro Preto with the Litoral. Still, some paths of this road with its stone Roman Arc bridges, exist.

One of them served as traveller's Inn, some of them were gold smugglers, which come down from the hills passing through the small town of Itatiaia. Which give the name to the town: "At the hills foot". It was built in two different periods. In the 18th.

century its stone walls were risen; in the middle of the 19th. century some small modifications were made. The purpose was to enable it to be used as a guest house. The new constructions did not injured its original characteristics.

"We think that this work was the most complete we have the opportunity to do" write Eolo and Maria Josefina, his wife. "We try to interpretate humbly the lessons given by this time builders. It was a careful, slow, and gratifying restoration".



Invited Lecture:
Miss Nancy Howard (U.S.A.).

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COLOR EDUCATION: PITFALLS AND PROGRESS

Only limited progress has been made toward improving color education on an international scale during the last decade. Most color educators work in a non-collaborative setting, on a limited budget, with limited time and resources in the classroom. The very nature of the subject demands an interdisciplinary approach, but in most classrooms art and science have not resolved their differences.

Isolation

Many color educators around the world work in isolation, separated from colleagues by distance or discipline. Few are able to devote more than a few hours to the teaching of color. Precious classroom time is often lost when misinformation must be corrected before new ideas are introduced (e.g. yellow and blue don't always make green). Frequently the interdisciplinary nature of the subject matter relegates color to brief, disjointed units taught in several different courses (e.g. art/design or physics/general science).

Shortage of Resources and Time

Those who attempt to bridge the chasm between art and science are faced with the daunting task of dealing with conflicting terminology and concepts (e.g. light<--bright-->saturated) without adequate knowledge or resources. Many color educators have only the limited knowledge, much of which is superficial or outdated, gained when they were students from their own teachers. In their isolation, they lack the motivation or opportunity to gain information and materials to help. Groups such as Nimon Shikisai Kyoiku Kenkyukai in Japan, Centre Francais de la Couleur in France, Inter-Society Color Council in the United States, and most recently Universita Di Padova in Italy attempt to bridge this gap.

Educational Materials

A limited number of countries have been able to coordinate the production of materials for color education. Usually this is only possible when recommended curricula have been established. There is, however, a growing awareness by companies that manufacture books, color order systems, color filters, artist supplies, etc. that the market will expand if they address the educational needs of customers as well as their material needs.

These efforts could be greatly expanded if organizations responsible for color education could become involved in the preparation of educational materials. A few movies, slide collections, and audio courses have been prepared by individuals in a number of different countries. They have addressed the needs of a limited clientele and frequently are unused because of high cost or poor distribution.

Guidelines for Color Education

Ministries of Education, or their equivalent, in a few countries have set guidelines for primary, secondary and high schools lessons. Bulgaria, Japan, Hungary and the Netherlands provide teaching plans which could, with some modification, provide important guidelines for an international standard for color education for children 6-18 years old.

Many would see this step as introducing unnecessary control and hindering creative ideas in both teacher and student. Without such commonality, however, there can never be any progress made in providing necessary materials and resources at reasonable cost to teachers. All too often, manufacturers of teaching materials or designers of classrooms rely on vibrant combinations of primary hues and are ignorant of the potential for reinforcing aspects of color education.

The Tenuous Link Between Art and Science

Paints and colored paper are usually a student's introduction to color. The link between color and art/handicrafts is usually reinforced throughout primary and secondary school. The study of color is confined to art/design problems by the teacher's curriculum and ultimately is bound there in the mind of the student. The link between color and science is usually not introduced until a student has reached high school (e.g. light/physics, vision/biology, etc.). By the time a student has reached college or university the interdisciplinary link between art and science is destroyed and the student is forced to specialize in a single discipline, presented as an either/or decision.

The daunting task of learning a new discipline stiffles commitment to the interdisciplinary approach to teaching. Many artists will claim that creativity, spontaneity, and imagination are forfeited under the influences of scientific thought. Many scientists will claim that artists who do not understand the scientific principles governing perception and production of color are not able to control its effects. Is is difficult to convince anyone, artist and scientist alike, that the link must exist. We must teach or colleagues as well as our children.

Symposiums

An effort is being made through a limited number of organizations to bring together teachers, especially those in the lower grades, for symposiums and workshops that concentrate on methodology and available resources for teaching color. Sadly, it is all too often the dedication and commitment of one or two individuals that make such meetings possible, thus reducing the frequency of such worthwhile endeavors.

This should not discourage other groups from planning such training sessions. The synergistic effects of a well organized meeting can generate much needed interest in color education. Since schools and colleges seldom see color as a unique discipline, time and travel funds are frequently not available to teachers. Local and national recognition of the importance of color education is necessary if these groups hope to expand their influence.

The 1993 AIC Congress is being coordinated by the Hungarian National Colour Committee in Budapest. Necessary steps should be taken now by each of you to ensure adequate representation by color educators not already associated with the AIC.

AIC Color Education Study Group

The AIC Color Education Study Group has recently begun reorganization. The past few years have witnessed periods of inactivity and few materials have been produced that have enhanced color education. Sadly, it is the nature of color educators to be under funded and over extended. Developmental work on new on projects depends on academic calendars and an ever changing population of students. Membership of the Study Group is hard to define and as a consequence it is a difficult to maintain a continuous effort toward predetermined goals. Sadly, many educators can not participate in international congresses, but it is hoped that a self-sustaining network of active members can produce ideas and materials which can benefit color education on an international scale.

I gratefully acknowledge the assistance of my colleagues for their assistance in collecting material for this paper and for their suggestions for the reorganization of the Study Group. I am encouraged by the number of countries that have participated and am attempting to expand repesentation. Many of those listed have agreed to coordinate their country's contribution to the Study Group. Others have been kind enough to suggest others who would be better suited to this task.

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Paris, FRANCE
&
Jose M. ARTIGAS
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HONG KONG

Diana CHRISTOVA
Sofia, BULGARIA

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Gunnar TONNQUIST
Stockholm, SWEDEN

Urban WILLIAMSON
Sandefjord, NORWAY

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I would like to close with a personal note. Many of you were at the Salamanca color education meeting. It was at that meeting that I announced my own efforts to launch an undergraduate program in Color Science at the Philadelphia College of Textiles and Science. Today I sadly announce its demise. Four years of low enrollment in the program and changing departmental priorities have convinced me of the wisdom of withdrawing the color major. I have plans for a new experiment. Not surprisingly, many of the ideas I have discussed today are to be incorporated into a new program...and the struggle goes on.

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TELEVISION AND COLOUR REPRODUCTION

Abstract

The analysis and synthesis of a scene to produce a colour television picture is considered after an initial statement of the aims of a colour reproduction system. Use of 3x3 matrixing of the linear red, green and blue signals generated by the three camera tubes enables improved colour rendering to be achieved. The means whereby a colour transmission service could be drafted on to an existing black-and-white television system are described. The use of narrow-band colouring signals added to a high bandwidth luminance signal is seen to make use of some properties of colour vision (colour in fine detail). A brief description of elements used in achieving analysis and synthesis includes the spectral power distributions of the phosphors used in suceeding generations of colour display tubes. Factors modifying a simplistic approach to colour television reproduction are included in a mathematical model giving a quantitaive assessment. A final section deals with with future trends in television including the introduction of systems with appreciably improved definition via satellite transmissions.

TELEVISION AND COLOUR REPRODUCTION

W. N. SPROSON

1 INTRODUCTION

The general aim of any colour reproduction system is to produce a picture which approximates reasonably closely to the original. Precise similiarity may not be possible because of technical limitations of the processes involved and there are some occasions when it is not necessary or even desirable. In scientific and medical applications, for example, accuracy of reproduction is usually the aim but this may not apply in other fields. The subject of colour reproduction is not entirely straightforward for a number of reasons. Usually a reproduction in television or photography is concerned with a large three-dimensional original scene which, because of technical limitations, must be reduced to a relatively small two-dimensional representation. Cine projection (either in television or photography) may overcome the problem of size but this does not apply in domestic television reception.

Television is limited in the luminance of the reproduction to about $100cd/m^2$, particularly in Europe, but the original scene may have been illuminated by bright sunlight or daylight. Further the white balance point of a television display is frequently different to the illumination of the original scene.

The dim surroundings in which television is often viewed also has an effect on the perceived colour both in television and in photographic projection.

Thus it may be seen that an aim-point of colorimetric accuracy in the sense of the same chromaticity coordinates of corresponding areas in the original scene and its reproduction will probably require some modification even in the case where the scene illumination is identical with the white balance point of colour television receivers and monitors. Most frequently there is need for chromatic adaptation as well as illuminance adaptation.

Hunt (1970) has described six kinds of colour reproduction. Some do not apply to television but it is convenient to list them all for completeness.

(i) spectral colour reproduction: this involves a spectral match between the original object and its reproduction i.e. identity of spectral reflexion curve for a print or spectral power distribution (spd) in the case of television. It does not apply to television but it would be a desirable objective in a mail order catalogue.

(ii)colorimetric colour reproduction: in this case the original and reproduction have the same u´v´ chromaticity coordinates and the same luminance with respect to white. This can apply to television if the original and reproduction have the same white point.

(iii) exact colour reproduction: this describes colour reproduction in which not only are the u′v′ coordinates of the original and reproduction the same but the same absolute luminances also apply. In general, colour television cannot achieve this kind of colour reproduction because flicker limits the luminance of the displayed picture, particularly in Europe.

(iv)equivalent colour reproduction: this allows for different white points in the original and reproduction as well as differences in illuminance and type of surround. The reproduction under its conditions of viewing should give rise to the same appearance as the original under its conditions of viewing

(v)corresponding colour reproduction eliminates the effects due to differences in illuminance.Thus the reproduction under its conditions of viewing is intended to be identical to the original if it were illuminated at the same level as the reproduction.

(vi)preferred colour reproduction departs from the above five categories in an attempt to produce a result more pleasing to the customer.

2 ANALYSIS OF THE COLOUR SCENE

Because of the trichromatic nature of human colour vision it is unnecessary to reproduce the spectral distribution of each picture element in the original, wavelength by wavelength. For the colour normal observer, it is full and sufficient for the analysis process to produce red, green and blue signals which match the original: this is the basis of almost all colour

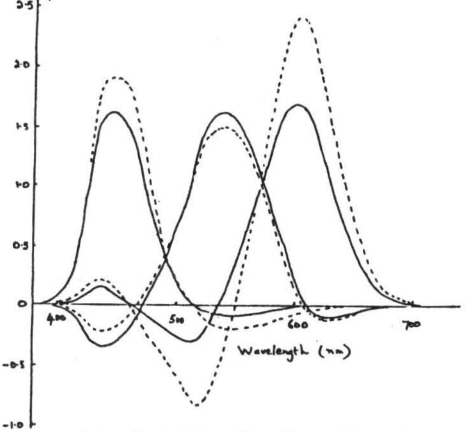


fig 1 Ideal Analysis Curves for NTSC primaries (solid lines) and PAL (dashed lines)

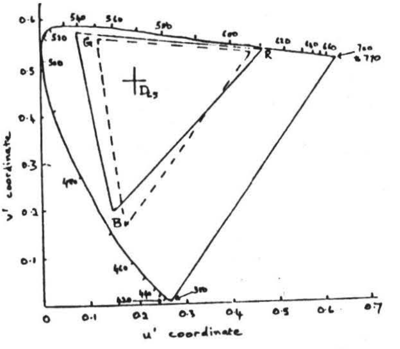


Fig 2 Colour gamuts given by the phosphor primaries: solid line NTSC, dashed line PAL

reproduction systems (an interesting exception is the Lipmann process which does give a wavelength by wavelength match by building a standing wave interference pattern in a very fine grain emulsion, but this method has some very severe limitations and is not used commercially).

Provided that the chromaticities of the reproduction primaries are known, it is relatively easy to deduce the mixture curves for the red, green and blue responses to reproduce the original colour by additive mixture. All domestic display devices in colour television use additive mixture and this proceedure gives ideal analysis curves. These are illustrated in fig 1 for the two sets of primaries in use viz. NTSC and PAL. NTSC (National Television Systems Committee) is the American system which pioneered colour television, PAL (Phase Alternate Line)is used over a large part of Europe. Apart from electronic system differences, it uses different phosphor primaries. The French SECAM system uses the European primaries.

It will be observed that parts of the analysis curves are negative, more so in the case of PAL than NTSC. This difference is a direct consequence of the saturation of the primaries e.g. the NTSC red primary is on the spectrum locus, the red PAL primary is slightly desaturated (see fig 2). For correct colour reproduction the negative lobes are essential for reproduction within the triangle given by the display primaries: they should not be interpreted as attempts to provide negative stimuli to give colours outside the triangle given by the phosphor primaries.

The most important parameters of the two sets of analysis curves are summarised in Table 1: they are the peak wavelengths, the wavelengths of blue-green and green-red positive cross overs and the principal negative sensitivities. The similarity of the major positive lobes meant that in the early colour cameras (using image orthicon camera tubes) it was not essential to match the system to the phosphor primaries. A slight narrowing of the sensitivity curves was helpful in reducing desaturation of the most saturated colours.

TABLE 1 Comparison of Ideal Analysis for Two Sets of Primaries

Primaries	Wavelengths of peaks			Positive Crossovers				Principal Negative Sensitivities					
	nm	nm	nm	nm	Amplitude	nm	Amplitude	nm	Amplitude	nm	Amplitude	nm	Amplitude
NTSC	603	534	452	492	0.042	572	0.095	512	-0.032	550	-0.090	444	-0.034
PAL	604	535	452	492	0.043	570	0.092	520	-0.084	550	-0.190	443	-0.024

Since the invention of the lead oxide type of tube it has been practicable to use 3x3 linear matrixing of the camera signals (before gamma correction) to implement negative sensitivities. This has resulted in appreciably better colour rendering (fig 3).

The properties of the lead oxide tub which were and continue to be most important in this respect are (1) linear output in the sense of signal current as a function of incident light flux and (2) a signal-to-noise ratio in excess of 50db which permits signals to be subtracted without an undue increase in noise level. The chromatic performance shown in fig 3 derives from a camera with spectral sensitivities shown in fig 4 together with a 3x3 linear matrix (eq 1) to produce the set of spectral sensitivities in fig 5. It will be noticed that there is a reasonably close similarity between the ideal analysis and that achieved by matrixing, although there are some spectral regions where the fit is not good. This set of curves (figs 4 & 5) is similar to practical examples of three-tube cameras with tubes typical of the earlier lead oxide type which had no sensitivity

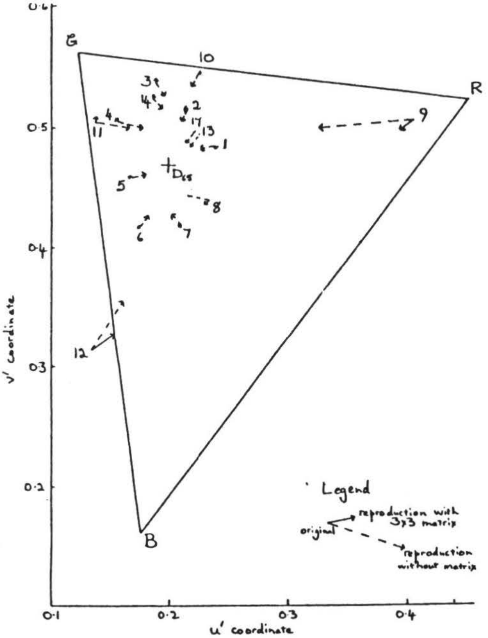


Fig 3. Accuracy of reproduction of hypothetical camera with responses given in fig 4. The triangle RGB gives the limits of colours possible with PAL System I phosphors.

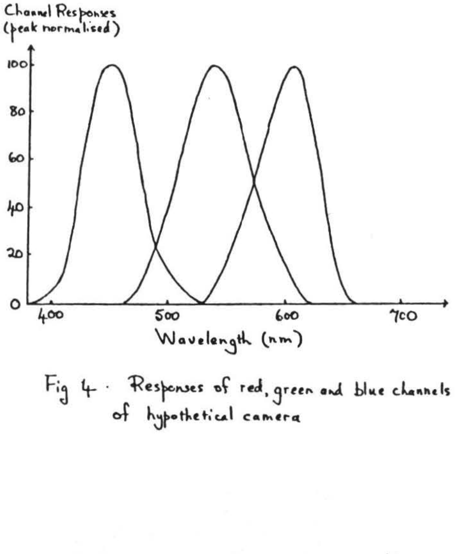


Fig 4. Responses of red, green and blue channels of hypothetical camera

in the far-red i.e. beyond 660nm. It is, in fact, an hypothetical set of sensitivity curves proposed by the Television Working Party of SC-3.2 (Illumination for Colour Reproduction).

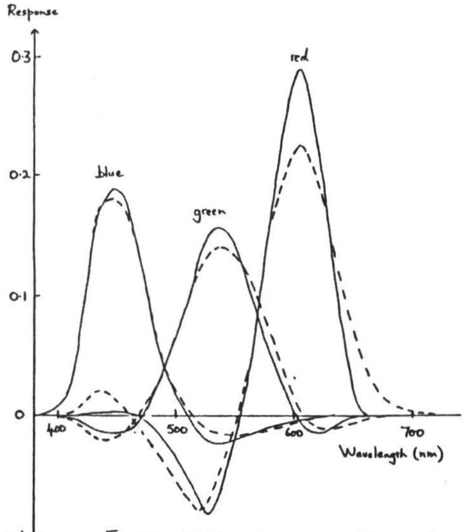


Fig 5 Solid lines: effective responses of hypothetical camera (fig 4.) with addition of matrix (eq 1) Dashed line: ideal responses. For both cases the ordinate scale has been adjusted so that each channel gives unity output in illuminant D_{65}. Responses shown are to equi-energy illuminant.

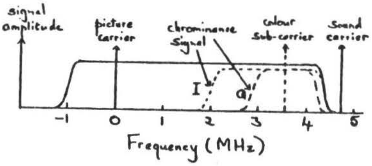


Fig 6. Spectrum of the radiated signal (NTSC)

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix}_{output} = \begin{bmatrix} 1.628 & -0.640 & 0.012 \\ -0.116 & 1.204 & -0.089 \\ -0.008 & -0.117 & 1.185 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}_{input} \quad --- (1)$$

3 TELEVISION SYSTEM CONSIDERATIONS

Colour television had to be designed to fit in with existing black & white transmission systems. A new colour-only system demanding completely new equipment and extra broadcast frequency allocations was not considered feasible. These considerations come under the heading of compatibility, which implies that a colour transmission shall be capable of giving pictures on a black & white receiver and a black & white transmission shall produce an acceptable picture on a colour receiver (reverse compatibility). Examination of the frequency spectrum of a television signal (Fourier transform of the waveform) shows that it consists of a series of lines separated by the line-scan frequency. This implies the possibility of inserting additional signals in the gaps between the spectral lines (15kHz apart). This was first achieved in the NTSC system where colour information was inserted on a sub-carrier at a half-line off-set of a multiple of the line scan frequency. The detailed considerations of how and why this was done are not directly relevent to a paper primarily on colorimetry. But an important colorimetric aspect is the way in which the colour information describing a picture (originally generated as R G B video signals) can be transformed very profitably into a luminance signal and two colour-difference signals. The luminance information is needed for both black and white receivers and colour receivers and requires a wide bandwidth to give good definition. The colour difference signals, in principle, carry no luminance information and do not generally require wide bandwidth. The effect of decoding the luminance and colour difference signals in a colour receiver is to produce a colour picture with good definition in spite of the low bandwidth colour signals. Thus large areas in the original picture are reproduced correctly although the fine detail at transitions from one colour to another suffer some loss.

When colour television reproduces small areas (of the order of a few picture elements) then the colorimetry is far from precise. In this, however, it is intended to resemble the behaviour of the eye. Konig in 1894 found that the eye becomes dichromatic for small areas of appreciably less than 1^{o} angular subtense. Fifty years later Willmer and Wright (1945) made further investigations confirming and extending the original discovery. Two primaries are sufficient to match the complete range of spectrum colours. Thus the spectrum reduces to a line from orange to cyan on a chromaticity diagram. Because of the very limited bandwidth of the colour sub-carrier signals available to the American NTSC system, experiments were carried out to find the most advantageous use of this bandwidth. The red and blue colour difference signals (R-Y & B-Y, respectively) were given a rotation of 33^{o} to convert them into I & Q signals. The I signal (orange-cyan) was given a bandwidth of about 1.6MHz and the Q signal about 0.6MHz (fig 6). These signals are quadrature modulated onto a 3.58MHz subcarrier and can be decoded in the receiver without cross-talk because the transmitted signal carries 8 cycles of subcarrier to serve as a phase reference.

Optical simulations of the bandwidth requirements for narrow band colour difference signals added to the wideband luminance signal were carried out by Hacking (1957). Optical simulation is only a guide to the television system requirements because the detailed mechanism and display is different. Nevertheless this study showed that the bandwidth of the colour difference signal depended on (i) the luminance contrast ratio between the two displayed colour patches and (ii) the colours being displayed, but to a much less extent than (i). Transitions at the same luminance demand maximum bandwidth: colour television works very poorly under these circumstances giving very blurred transitions (although a spurious dark band divides the two areas in real television, but not in the optical simulation). If the results for one colour pair and the different contrast ratios are averaged then transitions involving orange to cyan demand the maximum mean bandwidth (1.10MHz in the original experiment) and the minimum mean bandwidth is required for green to white

(0.62MHz). If the 1:1 luminance contrast ratios results are considered then orange to white demands the greatest bandwidth and magenta to blue the least. Small field tritanopia would suggest confusion lines running through a blue primary, but television experience indicates that, for a range of luminance contrast ratios, the green to magenta transition demands the minimum bandwidth. Fig 7 shows the results for a series of transitions involving white. The chromaticities of the pairs of colours investigated is shown in fig 8. The optical simulation gave results supporting the choice of I & Q axes made by the NTSC.

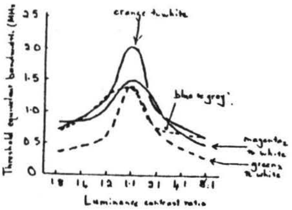


Fig 7 Bandwidth requirements for transitions between saturated and near white colours

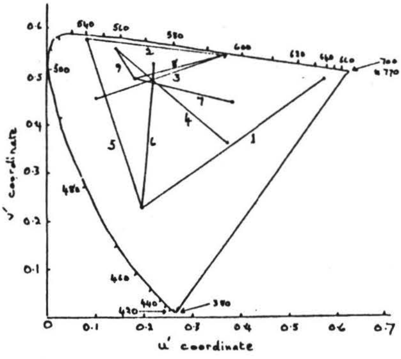


fig 8 Chromaticities of the nine colour pairs

When the parameters for the European PAL system were under consideration, a video bandwidth of 5 or 5.5MHz meant that the bandwidth of the colour sub-carrier was not quite as restricted as in the case of the American NTSC with a bandwidth of 4.2MHz. It was therefore decided to give both sub-carriers a bandwidth of about 1MHz with no rotation of the (electrical) axes by 33°. The colour sub-carrier for System I, as used in Great Britain, is a quarter line offset from a multiple of the line scan frequency rather than a half line as in the NTSC system. This is a consequence of the change of phase in alternate lines, which renders the PAL system substantially free from hue shifts caused by phase errors in transmission. In the NTSC system any phase error translates directly into a hue error in the received picture. Phase errors in the PAL system are converted into chroma errors which are less noticeable and can be corrected, when neccessary, by an increase in chrominance gain in the receiver.

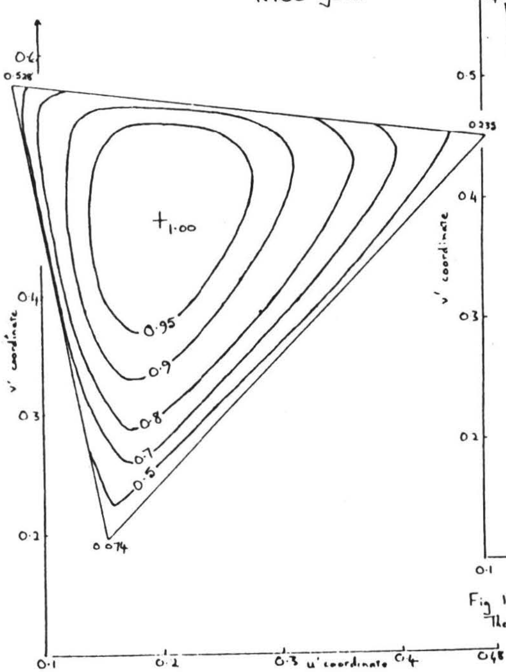
If the results of the Hacking experiment, based on the now obsolete 3MHz, 405 line system are scaled up to take account of the 5.5MHz bandwidth of system I, then the orange-cyan axis should have a bandwidth of about 2MHz and the green-magenta axis about 1.1MHz. It would seem that the 1MHz given to all axes in the PAL system is statistically adequate for green-magenta transitions but less than desirable for orange-cyan transitions.

In fact, the system does work tolerably well but this is due to the statistics of luminance contrast ratios at transitions. Transitions at or near to 1:1 ratio are very rare.

4 THE CONSTANT LUMINANCE PRINCIPLE

An important principle in colour television is the **constant** luminance principle which states that 'signals in the band-shared colour channel shall not affect the luminance of the reproduced picture'. In section 3 it was stated that the colour difference signals, in principle, carry no luminance information. This would be true for a linear transmission system but in fact signals are gamma-corrected. The transfer characteristic of display tubes is non-linear in that the light output depends on the voltage drive (above cut-off) raised to a power of about 2.8: by gamma correcting the red, green, blue and luminance linear signals, the need for non-linear circuits in the receiver, colour or black & white, is eliminated. The transmitted

Fig 9 Constant luminance index contours NTSC system



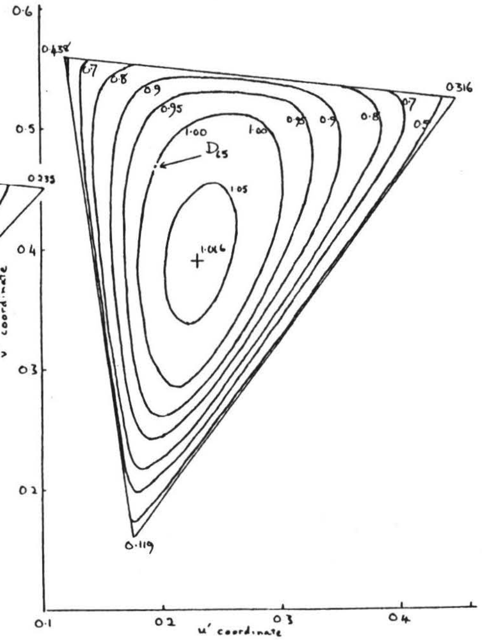


Fig 10 Constant luminance index contours, PAL system
The maximum value, k = 1.066, occurs at u' = 0.232 v' = 0.390

luminance signal ($Y^{1/\gamma}$) also gives a fair approximation to the visual response to luminance under most conditions where

$$L^* = 116(Y/Y_o)^{1/3} - 16$$

and this is advantageous for uniformity of perception of noise at various grey levels from white to black. However, one consequence of using gamma-corrected signals is that colour-difference signals do, in fact, carry luminance information: the proportion depends on the chromaticity of the colour being transmitted. Thus the sharpness of a transition from one colour to another may be appreciably less than expected. The most extreme case of this is a saturated blue in the NTSC system where only just over 7% of the signal has the full luminance bandwidth. Quantitatively this is expressed by the constant luminance index, k (Livingstone,1954).

$$k = (lR^{1/\gamma} + mG^{1/\gamma} + nB^{1/\gamma})^{\gamma}/(lR + mG + nB) \ldots\ldots(2)$$

where R G B are linear red, green & blue signals
l m n are luminance coding coefficients
γ = gamma (usually set to 2.2)

Contours of this index for the NTSC system are shown in fig 9.

A complication arises in applying the constant luminance index to the PAL system. The luminance coding coefficients (l, m, n in equation 2) have values of 0.222, 0.707 and 0.071 for the PAL primaries i.e. these are the luminances of the red, green and blue primaries required to give unit luminance of white (D_{65}).However the NTSC coding coefficients are also used in the PAL system i.e. 0.299, 0.587, 0.114. This does not affect the recovery of red, green and blue signals in a PAL colour receiver because the matrix effectively used in the receiver takes this into account. It does affect the luminance signal used by black and white receivers and also the constant luminance index contours (fig 10). The blue primary carries almost 12% of the full-bandwidth signal. A peculiarity of the contours is that the peak value is 1.066: white has a value of 1 as in NTSC. The significance of k values greater than 1 is obscure: it probably derives from using a formula for the luminance signal that is only approximately the proper expression. The matter is discussed by the author (Sproson, 1982a) but it does not very directly affect colour reproduction except in the fine detail of transitions or small areas.

The constant luminance index contours (figs 9 & 10) do relate to the compatible black and white pictures received from a colour transmission. Greens and yellows have approximately the correct luminance, reds are darker and blues appreciably darker than they should be.

It would be wrong to place too much emphasis on the failure of the constant luminance principle (due to the use of gamma-corrected signals). Over a considerable range of chromaticities the index exceeds 95%. The importance of the principle lies in the fact that interference in the chrominance channel produces no interference in the luminance of the received picture or colour: the chromatic interference in the displayed colour is substantially less visible than the corresponding interference in the luminance channel. This difference can ammount to 8 or 10dB in some cases. This was demonstrated by Bailey (1954) in a classic and elegant experiment and an optical simulation by Hacking (1966) extended the range of colour pairs investigated and determined the values of the chrominance/luminance advantage.

5 PRACTICAL IMPLEMENTATION: ANALYSIS AND SYNTHESIS

5.1 ANALYSIS

A colour camera to broadcasting standards requires red green and blue focussed images to be formed on the face plate of the three camera tubes. The splitting of the incident light flux into these three components needs to be done in conformity with spectral analysis characteristics (e.g. figs 4 & 5) and also with high efficiency. A camera with accurate spectral analysis but poor optical transmission would be completely unacceptable because it would demand high lighting levels. While this might not be an embarrassment in some daylight scenes where there is often a high illuminance, studio lighting is expensive and the heat produced, particularly by tungsten lighting, has to be removed by ventilation systems with very low acoustic noise levels.

One very efficient means of splitting light into spectral bands is the multilayer dielectric filter and these are widely used in colour camera analysis systems. They have two great advantages (1) they can be designed and fabricated (by vacuum deposition) to specific requirements (2) they have very little absorbtion over the visible pass-band so that reflexion plus transmission values add to about 98% or more.

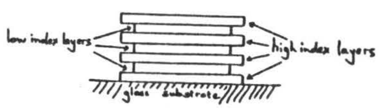


Fig 11 Diagrammatic representation of seven layer dielectric filter

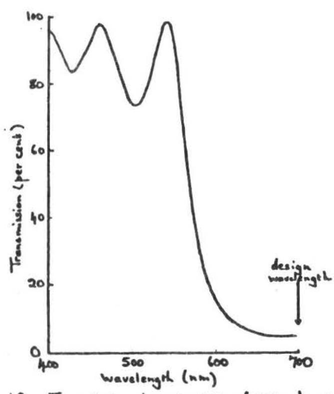


Fig 12 Transmission characteristic of seven layer dielectric filter at normal incidence (no dispersion)

As an example, a seven layer quarter wavelength filter is indicated diagramatically in fig 11 and its transmission characteristic at normal incidence is shown in fig 12 for a design wavelength of 700nm and using high & low index dielectrics of refractive indices 2.35 & 1.38 on a glass substrate of index 1.52. The reflexion curve gives a maximum at 700nm of about 95% and the transmission curve has high values from 400 to 550nm although with (unwanted) peaks and troughs. Variations in the design can reduce the magnitude of the peaks and troughs but detailed treatment of this topic is inappropriate here. A multilayer filter cannot usefully be used at normal incidence for image separation: when light is incident at non-normal incidence (& thus separation of image-forming beams becomes practicable) then two effects occur (i) the path difference in the dielectric for interference purposes is **reduced** (ii) the reflexion coefficients between layers depend on the polarisation of the incident light. The change in path length causes the design wavelength to be reduced, for example, the 7 layer filter (fig 12) has an effective design wavelength of 630nm for an angle of incidence of 45°: the peak reflexion is also reduced from 95% to a mean of 93% as given by the average of the two polarisations

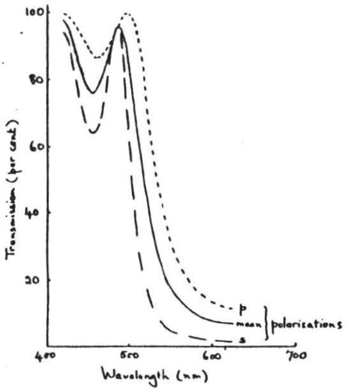


Fig 13 Characteristics of firstorder seven layer filter for 45° angle of incidence (cf. fig 12 for normal incidence)

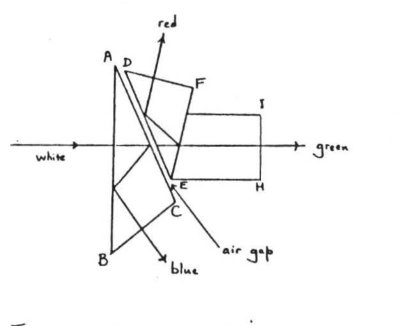


Fig 14 Prism-splitter block. A blue reflecting multilayet filter is depcsited on surface AC : a red reflecting multilayer filter is depcsited on surface FE. Total internal reflection takes place at surfaces AB and DE.

(fig 13). Both effects are reduced with smaller angles of incidence

Following the early colour cameras which used relay optics and plate type dichroic mirrors (at an angle of 38° in one version) and image orthicon camera tubes, a very significant improvement in colour camera design was achieved by the use of a prism splitter block and the lead oxide camera tube. Fig 14 shows how white light incident onto the surface AB is reflected by a dielectric multilayer filter deposited on the rear surface AC. Blue reflected light is totally internally reflected at the surface AB and emerges from the surface BC onto the blue camera tube. Yellow light is transmitted by the dielectric mirror on surface AC across a small air gap (10 to 15 wavelengths thickness) and is reflected by a dielectric mirror EF to form the red component. This is totally internally reflected at the surface DE and emerges from surface DF to form the red image. The transmitted green light emerges from IH to form the green image. Typical angles of incidence at AC and EF are 24^{o} & 19^{o}: however these are angles in glass (borosilicate crown) and the equivalent angles in air are 38^{o} & 30^{o}. This represents an improvement in reducing the angle of incidence at the second surface, the red/green split.

Because multilayer dielectric filters always have some transmission or reflexion over the whole band, shaping filters are often used to complete the red, green and blue separation. These are usually dyed in the mass glass filters. Like gelatine (Wratten) filters they are able to completely absorb some spectral regions. For example, a yellow filter (Wratten 8) completely absorbs all wavelengths below 450nm and also gives a high transmittance of all wavelengths beyond 550nm of about 90%. Blue and green filters of this type do not achieve the highest values and are typically of about 50 to 55% peak transmission.

5.2 SYNTHESIS

Many types of colour display tube have been invented but the one which has achieved considerable success and continues to be extensively used is the shadow mask tube (including some of its modern variants). The characteristics which are most important from the colorimetric angle are the transfer characteristic (gamma), the chromaticities of the red, green and blue phosphor elements, the absolute luminance available and the flare characteristics. Definition is also important for picture quality. The precise transfer characteristic depends on how the tube is driven (e.g. grid modulated, cathode modulated) but the relationship, eq 3, applies with in the range 2.8 + 0.2. As

$$Y = k(V - V_o)^{\gamma} \quad . . . . . . (3)$$

where Y = light flux k = constant V = drive voltage V_o = cut-off voltage γ = gamma

explained earlier, signals are "gamma-corrected" to avoid the need for non-linear circuits in the receiver.
The first shadow-mask tubes used a group of silicate phosphors; their spd's are shown in fig 15 together with the chromaticities (fig 16).These are the original NTSC phosphors: they cover a wide gamut of chromaticities but the brightness (luminance) was rather limited (17 to 34 cdm^{-2}). The number of phosphor triads and the flare properties were somewhat lacking but it is proper to note the immense contribution these first display tubes made to the eventual success of colour television. As an historical note we could mention a field sequential system provisionally accepted by the FCC about 1950 which used a black & white tube with a rapidly rotating disc with red, green and blue segments in front of the

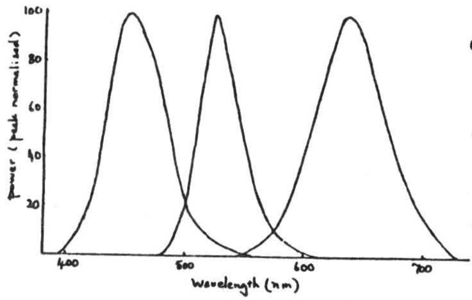


Fig 15 Spectral power distributions of the silicate red green and blue phosphors used in the first display tubes (1953)

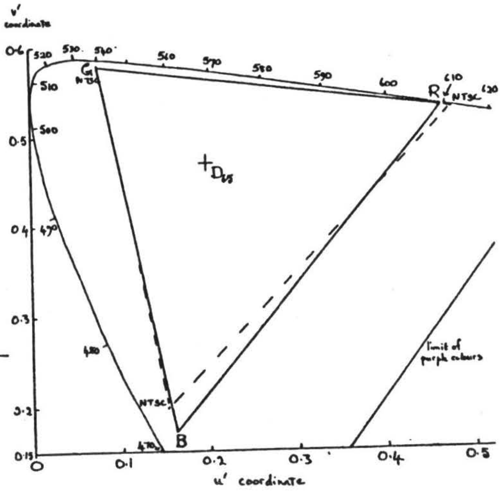


Fig 16 Chromaticities of a set of silicate phosphors. The NTSC primaries are also shown The solid line shows the gamut of the silicate phosphors; the dashed line shows the NTSC gamut. Part of the spectrum locus is shown with wavelengths in nanometres.

tube. This proposal was rapidly dismissed by the industry as not acceptable. A colour display involving no moving parts was demanded and the shadow-mask tube was one of the first answers and continues in the forefront of present day displays. The field-sequential system was also rejected because it was non-compatible with existing systems.

The next important change in displays arose, inter alia, from the use of a group of sulphide phosphors (figs 17 & 18) towards the end of the 1950's. Although the range of chromaticities was reduced in comparison with the NTSC specification, the improvement in brightness together with an improvements in flare characteristics gave better pictures. This was a very practical example of the importance of the luminance axis, which is inevitably omitted from any two-dimensional chromaticity diagram.

The sulphide red phosphor is rather orange than red, with a wavelength of about 606nm. A further significant improvement was the development of phosphors activated by rare-earth elements e.g. a vanadate phosphor activated by europium. The spd of this is shown in fig 19 and it will be seen that it is almost a series of line spectra from 590 to 700nm with a particularly strong line at about 613nm. The chromaticity corresponds to a spectral wavelength of about 609nm which is close to the chromaticity of the PAL system red primary.

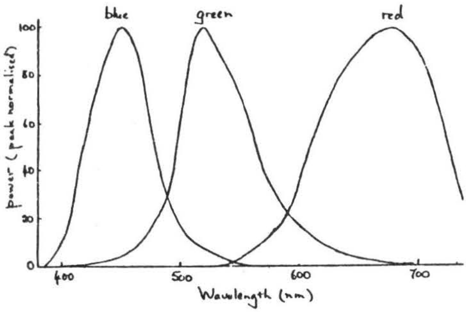


Fig 17 Spectral power distributions of sulphide group of phosphors

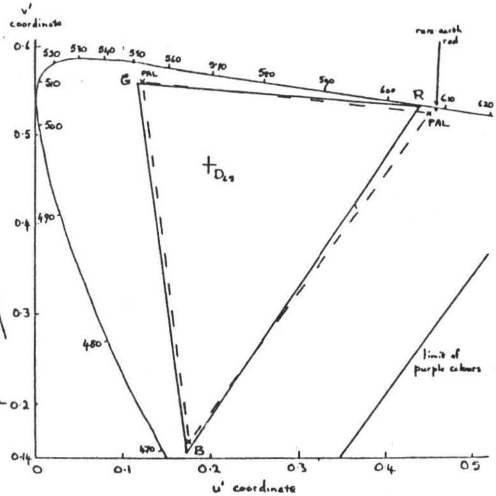


Fig 18 Chromaticities of a set of sulphide phosphors. The PAL primaries are also shown. The solid line shows the gamut of the sulphide primaries; the dashed line shows the PAL gamut. The chromaticity of a rare-earth red phosphor is also shown (see fig 19 for its spd).

5.3 PHOSPHOR PRIMARY STANDARDISATION

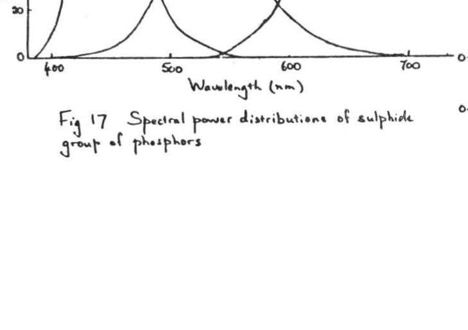


Fig 19 Typical spd's of the phosphors in a modern shadow mask tube. Note in particular the red phosphor which consists (almost) of a series of spectral lines.

Use of a 3x3 matrix to improve the colour rendering and to some extent simulate the negative parts of the analysis curves (fig 1) has already been mentioned. Whereas the positive only analysis curves do not change very much with a change of synthesis primaries, a more complete set of effective sensitivities changes significantly (Table 1). A consequence of this dependance is the need to decide what primaries are to be used. The NTSC set of primaries are of great historical interest but, in Europe at least, display tubes conforming to that set of primaries had ceased to be used by the mid-fifties. For the PAL & SECAM systems used in Europe, the EBU decided to standardise a set of phosphors more closely agreeing with phosphors in current use. This action was taken in the late sixties. Display tubes were also manufactured to comply with this EBU specification and thus, in principle, all European transmissions were monitored on display tubes with the agreed chromaticities. This standardisation was done so that the improved colour rendering available by using matrixing should be translated into practice. Experiments showed that serious errors (particularly in skin tones) could be introduced if the transmission (analysis) primaries were not matched in the display tubes.

6 OVERALL ASSESSMENT

6.1 EFFECT OF GAMMA

In order to avoid the use of non-linear circuits in the receiver, the transmitted signals (Y,I & Q in NTSC; Y,U & V in PAL & SECAM) are gamma corrected. The gamma correction used is not the inverse of the gamma of the display tube and the overall effect is to produce a transfer characteristic with a gamma of 1.2 to 1.3. The physical effect of this is shown in fig 20 for a gamma of 1.27. The chroma of all colours, except those close to the boundary

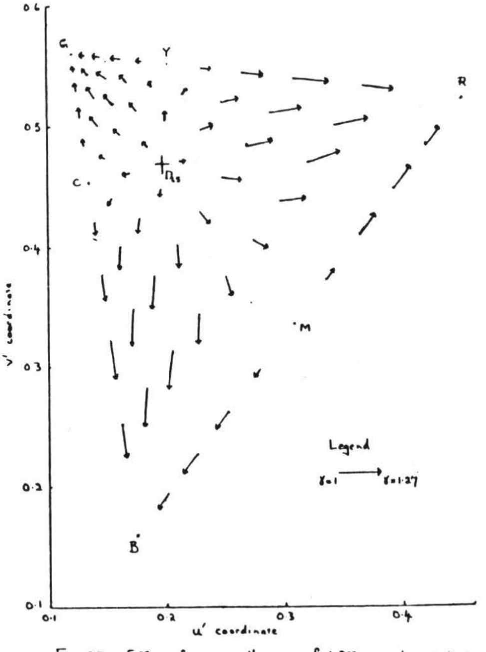


Fig 20 Effect of an overall gamma of 1·27 ; six chromaticities are unchanged viz. R G B and YMC in addition to white D_{65}.

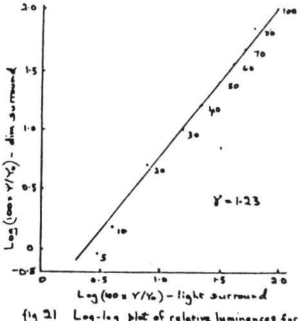


fig 21 Log-log plot of relative luminances for dim and light surrounds to give quoted values of L^{**} as defined by Bartleson

given by the phosphor primaries, is increased and the dominant wavelength is shifted towards the dominant primary (with the exception of the three directions red-cyan, green-magenta and blue-yellow). Broadly speaking the shift in dominant wavelength is very approximately along the lines of constant hue, although there are some exceptions. This increase of chroma might be regarded as contributing to colour errors in the television reproduction but there is one physiological effect which demands an increase of chroma for most viewing conditions. This is the 'dim surround effect'.

6.2 DIM SURROUND EFFECT

Television pictures produced with an overall gamma of unity are found to be very unsatisfactory in that they appear pale and washed-out. Some increase of chroma is required to produce pictures that give a reasonably close approximation to the original colours. No detailed investigation of this effect for television has been conducted as far as the author is aware, but there are extensive investigations in the photographic field that support the need for a gamma greater than unity under certain viewing conditions. Expressed very briefly the photographic studies (Bartleson,1968,1975; Hunt et al,1969) show that a gamma of about 1.25 is needed for viewing pictures with a dim surround and a gamma of 1.5 for viewing in complete darkness (e.g. slide projection, motion picture projection). These requirements for a gamma greater than unity also apply to black-and-white reproduction. Expressions given by Bartleson for L (quantative brightness) for bright and dim surrounds lead to a gamma of 1.25 for dim surround conditions (fig 21).

Experiments using colours with dark surrounds compared with the same colours with light surrounds show a desaturating effect. Pitt & Winter (1974) found a marked loss of chroma by the addition of a black surround but experiments using a mosaic of colours intended to simulate real pictures (Breneman, 1977) showed only a slight effect. Sproson has suggested a gamma of 1.15 as a compromise between the two different studies, although clearly γ =1.15 is less than that required for correct tone reproduction in black-and-white prints (fig 21).

6.3 Revised Aim Points

A consequence of the usual viewing conditions for television (dim surround) is that the physical chromaticity and relative luminance of the reproduced colour must be modified if the reproduction is to match the original in appearance. For the test colours used in fig 3, and ignoring any need for chromatic adaptation or illuminance adaptation, a revised set of aim points is shown in fig 22. These are calculated using an overall gamma of 1.15 and using the PDT primaries given by studies of confusion loci of observers with non-normal colour vision. These primaries are used rather than NTSC or PAL primaries because they are believed to be more relevent to visual processing in human vision. Details of the calculation are given by Sproson (1982b).

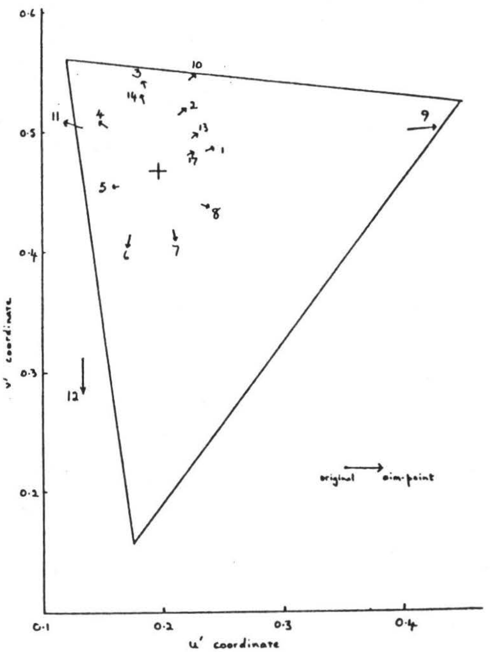


Fig 22 Suggested aim-points to compensate for dim-surround effect for CIE colours 1 to 14 and BBC 17.

6.4 Sets of Test Colours

In attempting to assess the performance of any colour television system, use has been made of various sets of test colours in a similar way to the Colour Rendering Index for Illuminants (CIE Publication 13.2). Fig 5 showed the effect of using the matrix equation 1 in conjunction with a set of camera sensitivities (fig 4). As previously mentioned, the agreement is fairly good and it has been suggested that the optimized matrix eq. 1 might be derived directly from some "goodness of fit" criterion between the theoretical ideal and that achieved by matrixing a practical set of red, green, and blue camera responses. This should be possible but the method has not been found to be very useful in practice. One of the difficulties is how to assess errors in different parts of the spectrum and how to form a meaningful index to measure "goodness of fit". Because of these difficulties, a set of test colours has been used to determine the optimum 3x3 matrix for a given set of camera analysis sensitivities. Considerable use has been made of the 14 test colours recommended in CIE Publication 13.2 together with a Caucasian flesh tone (BBC 17). In work on a Consistency Index for Television Scene Illuminants the use of the 18 chromatic colours of the Macbeth Color Checker has been recommended on the grounds that this chart is much used by the photographic & television industries and it is readily available. The absolute consistency of different printings of this chart may not come up to the highest standards but a standardised set of spectral reflectance data is used. One set of test colours used by BBC Research Dept used 25 colours including 8 skin tones. An objection to the CIE 13.2 set of test colours was that colour No 13 which represented a skin colour was a metameric match and did not have the characteristic spectral reflectance of real skin. Investigations associated with the Consistency Index for Television Scene Illuminants have cast some doubt on this objection. Undoubtedly acceptable reproduction of skin tone is important, but some of the test illuminants with poor values of the Colour Rendering Index, R_a, nevertheless gave highly satisfactory rendering of flesh tones.

6.5 Chromatic Adaptation

The usual situation in television nearly always includes a shift of white point between the scene illumination and the standardised D_{65} white point for the television monitor. The human eye automatically adapts to a wide range of scene illuminants including various phases of daylight and tungsten illumination. Expressed simply, it would seem that the eye has automatic gain controls to adjust the sensitivities of the red, green and blue receptors to suit the prevailing light conditions. Television cameras are adjusted in a similar way and the setting-up proceedure includes adjusting the red, green and blue gain controls so that a set of equal voltages are produced on each step of a neutral step wedge from black through to white.

In assessing colour reproduction e.g. for a scene illuminated by tungsten lighting and reproduced on a monitor with a D_{65} white point, it is inappropriate to compare the chromaticities in (say) P3000K of the objects in the original scene with the corresponding chromaticities on the television monitor. A more useful comparison is with the chromaticities of the objects in the original scene under a D_{65} illuminant. This does not necessarily give identity of appearance under the two conditions but it is a fair approximation. A more accurate method is to use a set of appearance grids (Pointer,1980) which give identity of appearance for two different illuminants at the same illuminance.

6.6 Illuminance Adaptation

The colourfulness of a scene increases with the one-sixth power of the illuminance (Hunt 1952,1953). Technical limitations prevent colour television monitors from achieving high illuminance and are limited to about 100cd/m^2 in Europe. Thus the colourfulness of outdoor scenes in bright sunlight cannot be reproduced. Under television viewing conditions, however, the chroma required to give this colourfulness would be rather artificial and the colours would probably have a fluorescent appearance. A more practical aim would be to achieve the colourfulness that the original scene would have if illuminated at the luminance of the television monitor. This is corresponding colour reproduction as defined by Hunt (number 5 in Section 1). Indoor scenes illuminated by 1500lux exceed the luminance of television monitors by a ratio of $(200/900)^{1/6}$ or 1.28: a decrease of 20-30% colourfulness is not unduly serious so that the reproduction of a studio scene is not much outside the technical limitations of monitors. (Chroma can be increased by use of the chrominance gain control in a domestic receiver.)

6.7 Effect of Chrominance Gain

Domestic colour television receivers have a chroma (or colour) control which enables the chrominance gain to be varied, frequently down to zero gain so that the black-and-white picture can be inspected and adjusted, if necessary, before colour is added. Fig 23 shows the effect of -3, 0, +3 and +6dB changes in gain relative to the correct setting on the eight test colours used in specifying the General Colour Rendering Index for Illuminants (R_a). It will be perceived that very considerable changes in chroma can be made. Use of this control to personal choice enables the sixth of the types of colour rendering mentioned earlier viz. preferred colour reproduction to be achieved. Enthusiastic use of this control can produce the highly fluorescent colour pictures that some viewers appear to like.

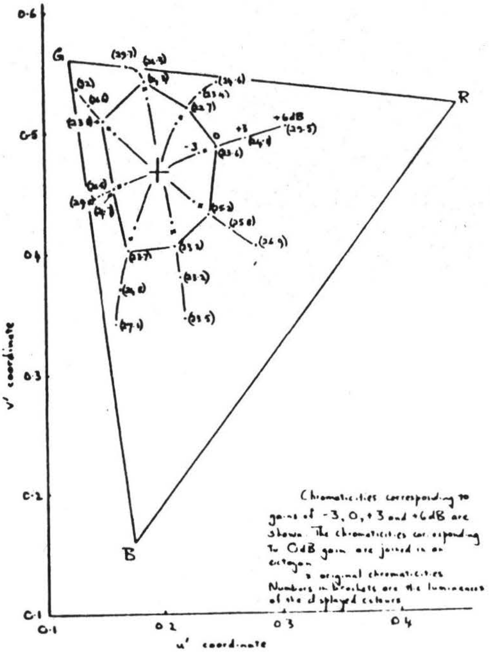


Fig 23 Effect of chrominance gain on displayed chromaticities signal gamma = 0.4, display tube gamma = 3, overall gamma = 1.2

6.8 A Mathematical Model of a Colour Television System

A means of assessing the performance of a complete system is outlined in the block diagram fig 24. Starting with the scene illuminant, light is reflected from a test object and passes

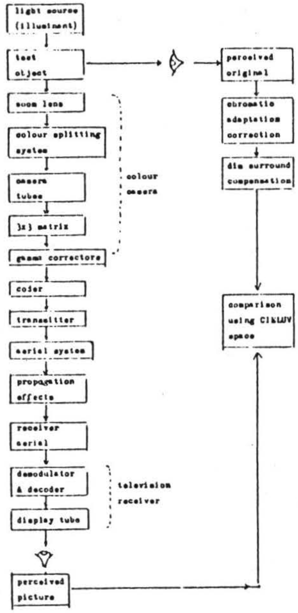


Fig 24 Block schematic of model of television system

through the entrance pupil of a zoom lens to the colour splitting system where three images are produced which are focussed on to three camera tubes. The outputs are adjusted by gain controls so that equal voltages are given for each step of a neutral step wedge (usually with a peak reflectance at white of 60%). The red, green and blue signals are processed by a 3x3 matrix to give analysis curves with negative sensitivities where appropriate. Gamma correctors follow and the signals are then coded to give a luminance signal(wide band) and two colour difference signals (narrow band). The three signals (Y′ I Q or Y′ U V) are amplified and modulate a UHF carrier: the transmitted signal radiated from a transmitting aerial is received on a domestic aerial: the signals are demodulated and decoded and amplified to drive the red, green and blue grids of a display device. The colour generated by the display is assessed for luminance and chromaticity to give a quantitative description. The original scene is assessed by the right hand set of blocks which includes chromatic adaptation correction and dim surround compensation. A comparison is made between the original and the reproduction using a suitable colour metric e.g. CIELUV.

Quantative data are required to perform the steps outlined in fig 24 as follows:-

- the spectral power distribution of the scene illuminant
- the spectral reflectance of the test object or objects
- the spectral transmission of the zoom lens
- the colour analysis of the splitting system
- the spectral responsivity of the red, green & blue tubes
- the coefficients of the 3x3 camera matrix
- the transfer characteristics of the gamma-correcting circuits
- the gamma of the display device
- the chromaticities of the phosphor primaries of the display device.

An example of this evaluation is summarised in Tables xx & yy for a P3000K scene illuminant, the 18 chromatic colours of the Macbeth ColorChecker, a camera with spectral responsitivities corresponding to the extended-red reference analysis used by TC1-11, an overall transfer characteristic with a gamma of 1.2, and a monitor screen with the EBU set of phosphors. The optimised 3x3 matrix is as follows:-

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix}_{output} = \begin{bmatrix} 1.4216 & -0.3923 & -0.0292 \\ -0.1582 & 1.2129 & -0.0547 \\ 0.0128 & -0.2242 & 1.2114 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}_{input}$$

TABLE 2

Colorimetric Performance expressed in CIELUV space

	Aim-points			Reproduction			Differences			
	L^*	C^*	h	L^*	C^*	h	ΔL^*	ΔC^*	ΔH^*	ΔE^*
1	37.13	31.09	29.99	35.78	31.39	29.98	-1.35	0.30	-0.00	1.36
2	70.23	48.06	30.86	69.67	51.59	25.91	-0.54	3.43	-4.29	5.52
3	51.77	40.94	-113.95	51.24	41.03	-112.86	-0.53	0.09	0.78	0.95
4	43.09	34.79	109.09	42.31	36.26	109.96	-0.78	1.47	-0.00	1.66
5	57.38	46.44	-92.30	56.81	48.76	-90.49	-0.57	2.32	1.50	2.82
6	75.01	51.51	170.51	75.64	42.26	170.00	0.62	-9.25	-0.41	9.28
7	63.04	105.88	32.32	62.59	103.97	32.10	-0.46	-1.91	-0.15	1.97
8	39.60	72.43	-99.16	39.30	73.22	-99.44	-0.30	0.79	-0.36	0.92
9	51.69	89.99	6.85	51.62	96.01	6.15	-0.07	7.02	-1.13	7.11
10	28.93	38.96	-69.43	28.03	36.54	-70.83	-0.90	-2.42	-0.95	2.75
11	76.25	82.80	97.85	76.70	83.39	101.06	0.45	0.59	1.74	1.89
12	74.99	100.74	47.43	74.83	96.40	49.40	-0.16	-4.34	3.37	5.50
13	27.38	73.66	-95.71	27.53	73.64	-97.11	0.15	-0.02	-1.79	1.80
14	56.67	68.11	129.73	57.02	67.60	126.23	0.34	-0.51	-4.13	4.18
15	39.45	109.81	8.95	40.99	118.70	8.51	1.54	8.89	-0.82	9.06
16	86.33	101.97	65.83	86.83	97.90	67.56	0.50	-3.91	-3.22	5.09
17	51.32	74.12	-30.93	51.43	77.06	-28.48	0.11	2.94	3.23	4.37
18	52.38	63.24	-139.19	52.64	56.47	-127.53	0.26	-6.77	12.14	13.90
				mean			-0.09	-0.07	0.31	4.45
				standard deviation			0.68	4.42	3.64	3.52

Key to the colours:- 1 dark skin: 2 light skin: 3 blue sky: 4 foliage: 5 blue flower: 6 bluish green: 7 orange: 8 purplish blue: 9 moderate red: 10 purple: 11 yellow green: 12 orange yellow: 13 blue; 14 green: 15 red: 16 yellow: 17 magenta: 18 cyan.

Note that h in Table 2 is in degrees; ΔH^* is in the same units as ΔE^*; the sign is taken from h(reproduction) - h(aim-point).

Three ΔE^* units are considered to be approximately equivelent to a just-noticeable-difference (jnd) under critical television viewing conditions. Nine of the colours have 'errors' of less than 3 units. The large error of colour no 18 arises because the aim-point is outside the gamut of the EBU phosphors, as also is the chromaticity before dim-surround correction is applied. The mean 'error' is about 4.5 units or approximately 1.5 jnds : if colour no 18 is excluded the mean 'error' reduces to 3.9 units.

The low mean 'error' of the ΔL^* is by design since the chroma & hue errors are directly related to the L* values and the mean values of the reproductions have been scaled to agree with the mean value of the aim-points. The variations about the mean, however, are meaningful but of small magnitude.

Note that some colours have an excess of chroma in their reproductions (particularly nos 7 & 9): others have a deficiency (e.g. nos 6 & 18) but the system is tolerably well balanced with a mean difference of less than -0.10 unit.

Hue 'errors' vary from +12 units for cyan (no 18) to -4 units for dark skin (no 2) but the mean value is close to zero at 0.3 unit.

This example is not quoted as the ultimate in colour reproduction but is intended to illustrate the methodology suggested in this paper.

7 FUTURE TRENDS

Much of the Research in colour television over the past decade has been towards higher definition using systems with over 1000-lines. The technical feasibility of such HDTV systems arises out of the higher channel bandwidths possible with direct broadcasting by satellites (DSB); cf 8MHz channel spacing for terrestrial UHF broadcasts in Europe with 27 MHz for DSB on a 12 GHz carrier: The aim has been to produce television pictures of the same, if not better, picture quality than those produced by 35mm motion picture photography. Much of the debate concerns ways of introducing new higher definition standards; for example, should they be drafted on to existing standards but with the ability to offer better definition with new receiving equipment or should completely new equipment be used.

The frequency interleaving principle where the colour information is modulated onto a sub-carrier within the luminance band has severe limitations in practice. Luminance signals close to the sub-carrier tend to be interpreted as colour. New high definition systems place the colour information outside the luminance band and thus avoid the sometimes very noticeable effects of 'cross-colour'

One of the defects of present systems is the failure to implement the constant luminance principle (figs 9 & 10). This arose because of the decision not to use non-linear circuits in the receiver. With advances in digital technology there is no longer an over-riding necessity to avoid these circuits and proposals are being made to instrument a genuine constant luminance system. This would appreciably improve the sharpness of many colour transitions.

There are also proposals for new phosphor primaries with a view to resolving the two sets of primaries (NTSC & PAL/SECAM) and bringing this aspect into line with present technology.

Whatever may emerge from the present intense activity in high definition television systems, the fundamental basis of trichromatic colour mixture will continue to underlie the principles of colour television.

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COLOUR IN FOODS

ABSTRACT

A review of the work done in the last years on colour evaluation or measurement on different animals, plants or fruits, including cultivation or breeding, seeds, genetics and other aspects, is presented.

The literature shows that use of proper colourimetric instrumentation are being extensively used and some work indicates that CIELAB System is yet little employed. Hunter's L,a,b (HUNTER 1948a,b 1958) system is the most extensively used, nevertheless, subjective evaluations are still being used, particularly through panel qualifications. In addition, there are those who use spectrophotometric measurements of transmitance or reflectance at certain wavelenghts to evaluate colour.

Products under research are very different: grains, seeds, vegetables, fruits, meats, mushrooms, honey, syrups, juices, alcoholic beverages, cooked foods and deserts.

The effects of the final product of irrigation, colour of seed, insolation on earth products, or electrostimulation, breeding, age, killing on animal products, freezing, temperature, storage time, enzymatic or non-enzymatic browning, and additives are amongst the variables found in the literature.

Some general recommendations with respect to colour measurement and procedures to follow in foodstuff, are given.

"Perhaps, through eons of time man has come to build up strong and intuitive associations between what he sees and what he eats. A good meal, to say the least, is always a beatiful sight to behold."

Birren,1963

"All of the factors which influence the visual appearance of a food are instantly assessed by a consumer and integrated into a response decision: TO BUY OR NOT TO BUY, TO EAT OR NOT TO EAT."

MacKinney, Little and Brinner,1966

I. INTRODUCTION

Since man appeared on the earth's surface, and as a part of his sensitive system, colour played a very important role in searching and selecting food to live. No direct testimony has been left from those early days, but since antique civilizations, there are descriptions of foods eated or served in which colour is a very important part of it, and therefore we believe that colour was a meaningful part of the alimentary habits of ancient inhabitants of this planet.

Today, most people live in a civilized, or what is called civilized world, and still the great majority of them, select, prefer, buy or eat what looks more agreeable or appetizing. This ability is not natural but acquired through experience by means of an empiric process.

Gourmets and sybarites are conscious that food not only must smell and taste well, but also must have a nice presentation. Common housekeepers, man and woman, when they go to the market, know that the principal basis to make a decision it is the appearance of the products exhibited. Each day it is more difficult to taste it before buying. Seldom it is possible to open a parcel, more often to touch it, but most of the time the choice is, fundamentally, based on what the customer sees. Processed food is even more difficult to evaluate if they are wrapped in transparent films, when details of the surface are hidden. If the food is canned or packed only the printed cover will give us an idea of what we are buying.

All those who are accustomed to buy foodstuffs, have certain patterns, mostly unconscious, to follow when they have to choose what they are going to cook or/and eat. Uniformity, good colour, reasonable size, appearance and experience are the main key basis to take these decisions.

What about those who prepare foods? If you put an steak on the grill, when is it ready? How do you make the decision? Roar? Medium? Done? These terms, what do they really mean? If you are in a restaurant and you are not allowed to cut the meat to see if its condition is or not "in the proper moment to be served", you should be trained to detect from the colour of the grilled surface how is the cooking going on. To decorate a fish or a desert is not only a question of combining adequately colour and forms, but also to stimulate the desire to eat it.

But,colour subject in foods do not restrict to consumers, who, undoubtedly, are the end of the process.In fruits and vegetables it starts with the farmer and the industry which process them. Some products, like fruits, are not harvested in the moment when maturity is the optimal for inmediate eating, but earlier, allowing time to mature during transportation or storage, or both, before reaching the consumer.

Other products are processed and the colour depends on the process. The list is almost endless and there is no point in describing longer these aspects. What should be emphatized is that most of the scientists working on colour on foods are trying, in some way, to control colour to satisfy the demand of a better quality. With the technology and knowledge available today the methods used become increasingly sophisticated and, perhaps, what people buys in the supermarket, in general, is not much better than that was able to acquire ten or twenty years ago, but, probably, looks better.

II.SCOPE

We have been working in the problem of colour measurement of foods since ten years ago. Apples, tomatoes, fruit juice, fish, meat of different kinds (cattle, pig, prepared, corned beef), honey, butter, seeds, natural pigments, etc., were some of the problems studied, but they were analyzed from a strictly colourimetric point of view. That is, not in a chemical, biological or any other aspect of food technology. Not the point of veiw of a food technologist, but that of a colour specialist who has to measure colour of different foods, therefore, this report intends to review the colourimetric aspect of the problem and not how the colour is produced.

It is felt that, for most of the present attendees, who are not food specialists, but people interested in colour, the review could be more attractive if it does not dig too much in food technology, but gives an idea of how the state of art on colour measurements on foods is. At least, the initial idea is that all the the delegates here present, eat something and have the curiosity to know what its colour means.

About 300 papers published in this decade have been reviewed. They heve been divided, mainly, in two groups: earth and animal products, with a small third group of papers dealing with general aspects related to this matter. There are also industrial products included in any of the first two groups depending on the raw product used in the manufacturing.

The first group -earth products- is divided in five subjects: vegetables, fruits, grains, non-alcoholic drinks, and alcoholic beverages. The second group is divided in four themes: meat (cattle,.lamb, goat and pork), poultry (chicken and turkey),fish and industrial products.

III. DIFFERENT ASPECTS OF COLOUR CONTROL OR MEASUREMENT

Colour is a part of the general organoleptic properties of foods and its control is being made in three different modes according to practice. They are:

1) Visual colour evaluation.
2) Instrumental evaluation using apparatus not specifically designed to measure colour as the recommendations established by the CIE.
3) Instrumental colourimetric measurements.

III.1 Visual colour evaluation

Normally, panels of people, trained or untrained, or both, evaluate colour of different products under certain conditions.

In few cases specified,very seldom under an appropiate psychophysical methods. In most cases the products are classified into categories such as: excellent, good, medium, acceptable and poor, which in practice, is very difficult to quantify.

Most of these works are a preliminary approach which gives little possibility to compare results in terms of reference. Is like to say "A green apple which has a very nice colour" and will produce in each person a different image of the real colour of the apple, even if everybody is talking about the same thing, all of them are thinking in different ones.

It is not rejectable, in principle, this methodology, but it could be suggested that authors must follow certain procedures to allow intercomparison of different evaluations. Such as to define colour quality and the spectral characteristics and level of the illuminant used, and colour characteristics of the place where the products are assessed, also, if possible, give the CIE colour characteristics of the anchors given in the subjective evaluation. When possible, to use a psychophysical method to frame the evaluation will be appreciated.

III.2 Non colourimetric instrumental evaluation

For many years before the CIE system was established and till proper colourimeters became commercially available, many people used glass filter transmittometers as "colourimeters". This common misunderstanding is still used in many places. Confussion between reflectance and/or transmittance measured at certain wavelengths is still present in many cases. Particularly when measuring reflectance the missconception becomes more evident. In cases when this applies, no paper refers to which is the standard, the geometry or the bandwidth of the measurement. The validity of the results presented are acceptable, but, on which extent? How comparable are they?

As in the visual evaluation,it is felt that these methods are approximations to the good practice. It is always better to do some kind of measurement than nothing at all, but still is not enough to be considered as proper colour measurements.

If the colour measurement is related to the ratio of two reflectance, transmittance or absorbance measurements, i.e. R700/R595 used to evaluate pimiento pastes in an experiment, different results can be obtained with different instruments or different measuring conditions. In that case, which is the correct one? Which is the error? How important is it? Statistical correlations can be high, but referred to what? These, and many other questions, can be arisen.

Despite of the importance of this aspect, it is felt that even more important, is to understand that colour is NOT the reflectance or the absorbance or the transmittance in one or two wavelenghts or the ratio of them, but the psychophysical evaluation of the total spectrum, and that depends not only on the object under measurement and the observer, but also of the illuminant and the observing conditions. With the actual knowledge it is difficult to accept a scientist to talk about colour in terms of measuring at certain wavelengths.

Although myself, sometime ago, preferred to talk about dominating or complementary wavelength and purity to express chromaticity of a colour, instead of the CIE x,y chromatic coordinates, the idea was completely abandoned favouring the use of "chromatic hue angle" and "metric chroma". Real world deals with colour which have nothing in common with pure spectral colours and that is particularly true in natural products. Even the rainbo has very desaturated colours when mixed with the ambient light. Psychologic associations with spectral colours so as to define an object colour is wrong and missleading, and it is strongly recommended not to use it.

III.3 Proper colourimetric instruments

As most of the specialists know, there are two types. a) Tristimulus colourimeters, and b) Spectrophotometers.

The first are instruments which, based on the three variances of colours can have one detector, in front of which three appropiate filters which can be placed one after other, automatically or manually, taking the necesary three measurements. Can also have three detectors, each of them with a filter, to obtain, in a very short time, the three measurements simultaneously, or secuently.

The papers reviewed show an extended use of US manufacturers (mainly Hunterlab and Gardner) measuring in Hunter L,a,b units. A part of these instruments are Differential Colorimeters, which were created to measure colour differences. Nevertheless, very few experiments measured colour differences, but colour coordinates, absolute values.

It is known by the specialist, that most tristimulus colourimeters are not accurate, the errors in reproducing the curves of the functions $\overline{x}_\lambda, \overline{y}_\lambda, \overline{z}_\lambda$ for the standard observer (2° or 10°), (There are a few instruments with filters corrected to fit the functions within the 1%, produced in Europe) and are suitable (or, more properly, were suitable) to control production and not for laboratory use, but as reflectance spectrophotometers are expensive and tristimulus colourimeters are cheaper, the extension of use of these types of instruments is much greater.

There is no point to complain about this. This is just a fact, and it is always better than nothing, but people must be aware of the limitations of such instruments and must have precautions for its correct use.

In all the literature read it was not found one mention of the used Standard Observer. It is supposed that probably, all measures are refered to CIE 1931, 2°, Standard Observer, but it could be that someone is using CIE 1964, 10°, Standard Observer. Who knows? Many papers do not indicate, even the illuminant used, neither the geometry (which sometimes can be deduced from the type of instrument used). Apparently, it seems more important to indicate the name and type of the instruments than that the specific characteristics of the measurement, which, really, is the important point.

These results cannot be invalidated, neither to diminish the merits of the work done. The auditorium must understand that these people are not colourists. They are food technologists who use colour just as a tool, among many others so as to evaluate products quality. Instead, on the other side there are technologists whose speciality is colour and are now involved in colour measurement of foods among other problems. We are dealing with colour from different points of view, therefore it is natural to have different approaches to the question.

There is a real need to establish a guide to those who work with colour, like the food technologists, in terms to use a common speech and to give results that can be used and compared by other researchers.

IV. REVIEW OF THE LITERATURE

More than 300 papers from different countries have been reviewed. Colour measurement on foods are subject of research in all continents. Different aspects are being studied. From basic genetics of seeds up to the effects of electrical treatment in cattle killing.

Most people simply think that natural products are simply "natural". They usually think about "natural" colours products namely, fruits, vegetables flowers, etc. Unconsciously they know that man normally has some participation in the production process, but as part of his irrational nature he tends to apply mystical justification to his ignorance. The fact is, that nowadays, more and more action of the human being tries to control the different parameters of food quality during its production.

The genetic studies of seeds and animals starts the initial step towards a full control of the production process. In vegetables the controlled variables registered in the literature are soils, irrigation, sunshine, additives and time of crop or recollection; in animals, breeding, keeping and killing. As the time goes by, more precise details are considered and set under control. Producers wish to have the least possible variability, and in some cases the degree of uniformity achieved is almost incredible.

Most of the actual problems are related to find good colour parameters to correlate statistically with other variables like those mentioned above.

Also variability in colour measurements of natural products can be due to different factors: type of measurements, instrument, illuminant, geometry, texture and form of the product, etc.

In the literature reviewed was often found out that, in many cases, there is a great detail in the process variables (chemical, physical, etc.) depending on the educational background and/or experience of the people involved in the research, and much less care in the proper colour evaluation. A great majority of these works do not give much detail of the colour measurement to make them comparable with results obtained elsewhere. Colour evaluations seems, in many cases, an indication of a tendency than a proper measurement.

For these reasons it is interesting to suggest a procedure to follow where it is needed to measure colour on foods.

These suggestions are given at the end of this lecture.

There are few papers dealing with general aspects of colour measurement in foods (CHRISTENSEN, 1985; KAMIKURA & NAKAZATO, 1984,1985; QUILICHINI, 1985, 1986a,b; SETSER, 1984) which studied different variables of this problem. Christensen worked on the effect of colour on judgement of food aroma and flavour intensity and he found that the results failed to support the hypothesis that colour alters the perceived intensity of the food aroma or flavour. He only could verify an increase of confusion in the visual judgements.

Kamikura and Nakazato were engaged in natural colorants extraction. In this particular case, it was the gardenia fruit.

Quilichini explained the use in foods, particularly in meat, of colour measuring instruments and on the description of a new portable apparatus developed in France, the Retrolux, giving its characteristics and evaluating its perfomance with reference to cattle meat colour measurements.

Finally Setser published a paper related with general aspects of colour evaluation, claiming that instrumental measurements must always be referred to sensory evaluations in regard to the necessary proper conditions to carry them on.

Let us see now the present situation discriminated for each type of food product.

A. EARTH PRODUCTS

This part will be divided into five groups as follows:

1) Vegetables
2) Fruits
3) Grains
4) Non-alcoholic beverages
5) Alcoholic beverages

There are products which are derived from some of these main groups, such as oils, flour, bread, noodles, backery and cakes jam and jelly, etc. A large variety of processed foods.

Processing adds value to raw material, and also adds one or more variable dependences to the final colour of the product. Freezing or low temperature storage stops or delays the process of deterioration. In some products also the storage atmosphere is controlled with this same purpose. Most of natural products are labile with time, with the exception of good alcoholic beverages which get better with age. But this is exceptional. Some processes are greatly altered with the colour of the product, others do in a much lesser grade.

A.1 Vegetables

The literature dealing with this matter must be divided in two parts: Pre-harvest and post-harvest research.

A.1.1 Pre-Harvest Research

DRAKE & MUEHLBAUER (1985), HURST et al.(1982), IWANZIK et al.(1983), SHIRZADEGAN (1986), SHIRZADEGAN & ROBBELEN (1985) and TAURICK & McLELLAN (1986) have studied different aspects of pre-harvest processing of different products (Peas, rapeseed and squash). Genetic effects on colour of rapeseeds (Brasica Napus L.) was investigated by Shirzadegan and Robbelen. They have found no evidence of it. Instead, they showed a relation with the oil and hull content. Peas were studied by Drake and Muehlbauer and Traurick and Mclellan. The last two have done a research on the effect of a single gene, while the others worked on the influence of soak time, solution and cultivar on the canning quality of peas. While Drake and Muehlbauer verified that the main effect was that the A-gene caused the peas to have a darker colour among other characteristics, suggesting that this type of study could lead to a greater understanding of the process, the others showed that the colour remained constant regardless of soak time but the appearance judgement is better with the increasing soak time, depending on the choosen cultivar.

With respect to summer squash, studied by Hurst et al., colour was measured under different circumstances: harvest date (3 different successive months), irrigation or not of cultivars, and two different methods of maturity evaluation through colour using Hunter's L,a,b units, a/b and C. Several results were analyzed but there is no indication of number of samples measured and the inconvenient way to interpretate the results expressed in terms of absolute values of L,a,b units instead of differences and their significance which could make the paper more understandable.

Finally Iwanzik et al. studied the relation of the carotenoid content in different German varieties of potatoes with the colour of its flesh showing a linear statistical relationship between them.

A.1.2 Post-Harvest Research

ADAMS & ROBERTSON, ANANTHESWARAN et al. (1986), HURST & SCHULER (1979), RAO et al.(1985), RESURRECCION et al.(1987), SANELLI (1981), SHEWFELT et al.(1986) and STONE (1986) have published papers related to beans, mushrooms, peas, oil and okra. Three of them dealt with snap beans and one with green beans. In the analysis of the statistical correlation between physical and chemical measurements and sensory quality parameters, the authors (Resurreccion et al.), said that "eating quality of vegetables may be directly evaluated by subjective sensory methods or, indirectly, through chemical and physical measurements". In fact, these studies deal with the evaluation of deterioration or the means to avoid it. Shewfelt and collaborators indicate that the quality differences, like colour, suggest that "cultural" and harvesting factors are most critical. Problems are attributed to the right moment to do the harvest and transportation. The use of Hunter's L,a,b and hue angle units showed to be satisfactory. This group of researchers of Georgia, USA, published a recent paper where they suggest the convenience to use multidimensional scaling evaluation through cluster statistical analysis, concluding that to evaluate the acceptability of the products on the fresh market, hue angle and moisture of vegetables were the most important objective measures.

Rao et al. studied also the effect of thermal processing on the canned snap beans and they found that a colour degradation could be expressed in terms of constant on the Arrhenius kinetic equation, which really is not correct. How is it possible to evaluate colour variation in this way? These authors indicated that the colour constant D, expressed in minutes (!), at a given temperature, the reduction of colour is by a factor of ten (!). It really would be very intersting to find out what a reduction of colour is!

Hurst and Schuler studied the loss of the green colour in peas when thermally processed such as humid refrigeration. They are based upon the USDA (US Department of Agriculture) criterium, which establishes that colour evaluation must be subjective, the authors say that "to give validity to the results expressed colour such as 'greeness' counting the number of 'green' peas in the hundred"(!).

Adams & Robertson studied the correlation of sensory and instrumental methods in the colour measurement of frozen beans and they found a good correlation between Hunter <u>a</u> value and chlorophyll content. Instead pheophytin correlated with poor colour in all cases (unbleached and underbleached samples).

Canned mushrooms were the subject of research for Anantheswaran et al. who studied the effect of two pre-treatments (vacuum hydration prior to blanching and no hydration) and thermal process to sterilize the canned product at different temperatures and for different periods of time.

To evaluate colour they used Hunter L value and it was found that hydration caused initial deterioration of colour. Afterwards, little was noticed. On the contrary, that was not the case of non hydrated mushrooms, where colour changes increase between treatments.

The research carried on by Sanelli related to others, like the above mentioned of Adams and Robertson, studying colour and chlorophyll content of vegetal oil. He uses a special value C as the total colour parameter and based in the photosensibility of chlorophyll, he deduces that decolouration due to lighting effects is related to chlorophyll content. The total C value depends on the saturation , the tristimulus value Y and the dominant wavelength λd, but the indicated expression does not include λd and does not show how it is calculated. The effect of degradation is measured after exposing open bottles to light during a period up to 120 days. There is no indication on the type or quantity of light. The results obtained shows that the visual explanations are more evident than the objective measurements. The graphs and tables do not give clear indication of what is really happening.

Finally, Stone et al. worked with a very popular vegetal consumed in tropical and sub-tropical countries due to its adaptability and resistance to hot and humid wheather. "OKRA" (Abelmoschus esculentus or Hibiscus esculents) is the name, and the studies deal with dehydratation, boiling water blanch with or without 0,1% sulfur dioxide (SO_2), drying temperatures and storage duration. Colour evaluation was done through spectrophotometric measurements. No effect was too evident within a 6 weeks period of storage. Nevertheless the colour parameters (Hunter's L,a,b) change a little depending on the previous bleaching process.

A.2 Fruits

Almost 50 papers were been reviewed on this subject. Some of them deal with general aspects of colour measurement of these products, a few with processed products (jam, jelly, puree) and the rest are dealing with pre- or post-harvest process.

A.2.1 General colour measurement aspects

ADAMS (1981 a,b,), CONRAD et al (1987), JUNGMAN et al (1986),LOZANO(1982,1984,1986), MINGUEZ MOSQUERA et al.(1981,1982,a,b, 1984, 1986) , SAPERS & DOUGLAS Jr. (1987), SHEWFELT (1986), URBANYI (1982), VANGDAL (1982, 1985), and VARADY BURGETTI & LUKACS (1986) have published different articles on general aspects of colour measurement of fruits.

Adams analyzes the problem on the effect of processing on colour. He states that generally these changes are undesirable. He also describes the effect of enzymatic and non-enzymatic changes of natural pigments, particularly chlorophyll and the stabilization of green, carotenoid isomerisation, anthocyanins, and Betalains indicating which process retain the natural colour. Conrad et al., analyzes the method to determine colour of pepper. He found out that the instrumental method using a/b coefficient (Hunter's L,a,b values) is much better than the visual OACS Munsell method. Minguez Mosquera et al. also studies pepper fruit, but he is more concerned with pigment content. Therefore, he recommends the use of instrumental colour measurement, but indicates only the absortion of red and yellow pigments at two different wavelengths (450 & 470 nm). In a later work, he and his collaborators recommend to measure the reflectance at 700 and 450 nm or to measure the absorbance at 495 nm.

In 1986, Shewfelt, has published a chapter in a book dedicated to Food Processing in which he analyzed the factors of processing that affects colour foods. He states that "Prior to the first bite or sip, the consumer has already made a quality judgement on the product appearance". He also says that "the art of preserving colour in fruits involves the selection of fruits with optimal pigmentation and the prevention of pigment degradation during handling, processing and storage. The major pigments of fresh fruits are chlorophylls, carotenoids, and anthocyanims. Undesirable pigments such us melanoidens and melanins are formed in browning reactions", (we shall talk about browning process later), he also explains that "heat preservation is destructive of each of the pigment groups. Chlorophylls are degraded to brown pheophytins; carotenoids are converted to epoxides; and anthocyanims are rapidly degraded..... Enzimatic browning is usually prevented by blanching and the addition of acid. Very little pigment degradation is observed in frozen fruit products, as enzymatic browning is the major factor in the decolouration of frozen fruits". Later, he analyzes the colour measurement methods and instrumental and then covers a wide speotrum of fruits (citrus fruits: oranges, grapes, lemons and lime; pome fruits: apples, pears; stone fruits: peaches, plumbs, cherries; berry fruits: blueberries, cranberries, grapes; cane fruits; and subtropical and tropical fruits: bananas, mangoes, pineapples) giving details of colour pigment process of each, providing an extensive bibliography on this subject with more than 170 references.

Urbányi deals with the subject of colour on fruits and vegetables in a rather more general approach comparing results of visual assessment between a trained and no experienced panelists. As conclusion he states that "it was established that evaluation of taste was influenced by colouring differing from the natural. These samples obtained lower score than those of natural colour. The influence of colour on the value of taste was stronger with panel members of no experience than with expert panelists. The disturbing factors may be reduced, or eliminated, by setting up a panel of highly experienced members or by selecting appropiate conditions for sensory evaluation" (e.g. coloured illumination).

Vangdal studied what the consumer would like, at least, in his own country. He investigated pears, plumbs and sweet cherries. He inquired about 1500 people. The most interesting part of this inquiry was that people replied that "internal quality" is the most important but in fact they make their election by the exterior appearance which for them must be "attractive". They think that "size was the most important factor", but, "size and colour were of less importance as long as the fruit looked fresh and free from injuries". How does a fruit look fresh?. How can a fresh fruit be attractive without good colour?

Finally, Varady Burgetti & Lukács, study the type of colour measurement to determine the picking up moment for apples, and they find suitable the use of CIELAB units to it.

A.2.2 Pre-harvest treatment

As for vegetables, many different aspects of cultivation for fruits, are studied.

IWAHORI & al 1981, 1986; PATTEN & PROEBSTING (1986); PROEBSTING et al.(1984); SAPERS et al.(1983, 1986); SEKSE (1987) and WHEATON et al.(1985) published papers on this subject. Iwahori has used chemical products to fumigate pokan (a citrus type fruit grown in Japan) to shorten the time of ripening, improve its colour and to enhance its quality.

Patten & Proebsting have studied the effect of shading (artificial) on sweet cherries and they found out that depending when these shading takes place different delays in ripening can be achieved. The product weight or firmness does not seem to depend on shading, on the contrary, colour depends logarithmically with it.

Proebsting et al. also have done researches on the types of irrigation on the quality of fruits and the life storage of apples. They inform that "trickle" and "sprinker" irrigation produced similar quality and quantity and the storage life was not consistently influenced by irrigation.

Sapers et al. have studied the selection procedures for breeding programs of canberry. They measured Hunter's L,a,b and θ (arc tan b/a) on whole berry, pureed berry and juice and found a reliable method to choose samples of higher quality attributes. In another paper published three years later, Sapers and collaborators found that pigment (anthocyanin) content depended more on berry size differences than on differences in surface colouration (!).

Sekse studies the effect of low temperarure during the growing process of cherries which produced a sensible discolouration.

Finally, Wheaton et al., studied the effect of aldicarb addition to citrus production where they found out that, in general, there is little improvement (fruit size increase, external colour, and better resistance to freeze).

A.2.3 Post-harvest studies

SJULIN and ROBBIN, (1987) have published a paper which studies pre-harvest factors on post-harvest quality on red raspberry and they found out that these factors modify significantly the final product, depending on maturity and harvest date, the fruit colour was darkened when these factors are increased, also their anthocyanin concentration, but, changes in real hue were not much related to them.

Other papers were of DRAKE et al. (1982), ESTANOVE & COLLINS (1985), GILFILLAN & PINER (1985), GORMLEY & EGAN (1982), MUGRIDGE & CHAVES (1984), SCHALLER (1987), SANCHEZ NIEVA & MERCADO (1983), SAPERS et al.(1984), STUART THRONE & ALVAREZ (1982), YANG & CHINNAN (1987).

Drake et al. have found a colour grade to determine the maturity index of canned dark sweet cherries. They recommended to use reflectance value measured in "red Angtron unit" instead of the USDA subjective colour assessment. Independently of their results, the Angtron and USDA are not universally accepted units, therefore it would by very convenient to refer them to some known unit such as CIE or Hunter's L,a,b.

Estanove and Collins, also tried to establish an objective method for colour evaluation of limes using the known method of colour disks introduced many years ago by Nickerson. They introduced the "LAB" System measured by a "Digicolor of Neotec" instrument which is connected to an Apple PC. Most colourists could imagine what these authors wish to inform but a very few would be in good conditions to know exactly what they wish to mean. To add a little more confusion, they indicate that they use an "Polyton" instrument as if these were the only instrument used all over the world. The reader can imagine, by looking at the figures, that the known instrument is a disk colourimeter, but he will be completely lost when the authors indicate that the disk used were two green called T12 and X12 and the yellows B7 and B12.

Just fantastic! From this point of view, they built a theory which explains in simple terms the variability of colour in limes, and they produced a colour chart to classify them. It is a pity they only work for themselves. It seems almost impossible for other people to profit their work.

Gilfillan and Piner in South Africa are very interested, among other subjects in colour control of citrus export fruits. They studied the effect of polyethylene film-wrap on these products and compared the traditional waxed and tissue-paper wrapped fruit with those made with high and low density polyethylene films. The results showed to be highly promisory, while their internal characteristics were less affected to the fruit colour and almost did not change.

Gormley and Egan were interesed to point out which cares are needed to mantain tomato flavour and colour recommending that colour must be from 0.5 to 1 Hunter's red/yellow ratio when sent to market and from 1.5 to 2 when ready for consumption.

Mugridge & Chaves studies the colour evaluation during accelerated ripening and conservation of tomatoes. These authors only use a simple linear plot of a/b and the calculations with E (CIELAB) which provided graphs with similar sinusoidal behaviour. They also used an Ethylene atmosphere to store the fruits and they found that ripening can almost be stoped to the moment of sending the product to market when colour can be rapidly modified to obtain the colour need to comercialize. This process can also be delayed using CO_2 instead of air to mature the fruits.

Sanchez-Nieva and Mercado studies the effect of canning of green bananas. They found that organoleptic properties suffered no significant changes during storage. Only a light pink shade was added to the product probably due to the reactions of anthocyanines during heat treatment.

Sapers et al., worked with blueberries studying the effect of freezing, thawing and cooking on their appearance and they found that there were increases of darkness and redness measured in terms of Hunter's L,a,b values.

Sapers and his collaborators also studied the colour of fruit and juice of thornless blackberry cultivars after processing (freezing, thawing and heating). They found that colour changes (reddening) during frozen storage were associated with within-sample variability in ripeness; they analyzed in detail the effects of each of the processing steps.

Shaller has studied canned tomato paste keep at 40 °C (313K) measured spectrophotometrically have verified that Hunter L value has a linear decreasing with storage time in days. Also a,b and C decreased, instead, h, increased.

Stuart Thorne and Segurajauregui Alvarez were interested on tomatoes and, among other parameters, their colour. They measured Hunter´s L,a,b values and calculated the ratio a/b finding that the application of a previously published formula (THRONE & MEFFERT,1979)

$$\ln \{[(a/b)-(a/b)mg] / [(a/b)rr-(a/b)]\} =$$

$$= 4.54 + 6.17 [t/(27.5-T)]$$

where the subindex mg correspond to mature green, rr to red ripe tomatoes and t is the time in days and T the temperature in °C.

Finally, Yang and Chinnan have tried to model colour development in modified atmosphere storage using 20 different gas. The equation proposed is based on the previous work and they developed,

$$(a/b) = \{(a/b)mg+(a/b)rr [\exp (Co + M(G))t]\} / \{1+\exp [Co+M(G)t]\}$$

where Co is a constant and M(G) is a colour development index and it is a function of a gas composition. These formulae can be extended for all gas present. For the studied cases, their approach seems to work correctly.

A.2.4 Derived products

HUSZKA et al (1985), SPAYD and MORRIS (1981) and YANG & YANG (1987) worked with red pepper powders, strawberry jam and lowbush blueberry puree respectively. The first work introduces instrumental colour measurement and the CIELAB units hijing to define tolerances in terms of E*(CIELAB) and to divide this ΔE* in ΔL*,ΔC*, & ΔH*, establishing that, for these products (pepper powder), a tolerance of 3 ΔE* is the limit as far as H*<0 and |C*| < |L*| < |H*|. The second paper dedicated to the use of inmature fruits to produce strawberry jam only give an indication of colour intensity of lack of discolouration for mixtures of rippened and inmature fruits giving clues to obtain an acceptable product.

Finally Yang and Yang studied the effects of pH, chemicals and storage at 50°C and -20°C on blueberry puree. They measured colour through the absorptances ratio of of A_{520}/A_{440} and Hunter´s L,a,b values. They found that a higher pH, and SnCl2, SnCl4 concentrations produced a darker and bluish colour. An stable puree colour can be obtained by joint action of pH and these chemicals with a minimun effect from holding time and temperature combination.

A.3 Grains

De SA SOUZA et al. (1984), HOOK et al.(1982), Mc AULEY et al.(1987), RASCO et al.(1987), ROONEY and MURTY (1982), SCHALLER and BERGTHALLER (1987) and STINSON(1986) have published papers related with colour on grains of flour.

De Sa Souza et al. have controlled a wheat variety production along years to verify the pigment content on "candeal" type used mainly to export for noodles production. A hard type of seed. They verified that carotene pigment content can be verified with instrumental colour measurement without the need of pigment extraction.

Hook et al. verified the improvement of flour content with wheat moisture content.

MacAuley et al. have worked with wheat-based breakfast cereals finding that Hunter L value were positively correlated with all measures of Lysine availability and protein digestibility.

Rasco et al. studied baked goods containing distiller's dried grains with solubles from soft white winter wheat and they found that even colour was significantly different from normal bread used as control, the consumers tested did not appear to be affected on overall preference.

Rooney and Murty studied the colour of sorghum foods products finding improvements using instrumental measurement of Hunter's L,a,b values.

Schaller and Bergthaller studied the colour of maize produced in four different cultivars in Austria from 1984 to 1985. They measured Hunter's L,a,b values and their related C and h. An statistical analysis determined the variability reasons of each difference, finding out that the only difference in cultivars were significant but not on harvest year.

Finally, Stinson has done researches on yellow cakes baked in different cooking devices (microwave and conventional oven) and measured in Hunter L,a,b values. The differences between both methods, finding that microwave ovens can achieve a similar performance than conventional ovens in about 25% less time.

A.4 Non-alcoholic drinks

Several authors (BUSLIG & WAGNER Jr., 1984, 1985; DRAKE & NELSON, 1987; FELLERS, 1986; FELLERS & BARRON, 1987; FELLER et al., 1986; HUGGART et al.,1979; JOHNSON et al., 1983; KACEM et al., 1987, MORRIS et al.,1983, 1986; OLIVIERI, 1986; RUBICO et al.,1987, 1988; SISTRUNK & MORRIS, 1982; SAPIS et al., 1982; SKREDE, 1985,1987 and SKREDE et al., 1983) have done researches with non-alcoholic drinks obtained from fruits (orange, apple, citrus, strawberry, grape, peanuts, blackurrant).

Buslig & Wagner, Fellers, and Kacem, have worked with orange juices: a very important subject in the USA. Buslig and Wagner have tried the use of a commercial instrument to measure this product finding that with due statiscal evaluation of constants is possible, almost for any type, such is the Minolta Chroma Meter, a very simple filter tristimulus colourimeter, to achieve a good correlation coefficient with any of the parameters measured (CR, CY and CN) calculated as follows:

$$CR = 200\ [(1.277\ X - 0.213\ Z)/Y - 1]$$
$$CY = 100\ (1 - 0847\ Z/Y)$$
$$CN = 22.51 + 0.165\ CR + 0.111\ CY$$

Drake and Nelson worked on ultrafiltration of apple juice finding that process increased quality of colour in comparison with plate and frame filtration through an increment of red and green. Green component remained stable independently of the storage temperature varied from 1°C to 21°C, as well as clarity of juice. It is interesting to note that a test panel which evaluated sensorially the product, initially judged that the product was too light in colour and waterly in flavour , but with experience the criteria changed to accept it as a better product.

Fellers has digged on the problem of evaluating the quality of frozen concentrated orange juice and orange juice during a survey which lasted for three years (1983 to 1985). They found, among other variables, that colour have varied through the years. Lately, with Barron, Fellers have done a research on a commercial method to recover natural pigment granules from orange juices used for colour enhancement.

Other papers of Fellers and collaborators have dealt with quality of frozen concentrated orange juice determined by consumers and physical and chemical analysis. Among other variables measured was colour, which instrumentally showed a colour value over that required by the standards used in USA, but surprisingly, for consumers were "just right" or "somewhat too light in colour".

Huggart et al. studied the effect of colour on grapefruit juice consumers' preference and they found that colour has a significant effect on the acceptance. In general they found that yellowish-white to brownish-yellow (chamois) juices were preferred over either white or pink juices, finding also a bias between male and female consumers.

Johnson et al. investigated the relationship between taste and colour in strawberry-flavoured drinks, particularly sweetness and redness and using instrumental to measure colour in terms of a*/b* (CIELAB) compared with psychophysical evaluations using the magnitude estimation method and found that sweetness increased from 2% to 12% for a 4% sucrose increase showing that colour-sweetness function was linear over a narrow colour range.

Morris et al., and Sistrunk and Morris did a research on different factors affecting the production of grape juice colour (effect of Potassium addition, fruit maturity, storage, extraction temperature, cultivar and storage time and temperature). Potassium added in excess during fertilization can diminish colour quality and stability. Mature grapes produced juice with a better initial objective colour , as well as a superior sensory quality. High extraction temperature (99°C) resulted in juice with better initial colour than extraction at 60°C, but resulted in a greater browning and loss of total anthocyanins. High storage temperature (35°C) greatly accelerated quality loss. They found that sensory colour ratings correlated better with a ratio of absorbances at 520/430 nm and Hunter's a/b than any other objective colour measurement. Cultivars showed different behaviour for muscadine grape juice but results were similar to their previous work.

Olivieri investigated the effect of thermal treatment on the quality of concentrated grape juice, defining colour as a variable to adjust technological control, but this author "measure" colour through the spectral absorbances at 420 and 520 nm and their ratio. The same method is used by Sapis et al.

A very typical product of the USA, not much outspread in the world is the peanut beverage which is studied by Rubico et al. The only colour parameter measured is Hunter L value which is compared with sensorial attributes from light to dark, finding a good statistical correlation with other factors studied (suspension stability, and texture, for different temperature and time of processing).

Finally Skrede and Skrede et al. in Norway have been doing a research on blackcurrant syrup and juice evaluating it through Hunter's L,a,b values. They found that colour quality is better defined using the absorbances ratios at 520 and 420 nm. Also the hue angle [arc tan (b/a)] showed to be a good single indicator of acceptability. In a later work, Skrede compared CIELAB units with Hunter's, and the results showed that Hunter values expanded the scale allowing a better discrimination.

Deterioration of blackcurrant syrup were studied before on the same principles, finding that in this case the absorbance ratio has the advantage of being independent of the initial pigment content.

A.5 Alcoholic Drinks

The main subject under study in this group is the colour of wines. DIAZ, 1984; DIAZ et al.,1979a,b,1980.1983; HEREDIA, 1986, 1988, KERENYI & KAMPIS, 1984; NEGRERUELA & ECHAVARRI, 1983,1988a,b,c; SIMS & MORRIS, 1985,1988; SOMERS et al.,1983 and SOMERS & EVANS,1986, have published papers related to this subject. BELCHIOR, 1983, completes the list with a paper on colour of brandies.

Diaz with his collaborators give a list of colourants of wines and study the quality atributes during preconservation process, finding that desulfitation produces an important loss in colour, measured through the absorbances at 520 and 420 nm and their ratios compared with visual estimation. Also these authors studied the effect during storage, finding that when the volatile fraction is kept with the liquid juice, the colour does not suffer major modifications. Instead, storage time modifies noticeably colour (in order of 25% after one year period) when storage is at room temperature (20-25°C) than when is stored at refrigerated temperature (1-5°C).

Heredia Mira et al. tried to measure colour in terms of the CIE frameship using also CIELAB transformation. Heredia Mira and Guzman gave a step forward in this direction, classifying the different colour of wine defined by the OIV (Office Internationale de la Vigne et du Vin) in terms of CIE x,y units showing that saturation appeared as the most representative parameter of colour evolution, showing that CIE Uniform Colour Spaces are more reliable than non-uniform ones.

Kerenyi and Kempis also did a research on the same line but they defined a colour parameter in function of the absorbances already mentioned

$$N = 23 \log [A(420nm) + A(520nm)]$$

which they defined as the "Logarithmic colour intensity of red wine".

Negreruela and Echavarri have published during the last years, three papers related to the same problem, this time dedicated to the well known wines of La Rioja, in Spain.

They compared the OIV method with the new official standard in Spain using L*,C*,H* in CIELAB units, finding it much more significative than the other traditional method. They also compared both methods in red wine dilutions and the Schefe's design to calculate the colour of the three red wines mixtures. In both cases the use of CIELAB units help to describe properly the effects of these processes.

Sims and Morris also were interested in red wines, but they produced their results in terms of the traditional method of absorbances. They studied colour components and colour stability of Noble and Cabernet Sauvignon red wine at different pH levels and the effects of acetaldehyde and tannins on the colour of red muscadine wine.

Somers et al. and Somers and Evans, worked also on colour of Shiraz and Cabernet Sauvignon red wines using the absorbances at 420 and 520 nm as parameters to evaluate colour. They studied the diversity of composition during early maturation.

Finally, Belchior proposed to measure colour of brandies measuring the absorbance at 440 nm.

B. Animal products

This part of the review is divided in five topics.

a) General.
b) Meat (Cattle, Lamb, Pork and Goat).
c) Poultry (Chicken and Turkey).
d) Fish and Sea products.
e) Industrial derived products.

B.1 Literature which deals with general aspects of the problem

Donald H. Kropf (KROPF, 1980; 1984; KROPF & HUNT, 1984; KROPF et al., 1984) have published different papers dealing with general aspects of measurement of colour of meat and frozen meat and their retail display conditions.

He explains that is in favour of reflectance measurement instead of pigments extraction. Textually, he asks "Since we are primarily interested in surface colour, how deep can sample be and still have the correct proportion of pigment?". He also is aware of the difficulties and states "However, reflectance measurements are affected by muscle structure, surface moisture, fat content and pigment concentrations". He also adds "With reflectance measurements, sample presentation causes more differences than the instrument" and he gives a general procedure to follow in these cases.

When he describes the effect of retail display conditions he is aware of the different factors which take part on the visual assessment, lighting spectral characteristics and intensity, temperature, packaging and atmosphere giving a detailed list of of parameters to be care of.

When he analyzes what happens with retail packed frozen meat he details the effects of temperature, film properties, management of the cut system, including lighting effects and the consumers answers. He refers to a paper of NELSON (1964) where it is said that "36.7% of meat purchases from self-service counters were unplanned and impulse purchases were made primarily because of attractive colour"

Kropf clearly describes the phenomena when he says that "display conditions frequently put meat under considerable stress. They are subjected to rough handling, to adverse effects of lighting and to temperature variations, which may include abusive temperatures" and he adds that "Rejection of displayed meat frequently is a result of product discolouration".

Other two papers from PIPEK et. al. (1981) and PRIBIS & REDE (1981), study the method to measure colour on meat and Pipek finds good relation between spectral reflectance measurement and other methods, instead, Pribis and Rede of Yugoslavia employ the term density and they replace transmittance by reflectance.

$$D=\log (100/R)$$

They also use the known Kubelka-Munk relation K/S at different wavelenghts and compare results with Munsell and Hunter systems.

It is interesting to find in the literature, works as that produced by BARACCO et al.(1984) where they investigated the use of natural pigment to colour meat, such as the canthaxanthin, a carotene type, which is applied to raw products of the type of sausage and fish patês. Other different subject but with the same goal: The display attractive meat is treated by Unruh and co-workers who studied the effect of low-voltage electrical stimulation during exsanguination on meat quality and display colour stability finding what that process is detrimental to meat quality. Many other aspects which affect colour of these products are under research.

A special paragraph should be made here on the work of a canadian scientist who really has innovated the field developing and using different kinds of instruments, mainly based on fiber optics. I refer to H.J. Swatland from the University of Guelph. His work is one of the most interesting of all reviewed. Using fiber optic spectrophotometry, he digs in many problems not previously treated such as iridescence of meat, determination of wetness of meat by optical methods, interface conditions and various other subjects.

He is not the only one who has used fiber optics for colour measurement, but he has done a great deal of work which have opened new frontiers in this type of research.

His work was very impressive and he, on our request, prepared, specially for this ocassion, a summary of his research, which, for reasons of space and time, it is necessary to shorten. It is highly recommended to read his publications if you intend to start with colour measurements in foods, particularly in meat. As Swatland lists, the main advantages of this optical fiber spectrophotometry method, are:

a) To bypass meat surfaces that have been partly dehydrated or exposed to atmosphere (thus avoiding surface oxymyoglobin and metmyoglobin).

b) To obtain measurements without slicing the meat in an attemp to produce a flat surface. Measurements from intact carcasses may be made without appreciable commercial damage.

c) Using a Xe flash and photodiode array spectrometer, measurements can be made in less than 10s. Portable instrument may be developed with low power requeriments and water resistance design. They can be sterilized or cleaned routinely.

d) With a long fiber the measurement can be taken at distance in different ambient conditions, like in a freezer.

The main difficulty of this method is the relationship between this type of measurement with the visual evaluation due to the factor that the optical fibers, normally, require to be in contact with the specimen.

With reference to this line of work he also was able to detect pale, soft exudative pork meat in carcasses, dark-cutting beef. He measured Rayleigh scattering in meat. Fluorescence excitation and emission spectra in biochemical types. ß-carotene in beef fat (yellowness) infared reflectance. Correlative studies of redness in veal with levels of dietary iron and pH. Hemoglobing degradation and pathology of porcine lymph nodes. Measurement and detection of deep pectoral myopathy (green muscle desease) in turkey. Darkening in muscle seams in poultry meat products. Measurement of nitrosylhemochrome formation in relation to the nitrite concentration in meat products. Research of pinkness in cooked meat products. Research to develop method for determinig the sex of new-hatched chicks. Measurement of meat pH using phenaphthazine. Real time measurement of meat browning during cooking. Reflectance spectrophotometry of particles and continuous phase components of chromatophore state in squid mantle. Measurement of browness of potato chips. Measurement of ripeness in tomato grading and measurement of chromatophores in fish skin.

The list is really impressing, and shows a very interesting new approach to appearance measurement on foods, in general, not only on meat with a very wide range of applications, which, if extended, promises a new dimension of the art and science of colour measurement of foods. (For more details see SWATLAND 1982 to 1989).

B.1.1 Cattle meat

BEVILACQUA & ZARITZKY (1982,1984),COSENTINO et al.(1982), FAGOTTI et al.(1984), FRESCHI et al(1984), GIAMBACORTA et al.(1984), MATTASINO et al.(1984a,b),MEANS et al.(1987), MILLER et al.(1986a,b), MOLINS et al.(1987), NEWSOME et al. (1985), ORCUTT et al. (1983) and ZARITZKY (1982), did a research on cattle meat.

Cosentino et al., Freschi et al., Giambacorta et al. and Mattasino et al., have compared the effect of different breading and age on the quality of buffalo and bovine meat in Italy. They measure the spectral reflectance at 9 specified wavelengths (426,470,490,520,550, 580,600,660 and 684 nm) and they compare differences in these reflectances deducting from them, the total colour difference, particularly if they observe that reflectance increase for the majority of the wavelengths. They conclude that brightness is increased. It is a pity that this interesting work does not use better parameters to specify colour differences.

Fagotti et al. worked on the thermal treatment of canned corned-beef and the sterilization temperature effect on the surface of this product, determining the colourimetric parameter which correlates better with the kinetics of the colour change in terms of the CIE, CIELUV and CIELAB units.

Means et al., Miller et al. and Molins et al. studied the problem on structured beef steaks, restructured steaks and patties, respectively. Means et al. were interested to know the effect of algin/calcium binder on the sensory properties finding that alginate coatings may positively influence colour depending on the type of package. It could look better but also can have a more rapid microbial growth and quality deterioration (!).

Miller et al. found that restructured steaks made with 1% KCl, 0,5% MgCl and 0,5% CaCl were more "desirable" and darker red that other blends. They tried also cooked products, and studied the effects of other additives such us STP (sodium tripoliphosphate), SHMP (sodium hexa-metaphosphate) and SAPP (sodium acid pyrophosphate) which can produce positive or negative colour judgement. One must be

Johasson and his collaborators were interested in station testing in pigs and the genetic factoring colour of pork meat measured with reflectance spectrophotometer and found that colour was affected detrimentaly.

Finally, once again, Swatland showed how to use a fiber optic spectrophotometer measure colour of pork and veal carcasses.

B.1.3 Mutton and goat meat

Only two papers were found on this subject: BARTHOLOMEW & OSUALA (1986) and CHIOFALO et al. (1983).

Bartholomew and Osuala were interested in the flavour, texture and appearance of mutton processed meat (frankfurters, sausage, rolls, patties, jerky). Instead, Chiofalo et al. studied the effect of electrostimulation in the colour of 10 goat muscles. Using a spectrophotometric colourimeter, they studied the effect under diverse illuminants of several consequences like colour tends to become slight lighter and redish after electrostimulation and by genetic selection. Colour is also better under illuminant CIE A than for C, D65 or F.

B.2 Poultry products

Colour of chicken and turkey meat has been studied by CORNFORTH et al. (1986), SWATLAND (1983), SWATLAND and LUTTE (1984) and YI and CHEN (1987).

Cornforth et al. studies the pink colour deffect on cooked turkey rolls using a spectrophotometer to evaluate colour effects and the action of reduced hemochromes.

Swatland was interested to evaluate colour changes in cooked chicken muscles which an optical fiber spectrophotometer and he found good agreement with the results obtained with a Gardner and with a Hunter colour measuring instrument. In his paper, Swatland shows the spectral differences only. It is a pity he did not evaluate them in terms of colour differences.

Swatland and Lutte tried to find a way to detect a deep pectoral myopathy in turkey carcasses by means of an optical method using a optical fiber probe, determining that three types of lessions could be identified through its colour (red-purple, green and yellow). The ratio of spectral reflectance at 480/550 nm was found to be a simple method to detect affected meat without slashing the breast muscles.

Yi and Chen worked on chicken patties studying the effect frying and internal temperature on yield, colour, moisture, and microbial content. They found that moisture and internal temperature was more important than the frying temperature. Higher frying and internal temperatures decreased Hunter's L and a values.

B.3 Fish and sea products

CHOUBERT (1982), RASCO et al. (1987), SKREDE & STORE BAKKEN (1986 a,b), TAKAHASHI & KHAN (1987), YANG & YANG (1986) and YOUNG & WHITTLE (1985) have worked on different problems related to careful when adding things to the "restructured" beef.

Molins et al., were interested in hamburgers called "patties" and the use of additives used like STP or the TSPP (tetra sodium pyrophosphate) which, at least, did not show evidence to be able to modify colour parameters (Hunter L and b).

Newsone et al., studied the effects of cattle finishing systems on carcass traits and ageing methods on loin shrinkage steaks colour, particularly the effects of final breeding of cattle with forage and limited-grain measuring the colour of processed meat, and they found that, in general, colour differences were not significant. In other words, if in the final stage of cattle breeding, the dealer saves money using less expensive grain, the produced meat with these animals will not show much difference.

Orcutt et al. studied how to avoid a dark, coarse band in the longissimus muscle of cattle, and use colour as a parameter to evaluate that phenomena, finding that the Hunter's L,a,b values were convenient to quantify the colour differences observed.

Finally, Bevilacqua and Zaritzky, and Zaritzky, were interested in colour of chilled and frozen meat products, quantifying the effect of these processes on the meat colour (cattle liver), establishing how the cristalline size of the ice formed in the surface, affects the product appearance.

B.1.2 Pork meat

ARGANOSA et al.(1987), CLAKINS et al.(1986), EDWARDS et al.(1985),HUSZKA et al.(1981), JOHASSON (1987), JOHASSON et al.(1987) KROPF et al.(1981?) and SWATLAND (1986) were involved in some aspects of pork meat colour measurement.

Arganosa et al. were interested on pork sausage, replacing fat or lean with collagen. To evaluate colour they used a tristimulus colourimeter and determinated the L,a,b values. They found that the replacement of lean tissue with collagen increase L and decrease a and b, in other terms, colour of pork patties were washed. When cooked colour was more homogeneous was due, probably,to non-enzymatic browning.

Calkins et al. and Kropf et al. were interested in the retail display lighting type to exhibit pork food and the colour produced. They have found interesting lighting effects on blood pigments (myoglobin, metmyogoblin) and, consequently, colour effects which were shown on the L,a,b values modifications through meat exposure time. Kropf et al. worked on the film used to pack the meat.

Edwards et al. studied the effect of maize gluten level feed on the colour of pig carcasses among other quality characteristics and they found that increasing the maize gluten feed in diet had good statistical correlation with a yellower, less white fat. The fat become darker.

Huszka et al. dig in the problem of change of colour due to nitrite adding used for pickling, but fundamentally, to show the improvements achieved using a colour measuring instrument and the CIELAB system, particularly ΔE to avaluate grading of meat.
these products.

Choubert was interested in the colour of rainbow trout after ingestion for four weeks of canthaxanthin and he found that a good statistical correlation for the dominant wavelength λd (0,905), the tristimulus coordinate $\underline{x}$ (0,856), purity $\underline{Pe}$ (0,821) and luminosity $\underline{Y}$ (0,717), concluding that reflectometric measurement are equivalent to chemical analysis and that measurement in both CIE (X,Y,Z) or Hunter (L,a,b) systems enable definitely to determine the muscle luminance in a canthaxanthin pigment trout and that the CIE systems allows a better differentiation between samples.

Rasco et al. worked on the consumer acceptability and colour of coated deeps-fried fish. The use of destillers dried grains with solubles from red and white wheat, and corn, could replace all purpose flour to obtain an acceptable product.

Skrede and Storebakken studied the colour of salmon. They used CIELAB units using a portable colourimeter and compared the results with an spectrophotometer finding a good correlation among them. They found no differences in colour of farmed and wild salmon, and that the redness and hue in processed salmon were predictable from the redness and hue of the raw flesh.

Takahashi and Khan worked on salmon steaks, they studied colour only through a panel evaluation in terms from very desirable to very undesirable.

Yang and Yang were interested in squid tentacle protein and its extraction and the effect on the quality on surimi gels, finding that the reddish pigments retained in the squid proteins also made the surimi gels darken and redder providing a natural colour to the finished products which resembles commercial frankfurtes.

Finally Young and Whittle defined a colour measurement method to be used with fish minces in terms of the Hunter L,a,b values evaluating differences in ΔE units. They classify different types of fish mines and give tolerances adding textually at the end of their paper: "The results so far show that colour matching of fish minces cannot be expected to be as good as in other applications (e.g. textiles, printing inks, and paints) because of the inherent difficulties of controlling the homogeneity of prepared minces. However, they do provide a good basis for assessing the practical limits of grading for colour, both among species and the various types of minces derived from them. The value of different approaches to processing and preparing materials for recovery of mince can be compared in terms of the likely effects on the colour of the product".

B.4 Industrial products and diverse research

Different industrial process elaborate raw food. Dairy products, protein replacement, processed meat are subject of research in different laboratories. Research on browning (enzymatic or not) is also a problem studied in several places. The following lines are dedicated to these aspects of colour on foods research.

B.4.1 Dairy products

Ádesso & Kleyn (1986) were interested in the acceptance of ice creams using a sensory evaluation panel which made general assessments, in which, there was an appearance judgement.

B.4.2 Processed food

GOUTEFOUGEA (1980), JIMENEZ COLMENERO & GARCIA MATAMOROS (1984), JIMENEZ COLMENERO (1985), NOEL & GOUTEFOUGEA (1985), SMITH &

BREKKE (1985), and THIEL et al. (1985) have investigated different processed foods.

Goutefougea studied the effects of residual nitrite level and packaging conditions on colour stability of cooked ham. He found packed ham exposed light with very small residual nitrite only a very good vacuum can mantain colour characteristics, almost as good as the non-exposed ham. Colour degradated as the vacuum quality decreased.

Jimenez Colmenero and Garcia Matamoros and Gimenez Colmenero et al. were interested in mechanically recovered meat used in hamburgers. In the first work they studied the effect of frozen storage and, also, in both works, the proportion and types of meat used. They found that the addition of mechanical recovered meat resulted in a significant decrease of <u>L</u> and an increase of <u>a</u> (redness). The <u>b</u> value depended only on the type of meat used. They also verified that freezing process will decrease a value (Probably due to oxidation of myoglobin and metamyoglobin).

Noel and Goutefougea presented a work on the study of Frankfurter sausages based in ....vegetable proteins(!). That is: without meat. The results shows how to elect the colorant and the quality needed, but, the interesting part, is that the panel evaluations were divided in two antagonic groups which have preferred colours in a contradictory manner: one group preferred pale colours because saturated colours seemed "not natural" and the other preferred saturated colours because pale colours are supposed to be due to a high lipid content of sausages.

Smith and Brekke studied frankfurters made with enzyme-modified mechanically deboned fowl, finding that enzymatic modification had no adverse effects on cured meat colour.

Finally Thiel et al., observed the effects of salt reduction on colour, among diverse characteristics, on emulsion-coated chunked and formed ham, finding that is possible that the salt addition could benefit colour intensity, although very little differences in cured ham colour uniformity were noted. A better colour uniformity was detected for hams with higher salt level content.

B.4.3 Protein sustitution.

Three french papers dealt with vegetable protein replacement of meat and the achievement of a colour similar to meat product using a hemoglobin product transformed by its nitrosation. CULIOLI et al. (1981a,b) and NOEL et al.(1984) have done this type of work, where they tried to produce meat products without meat. As we discussed before in the work of Noel and Goutefougea (which also are french), or, at least, with a much lesser proportion of it. With the aid of an spectrophotometer for colour measurement, they conclude that the results obtained permits to predict acceptance from consumers. It also has some advantages: colour does not change much when the product is exposed to light and air, and, in some cases, the fibre used had less free nitrite content than those generally found in traditional cured meat products.

B.4.4 Browning process

Browning process can be due to two reasons: enzymatic and non-enzymatic. The papers of the literature were divided in these two groups. SAPERS and DOUGLAS (1987) and SAPERS and ZIOLKOWSKI (1987) worked with enzymatic browning. Sapers with Douglas studied raw apple juice and pear fruits, and with Ziolkowski, only apples. In both cases the authors quantified the browning effect through Hunter L and a values, and they found that, in this way, they could measure the effectiveness of additives such as ascorbic acid or erythorbic acid.

BOLIN and STEELE(1987), BOLIN et al.(1985), BUERA (1986), BUERA et al. (1984, 1985, 1986a,b, 1987a,b,c), KACEM et al. (1987), PETRIELLA (1983, 1986), PETRIELLA et al. (1982, 1984, 1985, 1986) and TORIBIO et al. (1984) have published works on non-enzymatic browning process.

Bolin and co-workers investigated this process on dried Granny Smith apples during storage and the effect of sulphur dioxide on them. Using a portable tristimulus colourimeter they measured L*, a*,b* CIELAB values and they measured ΔL* verifying that non-enzymatic browning can be diminished using additives like SO2, with vacuum or with gas atmosphere (CO2, N).

Kacem et al. studied this phenomena in aseptically packaged orange drinks, and the effect on it of ascorbic acid, amino acids and oxygen through measurements of absorbance at 420 nm, and they found that packaging in polyethylene pouches greatly accelerated the loss of ascorbic acid due to higher oxygen content and increased, consequently, browning. They also found that ascorbic acid was the most reactive constituent of orange drinks with respect to the formation of browning pigments and, that its effect on the browning reaction, was much more intense in the presence of oxygen, and that the effect of the amino acids on browning of orange drinks, was strictly linear within the concentration range and produced greater browning reaction in the presence of high levels of ascorbic acid.

Finally, the work of Buera, Buera et al., Petriella and Petriella et al. deal with non-enzymatic browning in liquid model systems of high water activity for different carbohydrates (fructose, glucose, hexose, lactose, maltose, sucrose and xilose), with or without aminoacids (lysine, glicine, di-glicine, tri-glicine), potassium sorbate to control bacterial growth and phosphate buffers.

This research carried on for several years, was oriented to find the kinetics of colour degradation. The use of liquid model systems allowed to determine the basic reaction effect present in most natural products which contains carbohydrates, in systematical form, making possible to predict fundamental browning reactions in many natural products like foods, such us the Maillard reaction and caramelization.

The authors measured colour spectrophotometrically and correlated statistically different colour parameters (such as CIE, CIELAB and CIELUV units) with the reactions observed, finding that several of them can be used to describe adecuately the kinetics of the browning process.

As result of all this work, and processing all the data obtained, BUERA et al. (1985/86) have published a paper which describes what colour is brown in the browning process in terms of CIE x,y chromatic colour space.

V. CONCLUSIONS

After all what was said, the main remarks are:

i) Many studies are being made or under development respect to colour measurement on foods or food products.
ii) Most of them define colour parameters inappropiately.
iii) There are some remarkable work done with respect to colour measurement. Particularly those of Kropf, Lukács and co-workers, Negueruela and Echavarri, and Swatland.
iv) There is a general need to give guidelines to food technologists (perhaps through specializated literature such as the Journal of Food Science, etc,) how to proceed with respect to colour evaluation and measurement. Perhaps, too, this can be a task of the AIC.

VI. APPENDIX

BASIC GUIDELINES HOW TO PROCEED WHEN COLOUR EVALUATION OR MEASUREMENT IS NEEDED TO BE APPLIED IN FOODS OR FOOD PRODUCTS

1) If the colour evaluation is made subjectively, a psychophysical method should be applied (e.g.magnitude estimation, ranking, etc.) Samples should be measured objectively. When this is not possible, they should be described in terms of some known Colour Order Systems such as the Munsell, DIN, NCS, etc., which can be translated to the CIE System. Particularly, the anchors of the visual experiment should be identified in these terms. Lighting is a matter of importance and should be described in terms of the spectral composition or the Colour Rendering Index with respect to the Standard Illuminant selected. Also the illumination or the luminance level of the task should be quoted.
2) If the colour measurement is made objectively, CIE chromaticity coordinates or tristimulus values or any of the alternative recommended Systems should be used, preferably the CIELAB. The data must be completed indicating the Standard Observer used, Illuminant, geometrical conditions, reference used (in absolute values) and all other pertinent detail. It also should be given the instrument error and the dispersion of the measurements.

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COLOUR IN SIGNALLING

INTRODUCTION

James Clerk Maxwell, the great Scottish physicist, who was not only a pioneer in the area of the physics of light, but also in the area of the psychophysics of colour vision, once said: "All vision is colour vision, for it is only observing differences in colour that we distinguish the forms of objects. I include differences in brightness or shade among differences of colour"(1). On the basis of our present knowledge this might be considered a too extreme point of view, but colour, including black and white, is undoubtedly the most important "substrate" of our visual perception. It is almost self evident therefore, that colour is the obvious means for visual signalling. In nature this aspect of visual communication takes many forms, as in the colours of fruits of plants and trees, that depends on animals for their dissimination. When the fruits and plants are ready for comsumption this is indicated by a change of colour, like for example the change from green towards orange of the berry of the Rowan tree. Also the colours of flowers, tuned to the visual system of their pollinators, act as beacons in a sea of vegetation.

In the animal world colour also plays an important role. This is particularly true for communication within the species, but colour may also be used as a warning signal against ennemies. Examples are the red belly of the courting male stickleback (an attraction signal for the other sexe), and the yellow and the black stripes by wich the wasp reminds his ennemies that he is unsuitable for consumption. The vivid colours and contrasts of some very poisonous South-American species of treefrogs have the same warning value. Unfortunately this works the other way around towards another ennemy, the Amazone Indians who catch them for extracting poison for their arrows. For the human species the signal function of his (natural) body-colour is of little significance. Even the changes in facial colour, signalling changes in emotion, are subordinate in respect to our mimically dominated visual communication. Colour, however, plays a most important role in society. In the folowing, example will be given of the countless applications of the use of colour, especially the specific advantages of colour coding and the visual ergonomic aspects involved.

WHY COLOUR?

Colour is only one of a number of possibilities for visual signalling. Other examples are the modulation of brightness (flicker), form coding (traffic signs) and, of cours, geometric and alphanumerical symbols. One of the questions is whether colour is better or worse than other sorts of achromatic information coding. As we shall see, a lot depends on the kind of information.
One can distinguish between information of whici the "what"is known but not the "where", and information for which the opposite is true. In the first case one is concerned about a search task, for instance a route-indication along the road, or an error announcement on a

control panel. In the second case we are dealing with identification tasks, for instance the colour of a traffic light, or the colour coding on a resistor. Much research has been done on the effectiveness of colour coding with respect to other ways of coding, usually in terms of the speed and accuracy by which information can be processed. In fig.1 an overview is given, based on the well known literature survey of Christ (2), of the result of various studies that compare the efficacy of colour coding relative to other coding modalities.

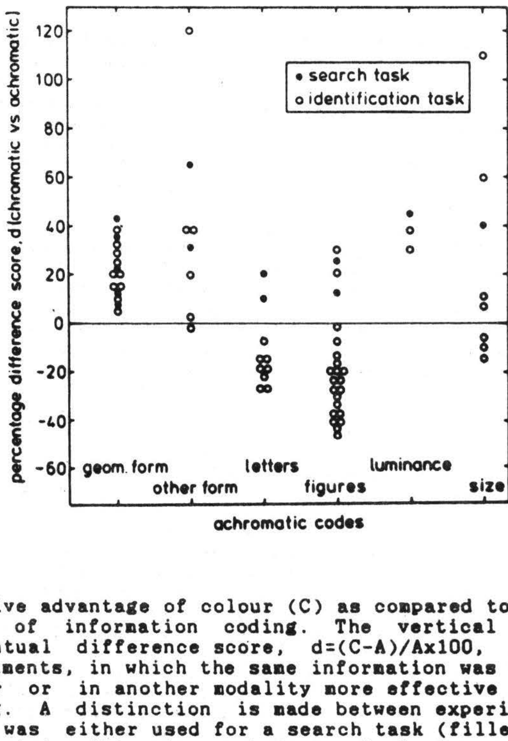

Fig.1 Relative advantage of colour (C) as compared to achromatic (A) forms of information coding. The vertical axis plots the percentual difference score, d=(C-A)/Ax100, of 65 different experiments, in which the same information was coded either in colour or in another modality more effective than achromatic coding. A distinction is made between experiments where the code was either used for a search task (filled circles), or for an indentification task (open circles).

In fig.1 the data indicate that for d>0 colour coding gives better results than the other, achromatic codes. this was always found to be true for search tasks. In identification tasks, colour also has almost always the edge on other coding forms. The exceptions are when colour is compared with letters and figures. A colour look at these experiment in which colour was used for quantitative coding, like the colour coding on resistors(3). It is not surprising that our skill of reading figures and letters, obtained over many years of practice, is better developed than our reading of colour combinations.

One of the most important advantages of colour coding is that it can be added without interfering with text or form. Put in another way, the physiological channels that analyse the form of the letters are not overloaded (no changes of form are introduced). The extra information is added parallel, by means of the colour channel. It is clear that parallel processing of information increases the speed and amount of information transfer.

A second useful property, associated with the former, is that colour coding does not take any space. It is particularly suited therefore, for adding labels to complex form information, like text or electronic wiring.

A third advantage is that colour is the ideal means for area-fill, a property commonly used in the reproduction of geographical information (maps). The alternative, adding texture (for instance shading or dotting), porvides less variation, and may interfere with the readability of alpha-numeric or geometric symbols (4).

A four important property of colour is that it can be perceived in the peripheral visual field, at excentricities where form coding is out of the question. Although this is also possible with luminance modulation and movement, the number of possibilities for variation is limited and not always practically feasible.

As a fifth and last useful property of colour the added contrast between signal and surround can be mentioned. The visibility of weak luminance contrast can be increased by adding a colour difference (5). Thus, too strong contrasts which may lead to dicomfort can be replaced by colour contrast.

The majority of these advantages of colour coding can be attributed to the fact that the visual system uses two separate channel for the processing of the chromatic and achromatic information (6). By omitting the use of colour one only exploits part of the available capacity.

After this discussion of laboratory results on the usefulness of colour coding, one migth ask what can be expected in practice. That depends entirely on the specific application, but next example of such an application, i.e., the improvement of the conspicuity of local guidesigns, shows that their colour can be very effective indeed (7). These relatively small signs, showing black figures on a light grey background, were hardly visible in town areas, so traffic authorities wondered whether conspicuity could be improved by adding a blue rim to the sign.

In order to evaluate the effect of the addition of this blue rim, slides were made which these signs were shown against various urban backgrounds. The slides were presented to testees as short flashes. The observers were asked to detect the sign using as few flashes as possible. The number of flashes necessary for detection was assumed to be a measure for conspicuity. A conspicuity index was definned, i.e., the inverse of the average number of flashes required for detection (1/n). Fig.2 shows that adding a blue rim increases the conspicuity index 3 to 5 times, dependent on the saturation of the blue rim.

ERGONOMIC ASPECTS

Colour coding for information belongs to the field of visual ergonomic. This implies that one has to take into account the restrictions and possibilities of the human observer. That, in turn, requires some knowlegde of the psychophysics and the physiology of colour vision. Here we will limit ourselves to only a few aspects that are important for the ergonomics of colour coding.

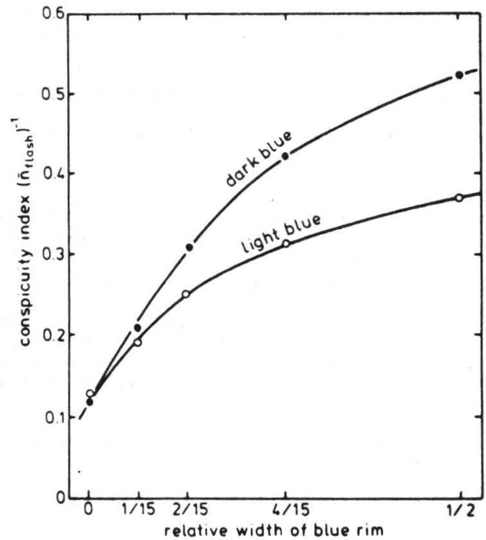

Fig.2 Effect of the blue rim width on the conspicuity index (see text) of local guidesigns. The width of the blue rim is specified as fraction of the total width of the sign.

Relations between colours

Colours can be related to each other. These relations come forth from the physiology of our colour generating system. Without adequate knowledge in this field one cannot apply colour in an optimal way, that is, have a natural mapping of task variables on colour variables. The following colour coding problem may illustrate this. On a process control panel, colour coding is to be applied for both the differentiation between several kinds of pipe (for example oil and water), and for indicating the temperature variations in those pipes. If, for example, red and blue are chosen for the description of high and low temperature respectively, then only one colour, white, can be used for the pipes. Otherwise, the combination of temperature and type of pipe is not possible in the colour domain. For example, a yellow pipe cannot be combined with blue (=cold), because we cannot perceive blue and yellow simultaneously (there is no bluish-yellow colour). By choosing green instead this problem would seem avoidable, for the combination blue-green exists. However, green cannot be combined with red, since no red-green colour perception exists. Therefore, the best solution for this colour coding problem is to use red and green for the temperature coding instead of red and blue. The colours white, yellow and blue and all their intermediates can then be chosen for colouring the pipes. Only these colours are perceptually compatible in the sense they can be combined with both red and green. This is a direct consequence of the antagonistic links whithin the red/green and the blue/yellow channel of the visual systems (8).

A three-tridimensional representation can best be used to describe the relations between colour. When limiting ourselves to the most saturated hues, then the most natural representation is a circle in which the colours are arranged in the same way as the wind direction on a compass. Thus the four main directions are represented by the basic colour sensations red, green, blue and yellow, in which red(R) is diametrically opposed to green(G) and blue(B) opposed to yellow (Y), all in accordance with the afore-mentioned antagonistic relations between blue/yellow and red/green.

In fig.3a the natural ordering of hues is shown according to the hue-circle of the Swedish Natural Colour System (8). Notice the every hue can be described as a combination of two adjacent main directions, either yellow and red, red and blue (the purple hues), blue and green or green and yellow. For example one can imagine that a blue-green which resembles green is composed of approximately 80% green and 20% blue. Using the NCS-hue circle one expresses this by B 80 G. Hues of complementary colours, or colors that exclude each other lie opposite on the hue circle. Moving inwards from the border of the circle towards the centre, the hue of the colour remains the same, but the saturation diminishes. In the centre the colour is neutral. Here third axis, the achromatic or black/white axis, provides a third dimension.

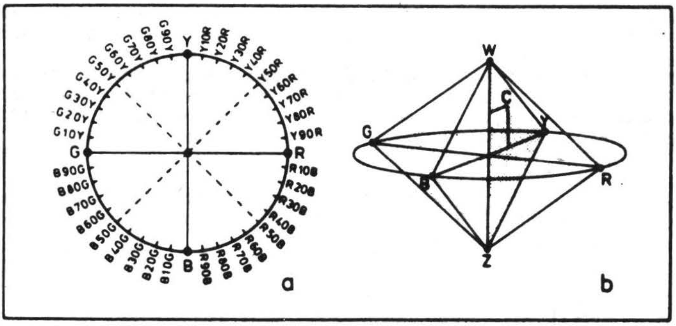

Fig.3a Example of ordening of hues in a natural order (NCS-system). The 4 basic colour sensations red(R) and geen(G) as well as blue(B) and yellow(Y) are diametrically opposed to each other (see text for details).

Fig.3b Colour space composed of the hue-circle and a central black/ white axis. In the plane B a colour C is indicated with a pure yellow hue. This colour is relatively unsaturated, i.e. rather close to the black/white axis (z/w) and with a light shade, i.e. closer to white than to black.

Fig.3b illustrates how the hue circle can be extended into three dimensional colour space by adding the achromatic dimension, the black/white axis (ZW-axis). By indicationg a colour point C it can be illustrated how a colour sensation can be located in this space. Point C indicates a pure yellow hue (Y), which a certain extent of saturation (the distance towards the black/white axis), and a certain lightness (the position along that axis). This representation only holds for colours of object (for example the red of a strawberry). In addition to these object or surface colour we also have to consider self-luminous or aperture colours (for example the red of a traffic light). How the latter have to be represented in an aperture colour space has still to be decided.

The colour space as shown in fig.3 gives a qualitative impression of the interrelation of colours on the perceptual level. On the stimulus level one can show these relations as well, in particular by so-called UCS (uniform chromatic scale) representations, like for example the 1976 u'v'-colour diagram of the CIE (Commission Internationale de l'Eclairage) which underlines the CIELUV system (10). Thus, more quantitative values can be given about distances in colour space, which means differences in hues including the differences in the relative luminance of the colours concerned. Systems like the CIELUV-system find applications in the evaluation of the contrast of colours relative to their backgorunds (11,12). This type of research can lead to rather unexpected results. Who, for example would suspect that for a given luminance contrast, a white text is far better visible against a red background than against a green background.

Perceptual Artefacts

A perceptual artefact might be defined as a colour responce to a stimulus that differs from what would have been the "normal response". There are quite a few of such atrefacts that may interfere with colour coding. Best known in this respect are the chromatic colour induction effects (simulations colour contrast, chromatic adaptation), that are consequence of different mechanisms the visual system employs to analyse the colour information in the retinal image (13,14). Thus, a colour which normally is perceived as white, can turn into any other colour, dependent on the colour of the adjacent surround (15).

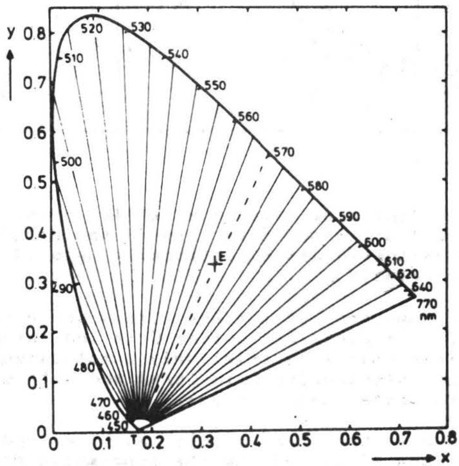

Fig.4 CIE colour-diagram with colour confusion lines for tritanopia. These lines connect cromaticities that are indiscriminable for tritanopes. The dotted line connects points which are confused with the white point E (equal energy).

Approximately another dozen of chromatic artefacts exist (17). One of these, in the literture described as "small-field tritanopia", is a form of colour vision deficiency, to which everybody is susceptible. It occurs for stimuli subtending angles smaller than about 10′. This form of colour vision deficiency can be attributed to relatively small numbers of blue-sensitive cones in the retina (18). It is well known that the stimulation of blue cone system may drop below a colour discrimination deteriorates rapidly, resembling a rare form of colour vision deficiency: tritanopia. Tritanopia occurs when the blue cones are absent or inactivated. Fig.4 shows the tritan confusion lines in the CIE xy-diagram.

As can be seen in fig.4 the tritan colour vision deficiency is manifested by confusion, between amongst other green and bluish-green, yellow and white and red and purple. In the field of colour coding small field tritanopia becomes an important consideration, at least when the perception of details is at stake. This is illustrated by several researches in this area, for example through experiments on colour recognition of (small) colour coded geometric of alpha-numeric symbols on visual display units (19). These show that colour like bluish-green, purple and yellow, typically problematic colours for the tritanope, are already difficult to identify at a visual angle of 10′, whereas colours like red and green can still be recognized at angles less than 5

Colour vision deficiency

Next to the small angle colour deficiency, which is experienced by everybody, hereditary forms of colour deficiency have to be considered. A significant part of the population has one or other form of colour vision deficiency; about 8% of the male, and about 0,5% of the female population. Unfortunately, in special colour coding applications it is not always possible to take the existence of colour vision deficiency account. However, it is always possible, for instance, when choosing colours for traffic lights, or a colour palette for display, to optimise the colour code by avoiding colours on confusion lines.

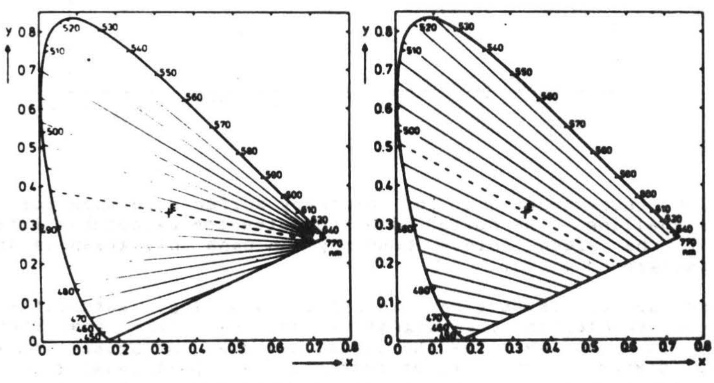

Fig.5 Respective colour confusion lines from the protan-type (left) and the deutan-type (right). The dotted lines have the same meaning as in Fig.4.

In practice one only has to deal with red-green differences. These can be divided in red-deficiency (protan-type) and green-deficiency (deutan-type). Both groups have difficulties discriminating colours along their characteristic colour confusion lines (fig.5).

This is particularly true for small angles. It is important to recognize that complete confusion between colours only occurs when there is no brightness contrast. It is therefore important, when choosing colours for a particular coding application, that the colours in question differ in brightness. In protanopia one has then, also to take into account that the protan-type has a low sensitivity in the red.

Standards for the use of colours

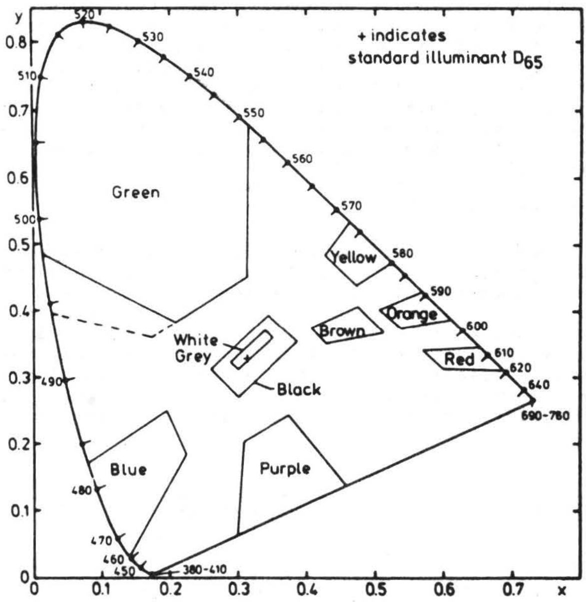

Fig.6 CIE recommendations for ordinary surfaces colours for visual signalling. The dotted line indicates the exceptable extension of the green colour boundary in case only green is used as background colour.

As long as colours have been used for signalling, authorities have tried to standarise the signaling devices, like road signs for example (20), as well as the signal colours. At present there are several standards and recommendations, in particular for traffic colour applications. Most of these standards, usuallly based on extensive research (21,22), are for a particular use, as for instance the "recommendations for the colours of light signals as aids to navigation" (23) of the International Association of Lighthouse Authorities (IALA).

One of the most recent recommendations, developed by the CIE, is concerned with surfaces colours (24). Fig.6 shows the recommendations for several types of surface colour: i.e. normal reflection, retro-reflection and fluorescence.

The colour boundaries in Fig.6 have a long history, the first attempt towards these recommendations was made in 1963. Experimental data are the basis fo these recomendations, but also many other reasons, like an attempt to conform to other existing standards. Moreover the reduced sensitivity at long wavelengths of protanopes, was taken into account. It is for the latter reason that the purple selected is closer to blue than to red. Essential in the choise of signal colours is, that colour are not easily confused. As a consequence the number of specified colours is limited to 10.

Due to still increasing use of visual displays there is a growing need for standarising colours fo a visual displays. Suggestions have already been made (25), but in view of the long time that committees usually need to reach consensus, it will take some time before final recommendations will be made.

Acknowledgement

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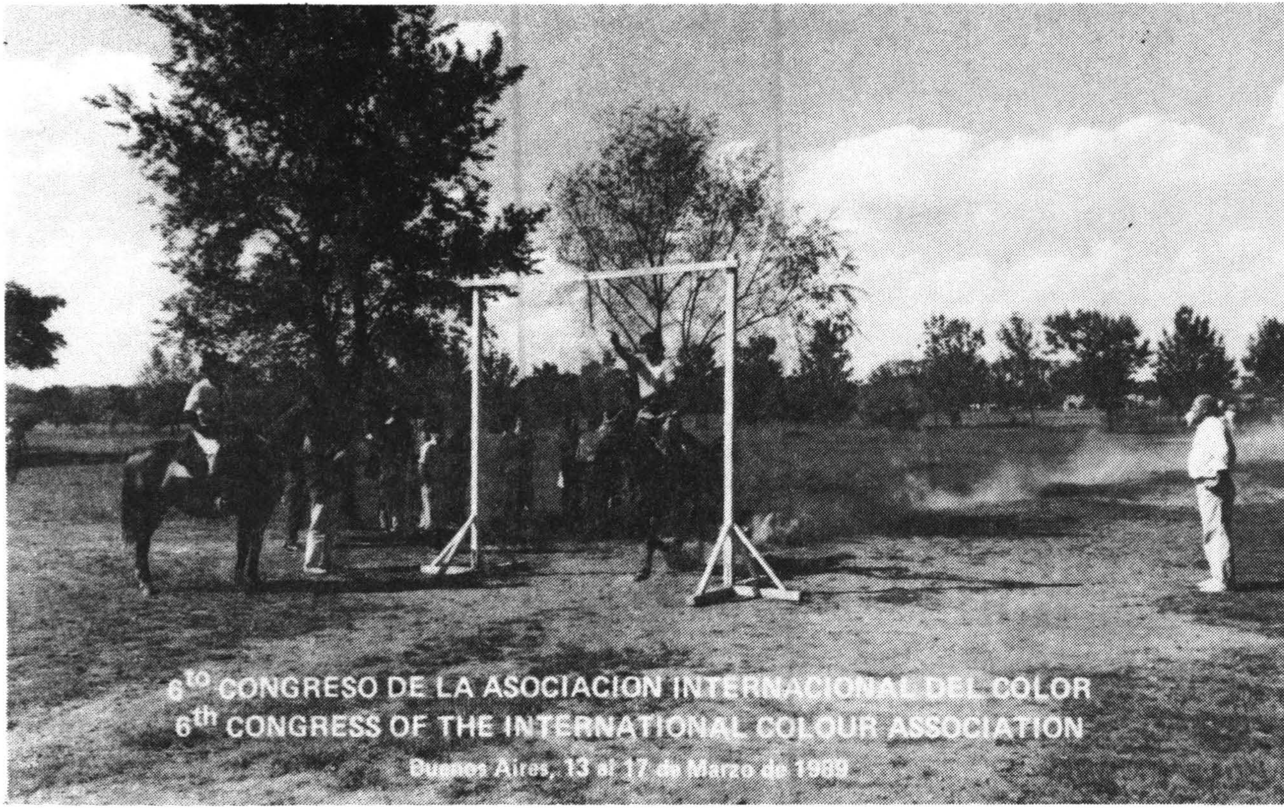

Creale Party:
View of one of the horse riding skills.

Panel Discussion

PANEL DISCUSSION

Subjet: Is any Colour Order System better?

Schedule: Monday 13th of March, 18.40 hrs.

Chairman: Lars Sivik (SWE)

Participants: Nick Hale (USA), Anders Hard (SWE), Antal Nemcsics (HUN), Franz Gerritsen (NED) and Tarow Indow (JAP).

L.Sivik: May I introduce you? You recognice the faces already. Dr. Hard from Sweden, the main motor behind the development of NCS in these days, Dr. Klaus Witt, from Germany, BAM, and Mr. Gerritsen, and Dr. Nemcsics from Hungary, and we do not need more introduction to Prof. Indow. We hear very much of this this morning. Welcome. I though we could start with a round that each could speak, let's say four to five minutes. Would you start, Anders?

A.Hard: When I saw this question at home in the program it sound ridiculous to me: Is any colour order system better?

In principle, this question is too general to be answered with one intelligent answer. Instead I think we have to formulate a number of criteria against which a colour order system (COS) might be evaluated. And we assume that the objective of the COS is to communicate or measure some aspect of colour.

I have tried to formulate some such criteria, which I have called 1,2,3,4. The first criteria: the validity of the COS. And with this term I ask mean nothing out that the colour of the system measure or communicate what we want to measure or communicate, and has to do with the concept of COS, and we can think of what I call the colour matching concept. And we can think of different concepts. We can think of the colour difference concept, which are an enormous amount of them, for instance: the detectability threshold, the perceptibility threshold concept, the distinctness of border concept, the colour contrast concept, the acceptability threshold concept, and, maybe, you can fill more concepts of this kind, and if we talk about these different concepts, we have to be very careful not to draw conclusions from one to the other. For instance: if we have done a lot of good experiments about detectability with threshold.....What says?: That is acceptable to have a multiple of a threshold could solve out as a specific perceived colour difference.

A threshold is an specific measure and nothing but that. And the difference is just where the difference start to appear which is not a perceptual difference at all.

We can also have what I call the colour appearance concept on this validity question. To say the following: I have compared the Munsell, DIN value scales, with the NCS value scales. Both Munsell and DIN deal with differences and the NCS tries to characterize achromatic colours according to the resemblance the ideal white and black. Then we can see that with one method, the DIN method on differences, the Dunkelstuffe 5, which should mean midway between black and white is in the NCS a colour much more similar to black than to white, and that is the difference between something that is based on differences or based in appearances, and, of course, you could also have colour connotative concepts for a COS.

The second criterion, I think, is the reliability of a COS which means if the experimental design has given reliable results. And this is all tested by statistical methods showing how individuals vary around some mean values. For example: in the Munsell experiments from 1933, 6 observations by 6 observers vary around the mean value about a 10% and nothing is reported how observations of individual vary, and for instance, in the NCS we have reported on absolute determinations, a confidence intervals for 30 observers of less than 5%. That is the way to evaluate reliability.

The third criterion, I call the accuracy of the psychophisical relationship of the COS. It could be an equation non-linear, non-parametric relationship between the psychometric scales and stimulus measured scales, and this is possible to judge too.

And the fourth criterion, I call the tolerances of the colour samples, and that might be a decision made. May I comment on Dr.Doring's paper that it is a good way to compare colour samples which are meant to illustrate something on a very cheap level compared to nothing. That is, in a way, just to compare a Volkswagen with a Mercedes. One thing is ten times more expensive than the other.

Now we can evaluate a COS in relation to any of the above criteria, but, to my experience, the question remains if this kind of information on different COS in every aspect, is available at all, and, to me, the most important criterion would, or must, be, the validity criterion, because, if the COS really measure or communicate what you want to measure or communicate, then is good from the begining or the other things can be improved, but, if the validity is bad or low, then nothing can be done to it.

L.Sivik: You set the standard of 6 minutes.

K.Witt: I been here without knowing what it is happening here, so just remembering what I should talk after the tremendous talk of Anders Hard. Perhaps, I can give another point of view, because mostly in colour design or in colour industry people ask what colour system should be used. Is there ISO standardizating a colour system? Which then is used as a color notation? Which is then an informal colour notation? Or with what?

My answer is: I do not know if there is any COS better, to answer the question. And it is like the Babylon's Tower which we have in COS. Every inventer of a COS invents his COS by certain questions which are not compatible to other things which already exists and I do not know what we should advice. What advice we should give to persons who ask the simple question: Why cannot you get together, and invent only one single system? And, I suppose, we are too diverse in our thinking, and I suppose, that every inventer, as long as he lives, he sticks to his system and won't give up, and, perhaps, the Ostwald System is, perhaps, a line which shows that it does not persists because the samples are missing, so it is not only the conceptual mind of the colour system which is essential, it is also essential to have colour samples which illustrate such COS and, if this is missing, I think that the COS will die out or become historic after a while. So I do not know what we should find out in this one hour of talk and see if we could find the line or going into future. This is my question to the auditorium.

N.Hale: I think when we look at a colour task and decide that we want to employ a COS to help us to solve the problem, and then we have to decide what we need to do, what are we trying to do. And then to adopt a system that is most inclined to help us to solve that problem. Now, for those who think the system solves the problem, I think you have been trying the approach yet, because a system is only a very small assistance in soving the problem.

Some systems are more useful than other for some problems. Now, I take a very broad view of this subject COS as might play earlier this afternoon. My friend, Dr.Hard, thinks that it should be a very narrow view here, and he has his point of view too. I think that methods for problems such as colour quality control, a system is related to CIE in a mathematical way and transformed to CIELAB, is an excellent place to start. I do not think it makes a great deal of difference which are the several transformations they use in a particular colour quality control situation, but by having a system that it appears almost instantly have you to make a measurement, you have dated to work with it inmediatly, and for that particular problem, you can soon find a figure around the end point that represents your tolerances. Tolerance is tipically, and are defined in terms of a ellipsoid, or a ellipsis in two dimensional space.

We saw in Dr.Pointer's slide, that in the work he did on selecting colours to match the original, reproductions to match the original, that the CMC formula, the CMC space, seems to work better, and at the end of his very fine talk, Mr.McCamy suggested that the CMC space had a colour preferences, fact on in it, and I think Dr.Pointer agree with that. Of course, that leads mean wonder why the ellipses we saw were not a circle, if the preference is been built into the equation. In anyway, whether you use CIELAB, CMC or Hunter, or some other transformation of CIE, you eventually work out some geometric figure which you can define in space through a line around to the end point and you have the basic units for solving your colour tolerances, colour quality control problems.

With the other type of colour problems, you also need a space that is malleable to working to that problem.

In colour education you need a space, I believe, that has the hue, lightness, and saturation attributes. This are the colour attributes that most people seems to understand most readily. In fact, when CIELAB was invented, we made by one from the opponent hue concept, to hue and saturation, were expressing the same results. Recognizing that we need to have hue, saturation, and lightness for many of the colour problems we face.

My experience in colour education is that we need to have lightness, hue, and saturation, because everyone can understand this. It is something that it is in everyone experience, their history. Once the students, no matter what age they might be, learnt that they can move to a more complex thing. And the opponent hue red-green, blue-yellow, to me, are more complex and more difficult, to the average, non-professional, to understand. So, in summary, I think we have not one colour space, but two, that we can use to solve all our problems. We need to select one, or the one that, is most nearly addressed to the problem at hand.

F.Gerritsen: Of course, we are not prepared, but I can tell you what was my connection with colour education.

I was working at a children community and there, the little ones were thought in what kind of world we are living and they have to try the tone from the music and try to feel into a package what they should feel inside the goodness easy, just could touch, Are this hard?, Are this metal?, Are this wood?, and so on. And they find the colour, What is the name of colour?, How do you call this colour for this purpose?, and so on, and then after they have gone into this material, they play with these colour things, colour names and the different kinds of colours and then, I have to think in Dr.Plaza, when we were in Colour Education Interim Group, and he was, I think, in Berlin, and he said "I think from the childhood, for the little ones from 4 years old, until the universe, they should use easy material values, that they come from the whole trait, the colour of a colour, the colour hue; and it is the lightness, from white to black, a light colour or a dark colour, and then from a full colour to neutral."

It is very simple to understand, and each field where you work, you have to do some measurements and to deal with colour models, then I thought it was an article when you ahead the lightness level, intrisic lightness, of the different colours placed on the same lightness level as the intrisic level of the lightness of colour. So the ultramarine blue is a lower and yellow is higher and, if you then study your colours and the all colours trees, one starts with one light colour, the yellow and from ended treats, purple, bizarre purple, and so. That is, you arrive from the colour mixing posibilities. But if you study the colour perception possibilities, this experience, or with the printing inks, or with the light sources, then you find out that the three primaries, red, blue and green perception, and if you combine two perceptions you get the magenta, the yellow and the cyan.

I showed you today, that if you have opponent signals, that is the black-white, the blue-yellow and the green-red, you can place it in the same colour perception scheme, because its possibilities of the same vision, visual organ, and there was the principles of how I have to do with colour and just to avoid dissapointments, and if you are working with children and you have to do so much things with the little ones, so are afraid of a big piece of paper, you know, and if you give them a pen with red, with green or yellow, they are dissapointed, because if you give them a pencil and they can work with it, they can make nice colour services, or with the chalk, you know, and you have to look at which child and so on. If you are working on easy or on a piece of paper. And when you study fiber on it and you play with this colour from nature and support, and you make a lot of this stuff, and you go to a museum to see the colours and so on. Then it is just a part of the life, and on the stage they must. They have the possibility not to make dissapointments, so, the teacher who has to lead the children, he must know his aims, how he can afford that meant they want to have very beautiful colours, that they don't put a red, and a blue, and a green, and a yellow, and to get a gray, so just you give those three colours. And with this colours they may work and then the next time you get the matter and sometime you let them free that they can choose of all kind of colours.

L.Sivik: Certainly COS has to do with colour education. Maybe you can continue that line in that specific topic.

A.Nemsics: First at all, I must apologize, ladies and gentlemen, for not being able to address the audience in english, and so therefore, my colleage, (Dr. Kerenyi) will help me in the translation.

It appears to me that one fundamental point is to determine the objective of using a COS and it will appear to me that, perhaps, are three alternative objectives. One could be teaching colour. The second could be the selection of colour. In other words: the determination of the difference between colours. And the third one would be colour design, and each of these three potential objectives we call for a different COS.

Since much has been said about training in colour I would not like to talk on that, but would prefer to speak a little about the selection of colours and colour design. As well as the difference between the two fields.

The selection of colours must be based on the ability of the human eye to distinguish different colours and therefore, it requires a colour space, the colours differs according to the possibility of the human eye to make a perceptual difference between them.

The real difference lies that in colour comparison we are only comparing two hues over two colours which are quite similar to each other, and we exclude the environment.

On the other hand, in colour design, we are working in a broader sense of a variety of different colours and therefore, a COS, which its aim of solving problems in colour design, must comprise a variety of colours which are distinguished according the possibility of the human eye to make a perceptual difference between different colours.

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................(some part is lost in the tape)..............
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We will only think in terms of his own set of parameters, but that could help others to realize that there are things that they tend to think of.

Such discussion enphatizes individual views, and it could really be fertilizing a more general understanding, and, perhaps, the unique system which was briefly mentioned at the introductory comment gave at the begining.

T. Indow: As the last speaker, just three very simple questions. Let me raise very naive questions: For many years I've wondering why this system is being called COS? To me is better, more informative to say surface colour system.

The second question is in this type of system we have to rely upon the physical spread of standard colour samples in a special form, so always it becomes very important to study about how accurate we can interpolate or extrapolate between these standard colours. That is one point established by Dr. Doring.

The final question is, and pointed out by many persons, when we use surface colours systems, we are very aware about on what principles standard colour samples are collected. In the Munsell Colour System, standard colour chips are collected according to three perceptual attributes: hue, value-lightness, and chroma-saturation, and the standard colour chips are selected that there is perceptual uniform standard sample steps in respective attributes, that is the form Munsell collected their samples, and also that are the principles that must have the intensive studies of the Optical Society of America sub-committees tested.

The original idea, even it was not tried to match perception steps in hue, perception steps in value and perception steps in chroma not equated, the three steps are defined separately. Appart we found that the Munsell system, when the three different units appropiately equated, not only colour to colour, which are different for each attribute, like difference in hue and difference in value, still we can have a good metric representation of perceptual colour differences, but all principles are based upon to have perceptual uniform steps in representation. In the other hand, for example, the NCS system, if I understand it correctly, that based on entire different principles, that is to take a single colour, how much redness, how much yellowness, etc changes from one colour to another, that is a different principle to introduce a metric between two colours. So on what purpose we use a surface colour system? We cannot tell until we make clear the purpose and principles we cannot say which one is better.

L.Sivik: Thank you Prof.Indow, We can answer this question inmediatly. We are a member os a ISO Working Group. We can answer these questions. We are talking about colour notation and colour appearance. We are dealing with surface colours and therefore with COS. I also wish to thank Dr.Nemcsics to ask us to be more open relationship and to listen to each other.

K.Witt: I just want to comment on connection with threshold experiments in too large scale experiments. We knew that there is no lineal connection on this.

I wish to focus the attention that in COS we deal with large differences and not with threshold scale differences, and therefore, we must not think about CMC optimization of the CILEAB space, and we cannot deal with acceptability or perceptibility of colour differences including this situation to colour ordering. I propose that we stick to these order scales and to the scaling that Dr. Indow have done with the Munsell order system, to try to get a deeper view inside the other COS of each inventor, and to think we have not done or finish this job of looking into the meaning of the existing COS and I think we should have, perhaps, some more scientific input to aswer this question, perhaps, some years later.

A.Hard: I think that, first at all, we have to formulate what is the purpose of any COS. Is what I call the validity level, because if you want to order colour percepts according a physical parameter, of course, you can do and that will be a colour system based on these premises and as far as I understand, the basis of the CIELAB system was not to define the appearance of colour. It was to define, in the way that Mac Adam ellipses within the CIE systen and this was pointed out by Hering in 1874 that, if you arrange colours accoding to differences, independently the method you make the differences, you measure differences and don't measure colours. And this is a very important thing and I think it is very intersting to hear that Dr. Nemcsics talk about harmonic space, but What do you really mean? What ask to your observers? What kind of questions do you make? Because if we try to evaluate the importance of your harmonic scaling, of course, we must know how reliable your experimental situation is.

Just another remark, if it happens that someone, like Michael Pointer find that might be simbiosis between someone who is trying to explain differences and another system explaining appearance, that it, of course, will be wonderful if can find it, but that must be based on experimental data.

C.Kleemans (NED): I am happy to be here to listen all this and, to be honest, I did not learn any new. We should like to hear if there is any planning in the future. Today we have heard that the japanese have a new colour system. We hear of the Colorcurve system. What can we do together in the AIC in the future? What is planning? What is worth while to develope in the future? What is the best thing to put your strength in it? That is my question.

L.Sivik : I believe in Darwin. The fittiest will survive.

F.Gerritsen: May I answer this question? I believe from the question of Dr. Kleemans that we, as the AIC, we have to continue as we are doing, stressing all kind of directions for COSs are just a tool, you know, is just one aspect of our perception possibilities. We have the music, we have the sound, we have our taste, we have our feeling. We have also a vision, besides all other feelings. The whole combination of all is that it makes our world and our people to live. And must be, has to be built together a better world and has to respect others ideas and meanings, and try to work, each found in each field and to make a better tool for different purposes. It will not be one tool. It will be lots of tools in this only meter colour. Colour can never exists alone, as a perception, without the sound, without the taste, without the smell and without the form.

Now I have the feeling, from your experiences, when you feel, your living, you know, communicating this, your world around you and just with contact. We have traveled a lot around the world and you did'nt speak all the lenguages, but most, and just contact from people to people. That is, I believe, the nicest thing, and one of those things is colour, but a very little part, and we need for this little part a lot of tools to work with.

T.Indow: I am ver sympathetic with this comment. I use a computer for many years. I study how to use a computer before FORTRAN existed, but now we have so many different computer languages, and I feel exist the same situation in colour systems. There are so many different systems. But I rather prefer to see, to scrutinize the established colour systems than to add something new.

R.Stanziola (USA): First at all, I like to agree with Dr. Witt and say I am a sole prejuidiced as my colegue says. I hear that I seem to wrong play. That anything to do with a physical description or to describe the stimulus is not been nearly worth while what we see, and obviously we see what we see and it is very important.

We have a small group of people here, and we can philosophy on different things, but there are millions of people out there. They try to make the chairs of this room, they have to make the paint of this stair, they have to make the green of the table cloth and the unique red of Anders Hard sweater, and they need some help, and we can do a lot of things. Somebody has to do the coat for photographic paper, so we get this beautiful images. We can do all we want to do here, but there is a lot of people we should be looking to help and at less we can include this physical descriptions which become a part of the map to help them to go where they want to go. Then we are just talking for a small group of people not to the majority

There is a real world outside this room which needs help how to specify colours. As long as this panel do not solve this need, do not providing the physical description, being a part of the map where we need to go, they are only talking for themselves. For a small group of people.

L.Sivik: Very good to hear that you feel as a minority. We, perceptual people had felt depressed for a long time.

M.Pointer (GB): I am myself a scientist, and most of you are also scientists, and perhaps, we think in the end-user, the engineer, the designer, the artist, the person who are going to use this COS.

How they view just what you have said? I imagine they will think, will come away more highly confused than when they come in. There are a good number of COSs, whatever you want to call them. They also serve for useful purposes well described. What I feel is lacking a sensible way of comparing those systems, so some people can be helped to make objective, than a subjective, discussion or decision, on which one they should use.

If you look into the literature, you will find that there is all the comparisons and they are not very helpful, because they nearly say: Well the system is different consistingly and it might show that the differences are very near, and this will not help the engineer, the end user. They want to know why they are different and they want to have some sort of measure they understands.

What the differences are? That he can understands x,y,Y, CIELAB, CIELUV, CMC, does'nt really help, because they do not understand either.

I suggest that as we are moving to how understanding colour appearance from the sort of measures we've developing within the CIE, which I admit openly, are very close to those of Anders Hard and his NCS system, and I also admit that our system happen to model the NCS system quite well, but it does not necessarily support it.

I think to me, that we are providing a metric which computable from the CIE and does give a way to take all your systems, perhaps by spectrophotometry and CIE colorimetry, into a metric that ordinary mortal will understand, because it does give a measure of what he thinks, he sees, and I think is the missing linkness. Dr.Nemcsics got it close to this. I think he actually says what I am trying to say now, but I think is what we need. We need some common ground that the ordinary mortal will understand.

N.Hale: I think Dr.Pointer is on the right track, but I don't think we are to evolve into a single system that will serve all the diverse groups. I think we are more likely to get one that will make sense to engineers.

In the area of colour harmony and design, I think we have a bigger problem. One part of that problem is that the system for the engineer, the CIELAB, CIELUV, CMC, and whatever come next, have multiple fathers, whereas, the individual systems, other systems, has, perhaps, a single father. And we have a lot of ego. He and everyone thinks that the one he created is the unique and has special merits and so they sould think in it. But I think what we can do is to answer the question of what should we do in the AIC, we could try to, perhaps, decide whether one system could, eventually, evolve. We could use for these diverse purposes we have, and, I don't agree with that, or we should try to decide to break up the colour universe, we study and discuss, into two or three or whatever the number of definable areas, and try to have one system in each of these areas.

Right now we have, as Dr.Indow said, many systems. I will get many more everyday. In Kungalv we hear about four or five extra systems. That, for good or bad, they did not get produced in material colour samples or material colour standards, but we need to look at the different areas and decide we can come up with a single system in each area which can concentrate on using, so that the average person can have some place to turn.

A.Hard: We have all the time to remember that when the research around the NCS was started, the aim was not to produce any technical system at all. It was based on how it was percieved colours in a natural surrounding, and, I would say, that there is a difference between the need of descriptions in one way or another, if we want to produce colours physically or psychologically, and to control what we produce.

On the other hand, most people, are not engineers, are not designers, they are ordinary people in the street, and they want to know how to chose and use colours for their own environment, and this is the main occurs for the NCS system, and one basic think in this is that we have a need for such a system in order to do much more research about the importance of colour to man, in the society, and to understand much more about the importance of colour for man. And how to help him to get better colour environment. And I am not sure that this will be fulfilled only by designers if they have no knowelegde about the whole conceptual side.

Just make us fool, an average remark, I make a parallel comment which I could use it.

I think that 800 years ago, they invented a order system of terms and I do not believe that this have been on hundreds to activity women that firm. Their love on music have been based on that phenomenological findings from the very begining, that had nothing to do with physics. It was what the people try to tell about what they hear and the same thing is on this aspect. That do not mean that we say that other aspects are unimportant, of course, we have also the need to produce what people want to have.

C.McCamy (USA): I came prepare to discuss all this in the Study Group on COS which will meet on Thrusday morning. It seems to me that this is a very good time to invite all who had such a deep interest in this subject, to come to that meeting and then we scatter.

A.Nemcsics: Indeed, I have the impression we have, more or less, come to the point of defining what we should discuss, just that time is out, and we have come to stating we are looking of some objective method for determining something which is similar to determine distance. Like the distance between two points defined by the meter introduced in the last century. The only question or problem, being that here we face a far more complex situation than the distance from point A to point B.

The first thing we should do will be to make an inventory of the parameters by which the various COS define colours. We should also pay attention to adecuateness of these parameters with the view of the objectives of their respective systems. The second thing will be to make an inventory of the colour space defined by the various systems, and the third one, will be to see what relationships between colour spaces and CIE X,Y,Z system could be established and with what methods.

K.Witt: I just can't to take up this point of Dr.Nemcsics. I have given a paper in Kugelv on this topic, that means, and we have a discussion on the ISO Group in Stockholm, which told that one of the first things we could do is to find measuring equipment which could be down to basic for comparing COS in the physical representation of colour terms.

This means defining the choice of measuring geometry, of the illuminant, and of the small or large field observer. And if we have done this, I think this could be the first step to have a help how the ordering of colours is, then down in these cases of different systems.

But, on the other hand, I just want to comment how many people are needed of COS when I go along the Ave.Florida (A Buenos Aires Street) and look at the persons I think that none person is there who need the help of a COS. I think that COS is more interesting people who do proffesional with colour and who do educational work with colour. And I think when we have this in mind, then we see the volume of the people who may be interested in our task.

L.Sivik: Thank you very much. I think that was the last comment. Thank you very much for your collaboration.

New President of the AIC:
Dr. Alan R. Robertson

Closing Session:
From left to right AIC Executive Committee: Spillmann, Robertson, Terstiege, Lozano, Mari, Hutchings.

General Discussion

FINAL DISCUSSION

Chairman: Prof.Dr.Heinz Terstiege, AIC President, (FRG)

H.Terstiege:..
So, What next? or What has been done in the last 4 years? Maybe one can think of one of the urgent, most urgent thing of the CIE, and the AIC together. Is that the CIE has recommended the colour difference formulae, the CIELAB and the CIELUV systems. There were, at that time, 1976, two formulae which have the advantage they were simple, more simple than many other and that CIE recommended two formulae instead of more than a docen existing once. And many of the industries come for a change using, maybe oriented formulae. They change to use only CIELAB formula in the industry for object colours, while in the television the CIELUV is used.

But we knew at that time that the CIE formula was not the last and the unique one and therefore, a lot of modifications, CMC, BDF, and so on. Maybe I sould ask Robertson, who is chairing the Committee on Colour Differences what we gain in the last four years, and how far are we ahead of, that the CIE would advice or recommends modification of the CIELAB, because CIE will only recommend when we really have a progress.

I think is no use when an international organization body recommends too many formulae and when we have a new one instead of the CIELAB it must be, really, a progress. Otherwise we could'nt convine industry to change all the programs again and all their data.

What do you think of this idea?

A.Robertson (CAN): O.K. Sorry! You call me little off gard on this. So I have to collect my thoughts a bit. The CIE Technical Committee is dealing with colour differences did have a meeting last saturday and we discuss colour differences to some extent and we decided the the CIE has to re-assess what it's doing in colour differences field. And instead of having one Committee, trying to do everything, is going to broke it up. We originally started it off, as you mentioned, some years ago, with the idea that we should'nt just recommend a new formula quickly, but we should try to re-establish or establish some of the fundamental data and come only with the new formula when there is sufficient reason, that really claim that the formula is better than the formula we have now.

But we have taking note of the fact that quite outside the CIE, there has been a progress that there is a modification proposed to the standard formula, particularly to the CIELAB formula, not so much to the CIELUV, and that those modifications have actually been accepted in many areas, become now a British Standard, for example.

And I think that one of the approaches of the CIE would be taking in this new approaches to colour difference. We'll be to have separated committees, looking at the fundamental data and whether the CIE can do anything to help or to contribute to the understanding to some of this new formulae. Will be splicing up a little bit looking at the applications and looking the fundamentals.

F.Simon (USA): There was only a month ago that the American Association of Textile Colorists in USA, agree to recommend the CMC that is pretty much in agreement with what the British Standard is. We did some small variations. We could'nt follow the British Standard exactly, as you can imagine. All them are additions, no changes. CMC as such, it is accepted exactly, without any changes. And what I understand is that the Society of Automvile Engineers and the American Society for Testing Materials were waiting for this action to be taken, and they would, we can't dictate them, I think the would follow very quickly. So there is. So, what I am trying to do, is really reinforce what Allan (Robertson) said, that are other organizations that are going to take the lead on this respect, and the CIE, naturally, can follow something and does not have to do any work, if you will, if this were done.

A.Robertson: I've been interested to hear you oppinion, Fred (Simon), or anybody else that had an oppinion on this, whether there is something useful that the CIE can do in this regard. I mean, Does it do any good to the CIE just to jump on the band wagon and say: This is a good formula!, Or the CIE can do something to help in clarifying some of the issues here? Or the AIC? I mean. We work together.

R.Luo (GB): The research carried out at the University of Bradford we collected about 4500 pairs, starting from the first step of the colour discrimination data from Davidson and Friede, so far we collected about 4500, so that is mainly data using both acceptability and also perceptibility results, then we come to the colour difference formula.

It is very confusing, at this stage, but, as far as the CMC committee concerns, the first thing it is that the CMC formula works remakable well comparing with the CIELAB formula, as far as small colour difference concerns. So we got it very confident, as far as people in any colour industry concerning with small colour differences, the CMC will work much better than the CIELAB. And we recommend the CIE to do, at least, put the CMC forward, ask us a test and a trial period. Give us now certain period. The people from all over the world will provide the information they get, just like Nayatani's chromatic adaptation formula.

I think, at least, we deserve to have some sort of treatment like that. That is my comment.

H.Terstiege: OK, so this will be given to the Chairman of the Technical Committee. Maybe the CIE will publish a report on CMC on the CIE Journal. What as I understood is that you did not want to have a recommendation at this stage, because it is too early.

Because if the CIE would make a recommendation, it would have to withdraw the CIELAB formula, but the people, also in other parts of the world, work in your formula to get more experience or, Do you think this formula works independently for all materials? Not only for textiles, but for plastics, paints, and so on, but the one for small, the other one for large?

R.Luo: The last comment of it. In this moment, in the CMC formula, we call l and c, which are our tolerance limit. There is a very confusing whether the people in the different industry, needed to apply different tolerance limits. If you put it forward, and forward you give a try, and then we can find what is the best lightness and chroma tolerance limit and it should be applied in a practical field.

R.Stanziola (USA): One comment and one question. CIELAB was a tremendous advance as far as I concern, because it was very much simpler than other methods that were used previously, so therefore, it was accepted by industry because they can understand it, rather easily. So it was very important because it got a lot of people who would avoid using the american tolerances previously, at least, willing to give it a trial. That is my comment.

My question is at those people who know a lot about this. Is CMC any better than breaking CIELAB into three separated tolerances, like a hue tolerance, a chroma tolerance and a lightness tolerance? Because, what happens, at last, what I found, that, some industries put more emphasis on one dimmension than they do in another. The textile industry put much less emphasis on lightness than they do on hue. But some paint industry that the emphasis is still less on lightness, but the degree is much more. So if we use the CIELAB but have separated tolerances, three separated tolerances, Is this disadvantages other than to have three tolerances instead of one?

I would appreciate some comment because I don't know.

K.Witt (FRG) I have no answer to this question, but I feel a little unhappy about the situation on colour differences evaluation, because we know that the simple formula CIELAB is not working very well, and the CMC formula is an improvement on the phenomenological basis that has taking together, collected together, lots ot thousend of colour difference evaluations in the industry and in scientific research, to bring them together to a better formulation by implementing some correction factor in the CIELAB formula.

What we have not done, and I think this could be a useful work, to go also into the psysiological regio and try to get a more concrete contact with physiologists, in order to find out what are the best indications of colour differences functioning in the brain, to the description of colour differences by colorimetry. It may be that, by this contact, a quite different formulation than the CIELAB, is possible. And I suppose we should push scientific research in this direction and not wait.

R.Berns (USA): I want to make a comment on Ralph's question. We've doing some colour difference work in our laboratory and just quite a little bit of an announce, which will be soon published in Color Research and Application, in which we compare the effectiveness of the equations like CIELAB, CIELUV, CMC and BDF, to a simple regression equation, which is the simple weighting individual lightness, chroma and hue components of CIELAB, and we did some very careful statistics, to insure that our data was not biasing the model fit, and find that a simple regression equations perform easily as well as the CMC.

It was also interesting that the CMC equation outperform the BDF equations in this particular announces. So in our oppinion, is not really clear this point that the CMC is significantly better than simple weighting lightness, chroma and hue components.

E.Cairns (USA): I have just one comment. On both the CMC and the BDF. I see them as equations which are fit to a lot of visual data and you all know, that all visual data has noise in it. So when you fit it, you also are fitting the noise. Now next some of your suggestions that came out, like Klaus Witt's. Maybe, if we can take some of the noise out of the visual data, and then make a fit, I think we have a more accurate and more representative of what it was happening and, maybe, this is something the CIE could do.

R.W.G.Hunt (GB): I want to respond to the suggestion that the colour difference formula might be based on the pshysiological foundations.

I think this is exceedingly difficult. The physiological knoweledge of the perception of colour in the cortex is very rudimentary, but it is interesting that does seem to have some evidence that the colour space associated with the model that I put forward, is, in fact, rather similar to the CMC, and so, you could, perhaps, derive a colour difference formula in the space of my model, which, would then, had some physiological basis.

And that leads me on to one other thing associated with colour difference formula: that there is some need for having a formula that is applicable to illuminant colours other than D65 and illuminant levels other than some standard usually unspecified level of say, 6000 lx, and, so, again, the model when I talk I mean my model and Nayatani's model, to take account of the effects of chromatic adaptation, and adaptation to different levels of illuminance. So I think we should not forget this.

And there has been some use of the CIELAB and CIELUV formulae for the illuminant A and another illuminants for which they were never intended, so the evidence is a need for a colour difference formula to apply to illuminants rather to colours.

I think that this should be borne in mind.

H.Terstiege: Should we stop at this moment with this subject, otherwise we shall stay all the available time with colour differences.

For colorimetry, I think is very stable, we have the new Publication 15 from the CIE, and we have two standards, but on the side of the Publication 15, like colour difference formulae, luminescence evaluation, daylight simulators, we hear some new methods that Mori told us about the third method to evaluate the goodness of fit of simulators of fluorescent lamps. Is there any discussion on this? (No answer).

Well I think, there is some work in progress and from Toshiba, and we expect new lamps.

We hear from Nayatani that the new model on chromatic adaptation that he is working on it, is a good formula and goes into many other things as Hunt just mentioned for is good to have the application in the field of colour differences but also to have it in the evaluation of goodness of fluorescent lamps, and daylight simulators.

Are any comments on this subject?

R.Luo: Some of the colour appearance results on which I introduced on monday in my talk, which is now also tested various colour achromatic adaptation formulae. The results will be to be presented in the Chicago ISCC conference. The actual perfomance for the moment is that the CIE model is not particularly good. For different chromatic adaptation formulas been tested using a high luminance level, a grey background conditions, the current CIE formula recommendation is not performing well, so I would like to raise an issue. It looks like more data is required in this particular area and more work is needed to be done.

H.Terstiege: Yes, I agree.

Y.Nayatani (JAP): The CIE TC-1.6 was founded in 1971 and, after more than ten years of study, in 1975, a non-linear chromatic adaptation formula was proposed for test, further test, and after that, my colleage and I, made three field-trials and they supported very well to the chromatic adaptation formula proposed by the CIE. I hear from Dr. Luo that his experimental results do not sufficiently support the chromatic adaptation transform proposed, but I understand that the CIE chromatic adaptation formula is proposed only for changing the adapting illuminant, without changing the background, allways using the same background, irrespective of changing the adapting illuminant. But I understand, Dr.Luo, made the experiments by changing the light sources and also by changing the backgrounds, so his conditions may not be the same as the CIE chromatic adaptation formula just propose.

So, I think it is further necessary to have various field trials to the chromatic adaptation formula all over the world. And also, we have to study about the experimental conditions used in the assessment.

So, I think it takes one more period. After four years, I guess, we shall be able to have some decisions to be made, but I do not like to take a long time, because already after starting at 1971, 18 years already had past, so I cannot wait another 18 years, you see.

R.Luo: The experimental results which we use to test the various chromatic adaptation formulae are being used at high luminance levels which is about 1000 lx, and also, the grey surrounding conditions are exactly the same as in your working conditions. And our results agree quite remarkably well with Helson results which were obtained in 1940. So in that case, our results are quite confident, we do not have a lot of arguments here. We can discuss it in Chicago.

Y.Nayatani: As I have said: everybody has a very good confidence in his own experiments.

H.Terstiege: So results the more experiments we have, more confident we will be. So we have other subjects in AIC, not only colorimetry and adaptation. It is colour appearance we have dealt.

One of the invited lectures was on colour in architecture and Werner Spillmann, I think is here. Werner, what would you say about the future in colour in architecture? Where should we improve our contacts to the architects?

Some of us were in Winterthur Interim Symposium of AIC which was well managed by him alone and Winterthur Polytechnic, Could you give some words on the future of colour in architecture?

W.Spillmann (SWI): I think that the most important is that we get contacts with the architects. We have already started in Whiterthur, in June will take place an Architects World Conference in Sofia, and I was charged with proposing a few lectures on colour in architecture, so colour comes now to the architects.

H.Terstiege: I think in AIC we have tha same problems like the CIE has. That there is very little contact between colorimetrist and architects, and there is very little contact between lighting engineers the architects. And we have to improve this and we hope we shall do it in the future.

There is any comment to this subject? (No answer)

One of our next invited lectures were on theme Colour

Order Systems. Colour Order Systems, is,I would say, similar to colour difference formulae. We have many Colour Order Systems around the world, and it would be nice to have only one applied in every country, but, I think, the future, as like we saw in the Exhibits, that even more Colour Order Systems come on the market, and then, Colour systems will be reduced to less? What do you think about the future of this? Where shall we go?

We have an ISO Committee established which will meet in November, this year, in Baltimore. We have Nick Hale talking on this subject here, and we have a Panel discussion on Colour Order Systems. Nick, what is your prognosis for the future?

N.Hale (USA): Well, I suspect that the number of systems that will be produced in actual material samples, that will allow people to attempt to employ them in various purposes will not continue to proliferate because there are some echonomic implications here. My own understanding and experience tells me that you can keep loosing money for long time, not even those systems that have some echonomic input from the goverment, so, I think, in the long run it will work out very much like everything else does in the free enterprise system, that the one which work the best, or the two or three that work the best will endure and the other will be out of bussiness.

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................(some part is lost in the tape)................

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H.Terstiege: Correlates the system and when we have data on Colour Order System we can transform into another and apply the colour difference in the other system to the first one.

R.Luo: I think that is a practical need to convert that each colour coordinate from each different colour system to another. There is a need of mutual communication between one Colour Order System, say Munsell to the NCS, specially in the display industry. High resolution colour harmonics is very common now, it was keep asking which particular colour space they should use and we got different response from architects, from textile fashion designers, from artists and painters. They all have different ideas. They use different systems.

I think there is a need for all the manufacturers, if they can, providing some sort of agreement, or the first thing, if they can standardize the measurement technique to measure colour order, colours, like as Klaus (Witt) suggested it, and also providing another agreeement to convert the whole system into X,Y,Z values, and that will mean that we have no problem to convert one system to another. That is the coment.

R.D.Lozano (ARG): I would like to comment about Colour Order Systems. For several years, in my courses, I have talked about the difference of the systems available, and, for a country which does not belong to what is called the echonomical developed world, it is difficult to make a choice. But, mainly, the people must understand, Which are the purposes of them? The purposes normally are two: One for the architects, or the people related to the artists, which try to make harmonies or that kind of things, and the other, for the people who are going to classify products, which is another approach. So I usually recommend to my students or people which come for advice, to use the simplest and the cheapest. This is the main goal, because I do not want to give them some Colour Order System which implies a lot of investment in many apparatus or atlasses, which cost a lot of money and they do not know really, if they can get the same service in a much simpler way, and, which is more important, more echonomic. So that must be kept in mind and people who look for a new Colour Order System. They must produce simpler and cheaper systems.

H.Terstiege: So, to leave the subject. We had a very good invitated lecture by Will Sproson on Television on Colour Reproduction. Are all the problems solved or what do you see in the future? I think that for colour reproduction we have enough problems.

W.Sproson (GB): I think, in terms of colour reproduction, television, perhaps, in someway, reach the stage of photography. Namely, it works. You get quite good results. I am speaking sole for colour reproduction, not other aspects of the system. And I do not know. It does not seem to be an inmense desire for great changes.

The future, as I see it, in colour television, I hinted to the end of my paper of this morming, is in the direction of very much high definition systems, which are as good, if not better, than 35 mm motion picture film, changes to the aspect ratio, so, instead of 4 by 3, which is the present system, we come to a recommendation that appears to be going to 16 by 9, which, I think, is some as cinemascope, or not precisely the same as.

Another feature, of course, is that we have many possibilities of transmitting pictures nowadays. When television started to deal with colour, around 1950, all stations were terrestrial, now we have satellites squeezing around the earth, and we are in active progress. Many countries are receiving pictures by satellite.

The possibilities of much greater bandwidth in the new systems existed. As I mentioned this morning, instead of 8 or 9 MHz separation between channels, in satellite work, one has 27 to 30 MHz. None of this very directly affects colour, except you get a far better definition. And that, in its turn, it is a good thing. But I think that the basic fundamental of colour, as far in colour reproduction is concern, being moderately well decided. Of course, it may be proved wrong, because someone cover with some brillant new way to do it and it shows exposes how to do about this. But it seems with still the test of time, so far, and this affair measure of the acceptance.

Of course, people get the sort of picture they want to get. There is a thing called the chroma control of colour, and the people like the picture nice an pale, and with washed colours, and they can have that way. My observation is that people seem to like it. They pay for colour, and they jolly are going to have colour! They turn out of chroma and the results are, sometime, quite terrific in my view.

I do not know whether that long will please you?

M.Pionter (GB): I dont't wish to disagree with Bill Sproson, but perhaps, after what he is saying, I think we are going to see in the colour reproduction world quite significant changes over the new few years, in colour television we already seen the LCD diplays fitted to the jumbo jet as they flight crossing the Atlantic. This means the primaries are going to diminish. The quality of colour reproduction is different.

You can have a printed attached to the side of your colour television set that would print out the teletex page in black and white. It will come very soon when that is in colour.

In colour photography we conventionally deal with emotions, photographic emotions, that later are in thin layers and yet we have digital cameras where images are stored on disk, and can be printed out, at the moment, in conventional ways. But soon we will have it in jet printers and we might have colour xerography.

We may have conventional television for displays our prints at home.

So, I think, we are going to see out of the store, of output devices and input devices, and we only need to compare them, and, in order to compare colour reproduction of it, we only have to have methods of doing it, which is why we've been working in the colour reproduction index, and why we've using it in houses. We've using it within Kodak just to evaluate the films that we are working into the future, which, of course, in themselves, at taking a change over the last two, three years to work out high chroma and more correct enclosed colour reproduction.

And so we do need a method of measuring. And, in order to measure colour reproduction indexes, we need a method of measuring colour reproduction. We need a method to measure what we see.

So, I think, what I would say, in answer to this subject, Heinz (Terstiege), is up to you, people working in colour vision models, to get cracking and really solve it out. So we can get on applying them, because I have a big computer program which calculates the index and now I've got to go home and change a little bit of it. And we can't go around this sit, of this circle, too long.

We've got to come a place where we are all happy and my CIE Committee are going to plug in the CIE again and finishes so, and write a recommendation, in a form of Technical Report for colour vision models, colour appearance models, and that we have to get on the application and uses, because we need to bear in mind, both in the AIC and within the CIE, that we are in a job of finding tools to be used by people, to the engineers out there.

So, I would urge, colour vision modelists, to get on over it, and let us know, when you get that, so we can close that book and I can open a new one on colour reproduction.

R.Stanziola: I think the AIC ought to make sure that is well understood the differentiation between colour television and colour monitors. Those of us, who do not know much about this, the whole concept of colour monitors, are hit with all kind of data and specifications that tends to indicate that the solution to all kind of design problems are hem, because we have colour monitors. So the question, I would like to ask, not this number that floats around, Can somebady, perhaps, in the AIC, answer the question of how many colours we can really see on a monitor? Not the 16 millions supposedly we have available, because is just numbers.

And too, Is there any work been done to have more than three phosphors on the monitors, so we can minimize this terrible effect of observers' metamerism? Because when we do everything on a monitor, that it's fine, but sooner or later, somebody compares a real sample with what is pretended on the monitor and therefore, we have the whole world, the whole real world, being matched with three colorants. So we have this fantastic opportunity for observers' metamerism and, Is anything been done to minimizes the problem?

H.Terstiege: OK, Who can answer that question?

R.Motta (USA): I work for the Electronic Color Imaging in the US, just to drafting what Dr.Pointer had said, we are about to see a very large number of devices, computer peripherals, which will be produced in Catherine Color Imaging, tnat is a member of Computer Color Imaging Community.

I have the feeling of lack of direction from the CIE on how to approach that. For instance, working on ODA -Office Document Architecture- it will find ISO we come up with the concept that we want to achieve a device depending on colour rendering through colorimetry, but, on the available literature from the CIE, there is no guidelines, so for instance, what is an achievable Delta E, what is to be expected, and so forth. So even that there are good books, like Dr. Hunt's, has a good Chapter on the aims of colour reproduction, and there are the Proceedings of early meetings of ISCC which has discussed the subject for a great extent.

Our suggest to the CIE committee to publish one of the orange books providing bibliography, and if possible, some guidelines, like in term of ranges, of what can be expected, and some of the methods of measurement and verification.

H.Terstiege: Any comment to this proposal?..... No, then I think we come to one of the last subjects, that is education. We had also an Interim Meeting on Education in Salamanca and then we changed the chairmanship, which now is chairwomanship: Nancy Howard. She has given an invited lecture. Nancy, how do you see the future on your Committee on the subject?

N.Horward (USA): I won't go over all around for those of you who were there for my talk the other day. There were certain areas that I thought problems, and certain areas that I feel needed to be addressed, and I would just preview my comments by saying that we had a marvelous first meeting of our regenerated group, this afternoon. We're discussing some new directions and some new structure to work with what we are doing, and we are initiating some communication within the group to define some further direction, so that, hopefully, by perhaps, not a year from now, but two years from now, we'll begin to see some results of that cooperative work.

H.Terstiege: Thank you, Is there any question to this?

C.Kleemans (NED): May I make a remark? In the different groups, people were very entusiastic to start work again and to restructure and regenerated these groups, but, perhaps we can get some support from AIC, to give some, let's say, money or other or that there may be to help the groups workable, to help them to communicate, to help to structure the communications. That was in different groups a question, and perhaps, you can think it over inside the Board.

H.Terstiege: I can answer this question very quickly. There are no funds in the AIC. We have very little contributions from member countries, and this is just enough for the basic work, but not enough to support the committees. We have discuss this already four years ago, when we had the meeting in Kungelv, and Anders Hard wanted to arrange an Exhibition which had to be supported, and also there was no money for it. Is like the same as in CIE, although CIE have much more money, and CIE pays for a Bureau Central in Vienna, and pays for an Executive Secretary, but there is no money to support technical committees.

C.Kleemans: Dr.Terstiege, this should not be, that we want help inmediatly, but, most of us would like that you organize something in this field, either CIE or AIC. We must organize something in the future that the groups will be supported by the total organization.

H.Terstiege: Yes, the moral support is allways there, but it is difficult with the finnancial support.

C.Kleemans: Well, that is not a good answer. I hope you will give some more ideas in the future in this field.

H.Terstiege: So, we have two more minutes more. Maybe, just we did not discussed about what, when it was founded in the AIC, was called, in the meeting of Budapest, Colour Dynamics, and then we changed the title in Colour in Environmental Design, which is more appropiate to this. And we also there have a new chairman, he is Leo Oberascher, who is a new member of the AIC Executive Committee.

Leo, how do you see the future in Colour in Environmental Design?

L.Oberascher (AUSTRIA): I think I'll give just a brief report, which I try to draft out so I have taken the papel to keep to it. The Study Group on Environmental Colour Design can be seen as a loose group of approximately 170 members from different proffesional fields all over the world, with their main interest in how to use colour.

So we understand, on the environment, any conditional influence outside the organism proof or system we look at, and therefore, colour in environmental design refers to any entity in our visual surroundings, where the colour is a mean to its design influences, our conigtive perfomance and behavior. So therefore, the group have agreeded not to restric the emphasis only to the field of materials, design and architecture, but also to embrace a wider range and include fields of fashion design, advertising, packaging, film arts, video arts, fits with one step, and this is where we are going on in the future.

The major task of the group will be to bring together people interested in the field, faster communications and collaborations and to stimulate research world wide.

Now, there by, colour should no be treated as an independent variable, but is should be treated as one of the many factors within the complex arrangement of realistic design settings, and therefore, methodological questions will be of great relevance to our work, and the focus of the work should be rather on the complex interaction patterns, between physical and environmental human behavior. And I think we'll have to devote more emphasis on field research and cuasi-experimental situation, instead of classical laboratory experiments.

Or course, we'll be very thankful for other results which all the other people there could give us, and help us, and we have many good examples which we would have to apply and see whether this really works in the complete design program.

Now, in the Study Group, we also decided that we should contact other organizations, which have to deal with design. Maybe try to become a member also of these institutions, so that we get a broader information network and we would like to spread information about symposiums, congresses, and so on, related to our field, to our members.

Then, as we could not fulfill the task to have an annotated bibliography, we decided that the first step will be rather useful, to get the existing bibliography, printed all together and let our members to know where you get what, and keep it in record.

And, What come next to this question? We are looking really forward that in Sidney we'll have the chance to have papers presented in our field, and another possibility is that at the World Biennal, which take place, this year, in june, in Sofia, we have a colour day, and, as far as I hear, also in England, there is the interest of Tom Porter, to organize a meeting, and at last but not the least, As I had not the chance to visit the AIC meeting yesterday, I could not offer the idea that I would be very happy to recieve an Interim Meeting, in Austria, maybe, two years after Budapest meeting, in Salzburg, the city of music, and music is colour.

I think it would be the right place to have a meeting on colour in environmental design again.

H.Terstiege: Thank you very much, specially for your invitation to have one of the next Interim Meetings in Salzburg.

If there is no questions, we have finished in time. We started some minutes later, and I would ask all the members of the Executive Board to join me for the Closing Session.

Closing Session

CLOSING SESSION

Schedule: Friday March 17th, 1989, 17 hs.

AIC Executive Board present: Prof.Dr.Heinz Terstiege (FRG), President; Dr. Alan Robertson (CAN), Vice-president; John Hutchings (GB), Member; Lic.Roberto D.Lozano (ARG), Member; Dr. Leo Mori (JAP); Prof.Werner Spillmann (SWI), Member.

H.Terstiege: We have to thank all the members of the Executive Board and the Chairman of the Grupo Argentino del Color, Daniel Lozano, for organizing this meeting, although when we have this meeting in mind, four years ago, we did not expect this attendance, as we had before. Still people came from various places of the world, and we all knew that, of course, a meeting in Argentina is more expensive than to have a meeting in Europe, but, we were all of the same oppinion in the Executive Committee, that we have to give a chance, also to those people of countries who allways, have a long way to travel to Europe, and we usually have meetings there, or most of the technical meetings, of course, are in Europe. And Daniel Lozano mostly managed to come over, to find some funds to join us, and as a reward we said we have to support this, to have a meeting in Argentina. And we see that the idea was right, and many, many people came to Argentina.

For the meetings, I tell you that the first AIC meeting was Color 69 in Stockholm. It was the first official AIC meeting, though there were many meetings before. My first meeting was Lucern, four years before. This was in 1965, but also many of you took part. One of the oldest of you may have took part in the Dulsseldorf meeting, or the meeting organized by the French colour committee, and Dr. Manfred Richter. The time in Europe, Dusseldorf, Heildelberg, and so on.

But the official AIC started from the CIE meeting in 1967, in Washington. The time the AIC was founded. And the President was W.D.Wright, from the Imperial College in London, and the Vice-president was Gunnar Tonquist, who is here, and the Secretary was Dr.Ganz from Switzerland. At that time the AIC could be handled by three persons, only.

When the new Board was elected, then, the late Prof.Ives Le Grand, become President for the period 1970-1973. Late Jim Bartleson, become Vice-president, Ganz remained Treasurer and W.D.Wright, Gunnar Tonquist, Tarow Indow and Manfred Richter were members of the Executive Committee. Now, the next President was Tarow Indow from 1973 to 1977; Jim Bartleson from 1978 to 1981; Bob Hunt, who is with us, from 1982 to 1985 and myself from 1986 to the end of this year 1989. And yesterday we elected the new President, Alan Robertson. But this is already known due to the Statutes, that we have to elect him was unavoidable because, although he is a very nice chap, the Statutes say that the Vice-president will be the President of the next quadrennium.

So this were some names of the AIC officials of the past years.

The next AIC colour congresses. After 1967 in Stockholm, we had 1973 in York, in Britain. But between 1969 and 1973 we had the first AIC Interim Symposium, and this Interim Symposium, as the next ones, were always only on special subjects, and in Dribergen we had the first gathering together to discuss only colour difference formulae, and this subject was Colour Metrics, and we had very fruitful discussions, but we could not solve the problem at that time, and we have seen, now, after 18 years ago, still are a lot of discussions on colour metrics and colour difference formulae.

Then, after the meeting in 1977, the Troy meeting in the USA, the Interim meeting become a part of the AIC, from that time we had one meeting every year: One meeting in London on Colour Measurement and Applications; one in Tokyo, on Colour Appearance, one in Williamsburg on Chromatic Adaptation, then, in the next quadrennium, after the AIC Color 81 in Berlin, we had in Budapest on Colour Dynamics, which now we call Colour in Environmental Design; Kungelv, Sweden, on Colour Order Systems; Salamanca on Colour Education.

In the past quadrennium, after Color 85 in Montecarlo, which the french called Mundial Couleur, but this against the Statutes. The statutes clearly say that the word for this event is Color, and so on. Not Farbe, not Couleur, not Farbe in der Welt, not Mondial Couleur, but anyhow, was a very nice conference, and after this one, we had Interim Meetings on Colour on Displays in Toronto, Colour Vision Models in Florence and Colour in Design and Art in Winterthur.

The Executive Committee has arranged or agreeded for the Interim Meetings of the next quadrennium. The next will be Berlin in Germany, the last week of september, on Instrumentation for Colour Measurement, and the next one will be in Sidney, Australia the 26-28 of June 1991, just before the CIE meeting in Australia which takes place in Melbourne. This is on illumination for colour matching and design, but the title will be Colour and Light. For 1992, which is not very secure, may be a little change, in Waterloo, an Interim Symposium is planned on Colour Vision, and then we have the invitation from the Hungarian Committee on Colour to have the Meeting Color 93 in Budapest, Hungary. We all thank Prof. Nemcsics for the invitation to Hungary.

Last, not least, we also yesterday got an invitation from Japan, I think the invitation from Dr.Mori for 1997. So this is already fix. Which is still open for the Executive Committee, for the next quadrennium on Interim Meetings for 1994, 1995 and 1996, and we already are very happy to get the invitation of the city of music and colour, Salzburg, from Leo Oberascher, and he is a member of the Executive Committee. So I am convinced that this meeting will take place in 1994 in Salzburg.

So, the meetings of the AIC. I shall give you some figures of the attendance and accompanying persons. In Stockholm, the first AIC meeting, in 1969 we had 478 active participants and 83 accompanying persons. Figures which was never reached afterwards. Maybe later, people had not that much travel money or there are more events during the years, or we had very many sweeden that took part in the meeting, and when in York or Troy, not so many natives took part. More foreigners. I don't know. So, participants came from 22 countries and we had 150 papers presented.

In York, in England, we had a little bit less participants: 428 and 101 accompanying persons from 26 countries and 116 papers. In Troy, in USA, we had many less participants, only 271, because the air fare from Europe to Troy was also more expensive than air fares within Europe, we had 65 accompanying persons and 99 papers.

In Berlin, where we had 317 active participants and 65 accompanying persons from 29 countries, we first introduced the system of having papers and posters. Because we know that many participants have not a chance to come to a meeting when they cannot present a paper. And the poster sessions, which came on very well in the USA, enable participants to came to the meeting. We first started this in Berlin and they were very successful and we did the same in Montecarlo, where we had 100 papers and 45 posters, and we had 329 participants.

Here now, in Buenos Aires, we had a little less than 200 participants from 25 countries. The exact figures will be given later, and we also have about 110 papers and posters, but here we try to have as less parallel sessions as possible. The only which did not go very well, was yesterday, when we had the AIC meeting of the delegates, parallel to a meeting, and because of the time schedule was already set and some of the officials could not change their own private schedule to have the meeting after the papers presentation, so we had the meeting in another room and this, of course, prevented some people to take part of this meeting.

The result of that meeting was that we agree the meeting of the delegates and in the last AIC Congress we had a general discussion on this. AIC Color 89, which we all found very successful, we agree on AIC Color 93, and we accepted the invitation of Japan for 1997.

Are there any questions on these meetings? Is anybody against having a meeting in Budapest? Or the meeting in 1997 in Japan? ...(No answer). OK, so I see that the decision of the Executive Committee has a background of everybody, of all participants here.

The we also agree on the Interim Meetings, which , I just told you, 1990 in Berlin, 1991 in Sidney, 1992 in Waterloo, was a question mark, Is this all agreeable to you? (No answer). Everybody can live with these meetings, or are any other suggestions? (No answer). Thank you.

The small report or discussion on Study Groups. On Colour Order Systems, Colour Education and Environmental Colour Design. You hear the discussion just before. Because before you have no more questions I think we have no more questions to the Study Groups now.

OK!, then we have the item 7. We had the election of the Executive Committee, and again there we could not change the proposals of ourselves in the Executive Committee, because we chaged the Statutes, and this was agreeded at the Winterthur meeting, that we did not want to repeat what happened in Montecarlo where, from the floor, from outside, new names proposals for the Executive were made, so the changes of the Statutes is, that the existing Executive Committee makes a proposal for the next Executive Committee and send it around to the National Committees, then the National Committees have a few months time to make their own proposals, but every proposal has to be supported by at least, two other National Committees, and then the new proposals came and they were incorporated into the list of nominees of the Executive Committee and send around. And becasue this time there was no other proposal, then the proposal of the Executive Committee was the only proposal and the National Committees do not have to vote, but they voted. They could also been against the proposal, in which case we would be in trouble.

So, automatically Dr. Robertson was elected as a new President for the next quadrennium, and again I want to congratulate him.

So we elected the auditors, and we had Other Business, and that was all we have done yesterday in the meeting that some of you could not take part, but if you have any questions, now or later, the Executive Committee will answer these questions.

Now, I shall introduce you the new Executive Committee. The new Vice-president will be Mme.Ronchi, and, as I said before, automatically she will be President of the AIC. We elected the new Treasurer, also well known Dr. Michel Pointer. Then the members of the Executive Committee. As a rule we have one member of the country of the where the next AIC Session will take place, this is Prof.Nemcsics. Then we have Dr.Leo Oberascher, Dr.Alan Rodriguez, and then -we allways try to make an even distribution, that every country is represented sometime in the Executive Committee- we have one member of the country, just recently joined to the AIC, that is Dr.Paul Green Armitage. As I already mentioned, Australia joined the AIC, and also the Republic of South Africa, in the last quadrennium.

So, this is the new Executive Committee, and they will be in charge, begining next year, the first of January, and I can only, from my part, thank you, for your coming, not only for this meeting, but also come to the Interim Meetings, and the Executive Committee for the support I had, I can only say that it was a pleasure to work with them, and now I will give the word to the new President, starting the first of January, 1990, Dr.Robertson.

A.Robertson: Thank you very much, Heinz. Before formally closing the Conference, I would like to say a few words, particularly I like to add my thanks to those of Heinz, to the Argentine Colour Group for the excellent work they've done in organizing this conference, and I like to mention the Organizing Committee by name, and I hope they are here. The Treasurer, Cristina Melcon de Bellora, the Arrangements Chairman, Antonio Alvarez, the Administrative Secretary, Laura Yasan, the Exhibits Manager, Daniel Braguinsky, and of course, most of all, the Chairman of the Organizing Committee, Daniel Lozano.

Now, I know that Organizing Committee, was been supported by a very good Secretariat. A lot of help in the background during the meeting and I know I should'nt single out any one or two members, but I think I would like to render a risk of upsetting the rest of the people by mentioning two people, this, at all the Secretary of the Congress, Maggie Mizsey, and then the lady who has been running up to this everywhere in this Auditorium, fixing broken microphones, supplying water when it was needed, moving furnitures, I like to say, Thank you very much, Silvia Parotti.

For most of us, this is our first visit to South America, and I think, that most of us, now hope it won't be the last.

I think, you probe Daniel (Lozano) , with all your help, that it is not necessary for a meeting to be in Western Europe, in North America or in Japan, for to be successful, we had just a good meeting here as we had in that other places. Thank you.

And, while I am in the mood for thanking people, I like to thank Heinz Terstiege for this hard work over the last four years. It's going to be quite hard thing to fill his shoes, but certainly I'll do my best. Thank you very much.

Now, as I look forward to my four years in Office, I like at this time, to dedicate to the memory to my late colleague and friend, Dr. Gunter Wyszecki. He was prominent almost in every AIC meeting which was held in thre past 15 of years of AIC, and he died, four years ago, the very day you elected me to be your President. I hope that my actions, as the President, in the next four years, will allways be the one he would support it.

I want to work to help the AIC grow both in strength and numbers, and, I believe that there is two very important ways we have to do this. The first is by written communications, and most of you know we have a Newsletter that is been published every two years, for the last eight years. I've been the editor in the last two editions and I'll be producing one more within a few weeks. But I ask Paul Green-Armitage to take over that job from me, and to produce our Newsletter from now on, and we are going to try to make an annual Newsletter, so we are going to have a little more frequent news of AIC events.

The other way in which we communicate, I think it was well covered by Heinz already. That is by meetings. Heinz already told you the proposed locations and dates of several of our meetings in the next eight years, in fact.

So now it is time to bring the conference formally to a close. I hope to see many of you at the Interim Meetings, so in the next year, the first is the one in Berlin, next September, and then Sidney, Australia in two years time. And, of course, I hope to see all of you, in Budapest, in 1991.

So now I think all that remains to say is:

Good By! Au revoir! Aufwiedersehen! Adios!.

Thank you!

Post - Deadline Papers

Observer Variation in Mesopic Photometry

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An investigation is underway to study in which ways and to what extent observers agree and differ in their brightness matching characteristics, over a wide range of luminance levels (5-6 log units). The method of measurement has previously been established using two observers.

Suppose, for example, a yellow and a blue light are made equally bright at a photopic level. Attenuation neutrally (with a sector disk or a good neutral filter) into the mesopic region will result in the greater relative brightness of the blue light. Since rods are more sensitive to blue than to yellow light, this effect becomes progressively greater as the level is reduced within the mesopic region and rods become more active relative to cones. Also in this mesopic region the colours gradually become paler, and as the level is further reduced into the scotopic region colour disappears. Here the field which was previously blue remains brighter, but the relative brightness of the two lights does not change as the level is then further reduced towards the absolute threshold.

In the current investigation the yellow light, which is the reference, is adjusted by the observer to be equally bright to the blue light, typically at some 17-19 levels spanning the photopic, mesopic and scotopic regions, right down to the absolute threshold. The test light is blue in the case described above: in other runs it may be green or red or white, or any one of a representative range of spectral and non-spectral colours. But in all cases the reference light is yellow.

Comprehensive data acquired in this way on several observers, mainly on the NRC Trichromator, enable us to address several important questions. These include "How far downwards does the photopic region extend for different coloured stimuli?" and "How far upwards does the scotopic region extend?". There are no simple answers to these questions even for a single observer. For instance it cannot be said that there is a certain luminance level above which vision is photopic, and below which mesopic, for all colours. The extent to which the upper and lower limits of mesopic vision vary between observers is a major feature of the results of this investigation.

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"Colour in Architecture: a New Mentality and the Rôle of the Colour-Adviser"

Among many other sectors related to industry, the European architecture of today counts an the assistance of a new specialist: the colour-adviser. Thanks to a few precursors, this new specialization was launched about 1950 in the North Hemisphere, particularly in France. Looking back a century from then, to the mid-1800's, it is possible to spot discussions about the problable colours of the Greek temples in long-lasting arguments.

The European classicist mind had been formed by idealizing the architectonic shapes of the Greek ancient times, which were largely believed to have been all white due to the marble used. However, reconstructions on paper made by the French architects awarded with the "Prix de Rome", and who also spent some time in Greece after studying in the Eternal City for four years, demonstrated that the Greek architecture had not only received colours in the past, as had also been extremely polichromatic. Such matter of considerations was not restricted to France alone: in Germany as well, Gottfried Semper insisted that bright colours had actually been used in all the constructive components of the classic temples.

Still during the 19th century a new mentality rose up in Europe as a result of various factors, among the most determining; the grouth of the cities, the technological development fomented by industry, the use of new construction materials. In terms of architecture, the historicist styles set forth a true ecleticism and the buildings planned could be, for instance, of a neo-bizantine style, or neo-arabic, or neo-gothic... Mainly when influenced by the Italian Middle Ages, the latter used to be a tendency which proposed construction solutions with the presence of several kinds of stones, such as marble of contrasting hues that made façades colourful.

Another material used in the precedent centuries recovered its place: the brick. In England, some architects such as Street, Butterfield, Shaw and Webb, favoured the natural tones of the materials on façades and the so-called "true-wall" (an idea defended by John Ruskin, a well-known art critic of that country), had materials like stones and bricks combined in their buildings. George Edmund Street even wrote a book — "Brick and Marble in Middle Ages" (1855) — and transfered his thinking to projects of buildings like the churches St. James the Less or St. Mary Magdalene and, also in London, the Palace of Justice, with its flagrant binomial brick and stone in alternated colours. A consequent remarkable visual impact on the urban space reveals a structural truth. William Butterfield, stressing the importance of accuracy in wall building, designed surfaces to be composed with briks of different shades, so as to form geometric patterns, which were referred to as "tapestry". Together with William Morris, and being one of the founders of the Arts and Crafts movement, Philip Webb became famous for building the Red House, near London, entirely made of red briks.

In France, the brick apparent on façades was sporadically seen throughout this period, that is, the second half of the 19th century, Mainly found in the suburbs of Paris, preference was given to orange and yelowich bricks which were decorated with some others enameled in shades of green or blue. Publications like the collections of prints by Pierre Chabat got the title "La Brique et la Terre Cuite" (1881 and 1888), emphasized that such materials, suitable to the construction of popular buildings, could "receive a wide diversity of shapes and all the ornamental beauty of colour...".

Around 1860, after the use of cast iron, not even steel as a new material managed to keep off the presence of colour: either as painting to preserve metal from corrosion, or as enamel coated metal structures (like, for instance, the pavillions built for the French exhibitions, particularly those dated 1878, designed by Leopold Hardy). In such buildings, as the railway stations which were under the responsability of engineers, glass was assembled to metal as a means to let in more light.

By the turn of the century, the first Art Nouveau buildings had started to appear, counting an a special kind of creativity from the architects who mastered the use of the various materials available for construction, always including colour. Horta, van de Velde, Endell and Otto Wagner are some the European architects of Modern Style. However, the most famous of all was, inquestionably, Héctor Guimard, a Frenchman whose work was more concentrated in Paris, where many of his architectural projects can be seen, among them the Castel Béranger, the Hôtel Jassedé, as well the famous entrances of the subway stations marking Paris with the typical lines of the Art Nouveau and the green colour they were painted.

The most revolutionary construction material was certainly the concrete, which, thanks to Auguste Perret and his brothers, had its use largely spread in architecture in the beginning of the 20^{th} century. Nevertheless, the first buildings projected by Perret made it clear that a moderation of the hues had returned to impose itself in architecture. This was later patented in Germany, where Gropius and all the functionalist architects adopted cubic shapes generally whites. There was again in structural possibilities, the construction methods for concrete were improved, but all the simplification and the clean façades without ornaments led to a loss of colour, as pointed out by Spillman.

The reactions to this sterilization of the urban space was felt in Germany, through the "Chromatic Movement", led by Bruno Taut, in the 1920's. Therefore from his projects for the "Glass House", presented during the exhibition of the "Deutscher Werkbund", in 1914, in Köln, he declared himself in defense of colour in architecture. The small pavillion specially built for the occasion was analised by the historian F. Loyer like this: "This magic world of modulation of light and colour, made possible by the technique, shows at least as much importance in the 1910 - 1920's as does the functionalist movement". The houses produced by the Falkenberg project (near Berlin) and also the buildings of Magdebourg, turned out to be polichromatic due to the intensive campaign for colour carried out by Taut.

In Paris, where most buildings bear the grayish-beige of the cut stones, ideas and people met during the period between the two World Wars. In 1923, the De Stijl group, led by Theo van Doesburg, held an exhibition at the Galerie L'Effort Moderne, about the "chromoplastic" in architecture. Le Corbusier, yet recalcitrant in relation to the polichromatic architecture (and his position concerning this matter seems to be ambiguous) finally made use of colour for façades in France, for same of his buildings: firstly, the houses of Pessac, near Bordeaux, painted in bright colours; then, the main entrance to the "Cité de Refuge" (ordered by the Salvation Army) was painted in primary colours; later on, the "Unité d'Habitation de Marseille" and the House of Brazil (Paris) received a polichromatic treatment in the external varandas.

The personality whose influence was the most significant for the formation of a professional interested in colours, was Fernand Léger. Through his essays and lectures he made it clear and addressed to architects and artists, calling their attention to the importance of colours in modern life, stressing how the abstract art had freed the colour wich now started to exist as a reality in itself, being seen on out-doors and shop-windows. Without leaving aside his struggle for the mural painting, once as a painter he had done works of that kind, Léger proposed a new approach to incorporate colour to wall surfaces, differing from the old standards. Studying the laws of psico-physics regarding colours, he imagined spaces that could be modified by the single use of certain chromatic hues on the walls. For him, the white wall as proposed by the new architects, was like an "intermission diapositive" and he expressed his desire of seeing plain colours critically chosen to coat walls, matching places. One of his lectures became famous when in Zurich, om May 3^{rd} 1933, under the title "The Wall, the Architect and the Painter", he criticized the attitude of an architecte who had decided to distribute colour for himself: "In times such as ours, where everything is fruit of specialization, this is a mistake...", said he, explaining vehemently the rôle of a painter: "...it is up to us to take action towards colour in close relation ship with you...". After fighting for chromatism in the interior of houses, he also faced the problem of the external colouring of an architecture, its weight, at a distance may be diminued or increased, depending an the colours chosen. Léger's rôle was more didatic than practical in relation to the colouring of architecture. Shortly after the World War II, among the artists who used to visit his workshop, there was Georges Patrix, a young painter intending to leave the academic teaching of Fine Arts aiming at a closer contact with those he had elected as his masters - Matisse, Le Corbusier and Léger. He wanted to leave his easel behind and transform industrial premises with the help of his knowledge. Indeed, he wanted to take painting from the limits of the canvas, dreaming of a more authentic rôle for the fine--art artist in the society:the one of a contemporary environmental composer.This idea was totally supported by Fernand Léger.

Patrix integrated groups of precursors who started to meet in the 1950's in order to discuss themes concerning Colour, thus forming in France some research centres and associations of colour-advisers, and was one of the first to apply polichromy in industrial plants for both functional and estetic purposes. Machines, interiors and façades were made more evident by the bright colours proposed by him in factories, schools or shops.

Another colourist, contemporary of Patrix, was Jacques Fillacier, who infortunately passed away in late 1986.He had always supported a "social practice of Colour",which he demonstrated in many jobs: the colouring of working premises (factories, offices)or of public buildings (hospitals, schools, administrative offices, the subway of Paris). Some examples of his interesting colouristic action, such as the reservoirs of the refineries, in the south of France, and the noise absorving walls along the highways wich were close to residential buildings, resulted from a methodology he created, by which are taken into consideration aspects ranging from the termic effects caused by the tonal quality of the paints, to certain principles of composition derived from the architecture of a given urban space.

As a trainee at the Fillacier's workshop, the colourist France Cler developed the drive needed to open her own office — the "Atelier des Recherches Chromo-Paysagères". There, associated with her husband, Michel Cler, she has developed, since the 1970's, a work oriented to the urbanistic notion of assemble (in urban or rural spheres), a moment when she chooses chromatic hues for architecture.The operational methods adopted by Cler's atelier incorporate a knowledge of the land where big habitational complexes are to inserted, taking into account not only the colour of the natural surroundings but also of the constructed environment. Her principal interferences took place with the French " villes--nouvelles", but nowadays Cler also works abroad, as in the bridges for pedestrians in Hong-Kong.

Among other French colour-advisers, the name of Jean-Philippe Lenclos outstands for the coherence in which he has been developing his serious research about colours of the traditional architecture in different regions of France and his practice. The method of analysis of geographic site, which has a touch of archeology, has enabled him to improve processers to detecting the environmental colours and the proposal of chromatic palettes, to guide the preservation of colours at the more ancient areas in France. The "Atelier 3D Couleur"work also in the choice of colours for the new architectury and industry.

It is largely proved today that the task of a colour-adviser requires extreme sensitivity regarding colours, since most of them originally came from a background in Fine Arts. However, they should also bear a knowledge of the functional aspects of Colour and their psychological effects. The colour-adviser for architecture knows that the urban space is an area inevitably passed-by and therefore whatever they present ends up in influencing the human being. The monotony of the colourless cities was a rather recent reality as it was only in the 1970's that an outburst of colours effectively dominated the urban area: through advertising, the mural paintings, the grafitties, Colour seems to have been re-discovered as a new component, after the white period of a functionalist architecture then followed by a gray fashion resulting from the need of camouflage in the period of the World War II.

But the colour is not a solution for all problems; and there is a danger in the "flood" of colours presently registered in modern cities.

We would ask ourselves whether the appropriation of colour as simple "make-up", when employed in a improvised manner by those who are unqualified to work with it, would not be missing the beneficial qualities that this visual recource, when well used, can have over human minds.

The job of a colourist of architecture is not easy and does not admit last minute solutions. He must work for those who use the urban spaces, deciding to interfere only when it is proved necessary, for the solutions to be found must be positive and acceptable by the majority of passers-by. Obviously, the colour-adviser can not solve all problems, but will represent a means through which to re-establish balance in situations tending to a chaotic end.It's a job to be developed in a pluridisciplinar manner — together with the architect, the urbanist and the sociologist. The chromatic contrast is a necessary stimulus required by Man, but a balanced dosage is essential. It will depend an what sites will be touched by the colourist. Climate, geography, cultural data and the light of a given city will determine the path of such work.

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SOME FACTORS AFFECTING THE MEAT COLOUR IN SEVERAL SPECIES ENGAGED IN ANIMAL PRODUCTION

The meat colour is one of the most important qualitative characteristics for marketing. Mostly, the consumer tends to choose the meat provided by a species (and/or by a production type and/or by a cut) on the basis of the colour that, in addition to the marbling, is the only evaluation element at the purchase.

Various factors can affect the meat colour; among these, species, genetic type, sex, housing type, feeding, age and weight at slaughter, electrical stimulation, slaughtering methods, muscle and light exposure have great importance.

In this abstract some of the results, obtained within the researches carried out on the meat quality evaluation of some species (cattle, buffalo, swine, ovine, caprine, fallow-deer, turkey) by the working group coordinated by prof. Matassino, are summarized, factor by factor.

Species. A comparison between Italian buffaloes and Italian friesian cattle shows that the first provides a 'lighter' meat (Matassino et al., 1976a and 1984a; Colatruglio et al., 1975; Cosentino et al., 1982; Freschi et al., 1984 ; Gambacorta et al., 1984); the same for the kid in comparison with the lamb (Cosentino et al., 1980).

Genetic type. Matassino et al. (1976b, 1985a and 1986), in cattle, Chiofalo et al. (1983) in goats, Matassino et al. (1985b) in pigs and Matassino et al. (in press) in lambs have pointed out the importance of the genetic type in determining the meat colour.

Sex. In the ovine, the female tends to provide a meat 'lighter' than the male (Cosentino et al., 1986); the opposite was noticed in the pig (Matassino et al.,1985b).

Housing type. Matassino et al. (1985a), pointed out that in cattle the subjects reared in box with the slotted floor provide a carcass with a 'lighter' meat, compared with those reared in 'feed lot'.

Age. From 5 to 15 months of age, in Italian buffaloes and in Italian friesian cattle, the meat tends to be 'darker' (Matassino et al., 1978 and 1984b); the same result is noticed in the lambs and in the kids slaughtered at 28, 35 and 42 d of age (Cosentino et al., 1980). On the contrary, Chiofalo et al. (1983), in a research carried out on goats, remarked that by increasing the age the meat colour tends to be 'lighter' and 'more red'.

Weight at slaughter. By increasing the live weight at slaughter the meat becomes 'darker' in the cattle (Matassino et al., 1985a and 1986) and in the fallow deers (Girolami et al.,1988).

Feeding. In cattle, the feed level 'medium', in comparison with the feed level 'high' provides a 'lighter' meat (Matassino et al., 1985a and 1986). The quality of fat supplementation in feed, is not important in determining the meat colour in turkey (Girolami et al. in press).

Electrical stimulation. The researches carried out on the goat and on the lambs carcasses (Matassino et al., in press; Chiofalo et al., 1983) pointed out that the electrical stimulation does not influence the meat colour; on the contrary, in the cows the electrical stimulation determine a 'lighter' meat (Matassino et al., 1985c).

Slaughtering methods. The slaughtering methods (sticking, electricalshock and following sticking, pistol with captive bolt and following sticking, ecc.) affect the meat colour in relation to the degree of the bleeding induced in the animal; the lambs stunned by electricalshock before sticking and those which are only sticked provide a 'lighter' meat (Cosentino et al., 1986).

Muscle. The muscle shows a high individuality in determining the meat colour in cattle and in buffaloes (Colatruglio et al., 1975; Matassino et al., 1976a and b, 1984a, 1985a and c, 1986; Cosentino et al., 1982; Freschi et al., 1984; Gambacorta et al., 1984), in pigs (Matassino et al., 1985b), in ovines and in caprines (Cosentino et al., 1980; Barone et al., 1982; Chiofalo et al., 1983; Cosentino et al., 1986; Matassino et al., in press), in fallow deers (Girolami et al., 1988) and in turkey (Girolami et al., in press).

Exposure to light. In the modern supermarket the type of light utilized for the cases where the meat is commonly exhibited to the consumers, is an other important factor for the meat colour. Chiofalo et al. (1983) in goats and Matassino et al. (1985a and 1986) in cattle pointed out that the meat colour varies in relation to the light employed; the meat is 'lighter' and 'more red' if it is exposed to the incandescent lamp (2854° K) and 'darker' if it is exposed to the fluorescent lamp to a light which is equivalent to the sunlight with covered sky (6700° K) or to the open sky (6500° K).

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Correction	Page	Line	Original	Change to
1	2	16	14, 22 and 8	13, 22 and 8
2	3	14	15, 19 and 28	18, 24 and 39
3	3	15	19 to 9	24 to 10
4	3	17	19,23,25	20,22,24
5	3	18	21 for..	20 for..
6	3	29	CV values of 21	CV values of 20
7	3	31	500 to 800 for the	500 to 900 for the
8	3	33	200 to 1100	200 to 1400

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FINLAND	1	1	2
FRANCE	5	1	6
GREAT BRITAIN	7	-	7
HONG KONG	1	-	1
HUNGARY	1	1	2
ISRAEL	1	1	2
ITALY	4	1	5
JAPAN	19	7	26
NORWAY	1	-	1
PORTUGAL	1	-	1
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