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SCIENTIFIC ORGANIZING COMMITTEE

Dr. J.C. Combe
Dr. E. Dahl-Jensen (Scientific Secretary)
Dr. W.O. Lock (Chairman)
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Miss E.W.D. Steel: Organizing secretary
PREFACE

This volume contains the texts of all but one of the invited talks given at the Vth Conference on Nuclear Photography. I am grateful to the speakers who kindly provided me with the manuscripts of their talks.

I would also like to thank the Scientific Information Service for the production of the diagrams, the CERN Typing Services for their careful typing of the stencils, and my colleagues in the Emulsion Group for their help in the running of the Conference.

W.O. Lock,
Geneva.
November 1964.
I. RADIATION DETECTION IN LARGE CRYSTALS OF SILVER CHLORIDE:
A SURVEY AND REPORT OF RECENT EXPERIMENTS

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RADIATION DETECTION IN LARGE CRYSTALS OF SILVER CHLORIDE: A SURVEY AND REPORT OF RECENT EXPERIMENTS

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I. INTRODUCTION

This paper describes the use of large single crystals of silver chloride as detectors of charged particles. At room temperature, the tracks of these particles are made visible within the transparent crystal by deposition along them of metallic silver. The technique is based on two earlier discoveries:

i) the observation by Haynes and Schockley that it is possible to displace photoelectrons through macroscopic distances in silver chloride; and

ii) the extensive demonstration by Mitchell and his co-workers, beginning with the paper of Hodges and Mitchell, of the role of crystal imperfections as traps for photoelectrons in silver halides.

By combining these two techniques, it is possible to deposit electrons at defect sites throughout the volume of large crystals (of the order of 1 cm x 1 cm x 0.5 cm). Because of the great mobility of interstitial silver ions, each trapped electron gives rise to an atom of metallic silver which, upon repeated acquisition of electrons and silver ions, grows into a microscopically visible speck of silver metal. One thus obtains a delineation of imperfect regions throughout the crystal by decoration without recourse to an annealing process which might be expected to eliminate or at least change the character of the cracks.

*) Supported in part by the Advanced Research Projects Agency (Contract SD-100) and the Air Force Office of Scientific Research (Grant No. AF-AFOSR-450-64).

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This decoration technique for radiation detection still presents some difficulties and unsolved problems. The potential advantages of the method for certain specialized work, however, seem to justify continuing effort towards making the process useful and reliable.

These potential advantages, in comparison with emulsion techniques, are as follows:

i) because the tracks are embedded in a rigid solid, there is no track distortion upon decoration at room temperature;

ii) the high density (5.6 g/cm³) provides greater stopping power;

iii) crystals of much greater thickness than emulsions may be employed;

iv) the decoration process is quite simple, and saturates the tracks in less than 2 hours at room temperature;

v) the process is insensitive to humidity;

vi) the large refractive index of silver chloride (2.07) increases the microscope working distance by 35% over that in G5 emulsions.

The application of large crystals of silver chloride to track detection involves both the effects of high-energy radiation on crystals and the production of precipitate markers along the imperfect regions. It therefore seems appropriate to give a brief survey of radiation damage phenomena and of the decoration process. This survey is followed by a review of results so far obtained with silver chloride detectors, together with a discussion of the, as yet, unsolved problems and experiments currently underway.

II. SURVEY OF RADIATION EFFECTS AND DECORATION

A charged particle traversing a crystal loses energy in several ways: ionization (resulting in the production of free electrons); excitation of electrons of the host ions; excitation of lattice vibrations
by direct interaction with the host nuclei; and displacement of host ions to other (metastable) sites in the crystal. Conventional emulsions are sensitive primarily to the ionization process, recombination being inhibited by reactions at the surfaces of the microcrystals [see, for example, the review of Mitchell\cite{Mitchell}]. In the large crystals employed in the present work, however, the surface is so remote that electrons and holes cannot diffuse out before becoming trapped; the ionization process must eventually be reversed. Other, more permanent, effects of the passage of the energetic particle may remain, however. The intense local heating at the centre of the track\cite{Fowler}, followed by a rapid quenching back to ambient temperature, must result in a region of concentrated strain surrounding the track. In addition to the complex tangle of lattice dislocations thus produced, there may also be a residue of other defects, such as interstitial chloride ions and chloride vacancies (interstitial silver ions are too mobile to permit permanent point defects in the silver sub-lattice). It is this collection of lattice imperfections which must, in a large crystal, serve as the "latent image".

An additional interesting comparison between emulsions and large crystals concerns the question of amplification of the "signal", the latent image. In emulsions, the development process converts the entire silver halide grain which carries the invisible latent image into a macroscopic bit of silver. In the present technique, each atomic-scale electron trap is converted into a microscopically visible deposit of silver by repeated capture of photoelectrons and silver ions during the subsequent decoration process.

The term "decoration" refers to the deposition of precipitate particles of some sort along the imperfection to be studied, thereby rendering visible its location and course. The first demonstration that such a technique could be made to yield valuable information concerning dislocations was the work of Hedges and Mitchell\cite{HedgesMitchell}, who exposed silver

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bromide to radiation in the near-ultraviolet region, and found that the
resulting photolytic silver preferentially appeared along the dislocations.
This radiation is all absorbed very near to the surface, and since no
driving electric field was employed, the depth of the decorated region
was limited to about 30 microns [this is of the order of the diffusion
length before trapping; with a diffusion coefficient for electrons of
about 1 cm²/sec — deduced from the magnitude of the mobility — and a
lifetime of the order of a few microseconds, then 30 microns is approxi-
mately 2(Dt)½]. It is of interest to note that the individual specks
of silver show very little growth after reaching a critical diameter of
approximately 1 micron. Further work by Jones and Mitchell⁵ and by
Parasnis and Mitchell⁶ showed that the quality of decoration in silver
halides varies somewhat among different crystals and is also influenced
by the concentration of cuprous ion.

Decoration of dislocations deep inside the crystals may be
accomplished by precipitation of a foreign substance at elevated tempera-
ture out of a supersaturated solid solution. Alkali and calcium halides
have been studied in this manner by the Ghent group⁷—⁹, and similar experi-
ments on silver halides were performed at Bristol¹⁰—¹². From the point
of view of radiation detection, this technique of chemical precipitation
has several disadvantages: firstly, the specimen must be annealed at
elevated temperature, a process which is expected to destroy or modify
the lattice disorder in the region of the particle track; secondly,
the precipitates produced along the decorated dislocations vary consider-
ably in size, thus making it difficult to develop a procedure for identi-
fying the particles which produced whatever tracks which might remain after
the annealing.

The present method employs the Hedges-Mitchell technique but
achieves decoration throughout crystals more than 5 mm thick by driving
the photoelectrons with an applied field of several thousand volts per
centimetre, as in the experiment of Haynes and Shockley. Since the
ionic conductivity of silver chloride precludes the establishment of a
steady electric field (for crystals with a few parts per million divalent metal impurity, the relaxation time is approximately 100 μsec), both the ultraviolet irradiation and the electric field are synchronously pulsed. The electronic process is completed in 10 μsec, a time sufficiently short that no appreciable ionic current flows. In the particular apparatus used in this work, each light flash produces approximately 10⁸ photoelectrons per square centimetre, and the pulse frequency is 1000/sec. After one to two hours, the decoration is sufficiently intense for microscopic observation. It is essential that the illuminated surface be quite free of strains; otherwise, few electrons penetrate into the bulk.

The nature of the possible sites for electron trapping is of interest. Dislocations in ionic crystals may have points of effective charge where the dislocation makes a "jog" from one slip plane to another. For one type of "jog", the effective charge has the magnitude e/2, as was pointed out by Mott and Seitz¹³. A positively charged "jog" could then alternately trap electrons and the highly mobile interstitial silver ions, its charge thereby oscillating between +e/2 to −e/2. Presumably foreign inclusions and various positively charged impurity ions could also act as traps. The elucidation of the nature and role of such trapping sites should be the key to uniform production of high quality radiation detectors of silver halide crystals.

III. RESULTS

The use of electrically swept photoelectrons to study dislocations in silver chloride was first reported in 1960¹⁴. Earlier difficulties in driving electrons through the illuminated surface were here eliminated by careful polishing, etching, and annealing, to produce a relatively strain-free surface. It was also found that the contrast produced for dislocation
observation depended on the purity and previous thermal history of the crystal (for example, whether and in what manner the specimen had been annealed before decoration); on this basis, one could account for the fact that Haynes and Shockley, along with later workers, did not observe dislocation decoration in their experiments.

This technique was then extended to observations of tracks produced by cosmic radiation\(^\text{15}\) and by energetic particles produced in the collision of 1.6 GeV protons with nuclei of the silver chloride lattice\(^\text{16}\). Experimental details are given in references 15 and 17. It was apparent from this work that relativistic proton tracks were not made visible by this technique, but that heavy particle tracks could, in the better crystals, be delineated sharply and with high contrast. (See Fig. 1.) Schmitt\(^\text{18}\) obtained the first quantitative data by this method, decorating the tracks of alpha particles from polonium (Fig. 2) and demonstrating that the observed range (16.8 microns) agreed with the calculated value (17 microns). Figures 1 and 2 show the typical track structure: discrete specks, about 1 micron in diameter.

One question that arises is that of the permanence of these decorated tracks. Storage in the dark for several months has shown no regression. Shorter exposures to visible light plus exposures of over 60 hours in the microscope have likewise produced no detectable deterioration.

There remain two major problems:

i) the development of procedures of specimen preparation which will ensure good track decoration and contrast with high reliability and uniformity; and

ii) the establishment of relations between characteristics of individual tracks and the nature of the particles which produced them.

Let us first consider the second question, the problem of "calibration". Two properties of well-decorated tracks which might be used to identify the original particle are the track width and the speck density.
Results obtained thus far indicate that both of these characteristics are relatively insensitive to the exact extent of the photoelectric "development" treatment, probably because of the fact that individual silver specks show little continued growth above 1 micron. Both track width and speck density might be expected to increase with increasing energy loss rate of the incident particle; this is illustrated qualitatively in Fig. 1. In one crystal which was exposed to primary cosmic rays along with an adjacent G5 emulsion, the speck density of six tracks varied from 13 to 55 per 100 $\mu$, qualitatively paralleling the order of increasing energy loss rate as deduced from the emulsion. Quantitatively, microdensitometer scans may be employed, as shown in Fig. 3; note, for example, the increase in speck density as the particle nears the end of its range.

Detailed comparisons between the scans and speck counts in crystals and those of tracks of the same particles in an adjacent emulsion should lead to a calibration of the detector, as well as a determination of the resolution that can be achieved.

The problem of the role of impurities and previous thermal history of the crystal remains perplexing. Not only does the track contrast vary considerably from one boule to another, as shown in Fig. 4, but also the conditions for good track decoration are not the same as those for good dislocation decoration. Thus, with proper understanding of the processes involved, it should be possible to treat crystals in such a manner that dislocations remain invisible while the tracks are delineated with high contrast. In fact, for one specimen which had been annealed in air at high temperatures, embedded in powdered quartz, the surface regions (300 $\mu$ deep) gave excellent dislocation decoration but no trace of tracks, whereas the interior showed excellent track decoration with no trace of the dislocations. Presumably something had diffused in or out of the crystal during the anneal, making the surface regions chemically different from the interior.

One difference between the isolated dislocations and the tracks is that the tracks may contain such defects as chloride interstitials and vacancies, in addition to their own tangles of dislocations. Also, the isolated dislocations were present during the earlier history of the specimen. They may thereby have acquired an excess of various impurity ions.
which could affect their electrostatic charge and ability to serve as
electron traps and nuclei for silver specks. The tracks, on the other
hand, have never been annealed at elevated temperatures, and cannot have
accumulated or lost those impurity ions that diffuse slowly at room tempera-
ture. Since metal ions generally diffuse rather rapidly in silver chloride
at room temperature, whereas non-metals do not, it seems likely that such
impurities as oxygen may be involved.

Experiments aimed at answering these questions are currently
under way. The effect of annealing atmosphere on the subsequent decoration
of dislocations and of tracks is being studied. It also appears that metal
impurities, such as Al, Fe, Ni, and Pb, can inhibit decoration when present
in concentrations in excess of about 10 parts per million.

It has been observed that such impurities do increase the undesir-
able background of random specks. Presumably, multiple charged positive
ions act as electron traps and thereby give rise to specks of silver during
the decoration process. This cannot be the complete explanation, however,
and the extent to which impurities directly affect the density of electron
traps along dislocations and tracks is still an unanswered question. In
any event, such effects must be due to the impurity ions themselves and
not simply to their influence on the concentration of silver ion vacancies,
since it has been found that there is no apparent correlation between the
room-temperature ionic conductivity (which measures the concentration of
silver vacancies) and decorability.

These effects of impurity atoms are being studied at present from
two approaches. Firstly, techniques for zone-refining and doping silver
chloride crystals are being set up. This will allow a detailed investi-
gation of the role of known impurity atoms. Secondly, it is planned to
study carrier-trapping phenomena in these specimens by means of electron
paramagnetic resonance investigations after low-temperature X-irradiation.
In addition, the effects of annealing in vacuum, in chlorine, and in
oxygen will be explored for each impurity. There are also indications that the quartz powder used as a support during annealing may not be completely inert; this possibility is currently being examined.

In addition to these experiments, aimed both at understanding the physical processes involved in decoration and also at the development of a reliable procedure for producing specimens with the best track contrast, there are two other investigations under way. One is simply to repeat for silver bromide crystals much of the experimentation thus far concentrated on silver chloride. The other line of investigation concerns the possibility of what might be termed a "self-decorating" crystal\(^1\). It has been shown by Moser, Nair, and Urbach\(^2\) that cuprous ions are excellent traps for electronic holes in silver halides, thereby inhibiting recombination and facilitating the formation of photolytic silver. The role of cuprous ions in the decoration process has also been studied by Parasnis and Mitchell\(^6\). The "self-decoration" process would involve the irradiation of such specimens with light in the tail of the optical absorption—light which can penetrate the entire crystal and yet have sufficiently high photon energy to produce hole-electron pairs. If the holes were trapped at isolated cuprous ions, the electrons would be free to produce track decoration. The advantage of such a technique would be the "development" of tracks by simply illuminating the crystal, with no need for auxiliary electronic apparatus. Preliminary experiments on several copper-doped crystals showed that some "self-decoration" of the dislocations did indeed take place throughout crystals 4,000 \(\mu\) thick. Under further exposure to yellow light (Wratten K-2 filter, 25 watt tungsten lamp, specimen 2 feet from lamp), the decoration slowly regressed, disappearing in about five days.
IV. CONCLUSIONS

The utility of large crystals of silver chloride as specialized detectors for high-energy particles and events has been demonstrated. Although there still remain problems of reproducibility and calibration, the fact that high-contrast, low-background specimens have been prepared from commercially available material indicates the feasibility of economic production of such detectors. The solution of the remaining problems would not only assist the attaining of this goal but should also contribute towards our understanding of the photographic process and radiation effects in crystals.

V. ACKNOWLEDGEMENTS

We wish to express our sincere appreciation to F. Moser of the Eastman Kodak Research Laboratories (Rochester) for contributing special crystals, to C. Fichtel of the Goddard Space Flight Centre for his invaluable assistance with emulsions, to R. Johnson of the Harshaw Chemical Company for his co-operation in selecting and analysing crystals, and to R. Miller and D. Buchanan of Chemstrand Research Laboratory who performed the microdensitometer scans.
REFERENCES


9) S. Amelinckx and W. Dekeyser, Solid State Physics 2, 325 (1959). References to earlier work are given here.


13) F. Seitz, Rev.Mod.Phys. 23, 328 (1951).


19) C. Childs, in reference 17.

Figure Captions

Fig. 1 : Two primary cosmic-ray particles as observed in G5 emulsion (top) and silver chloride crystal (bottom).

Fig. 2 : Alpha-particle tracks by Schmitt (reference 18).

Fig. 3 : Microdensitometer scan of centre track in top photograph. There is an increase in density as particle stops.

Fig. 4 : Comparison in background of "good" crystal (left) and "bad" crystal (right). The background is partly caused by participation of impurities with the latter crystal having higher impurity content.
Discussion after the invited talk by C. Childs

Schopper : Dr. Childs, you have kindly given us for comparison one of your early crystals irradiated by cosmic rays together with a photographic emulsion. The number of stars per unit volume is much higher in the emulsion than in the crystal. This leads to the conclusion that the sensitivity of the crystal is different in different areas. Do you observe this phenomenon also with your present crystals and techniques of handling, and what is the limit of sensitivity for track formation you assume, in terms of dE/dx?

Childs : There is a variation of impurity content across the diameter of a boule. This variation can be significant where there is a large-angle grain boundary which, during crystal growth, may act as a purifier by sweeping impurities into a grain as it moves into that grain. However, in the good crystals, there is less than ~2 ppm variation across a diameter of about 8 cm. (See reference 19 of my paper.)

Giller : À la demande du Professeur Schopper, je me permets de signaler que la décoration des monocristaux de chlorure d'argent telle que nous l'avons expérimentée à Strasbourg présente actuellement de nombreuses difficultés méthodologiques. La décoration par zones, plus importante en surface, irrégulière, instable parfois, indique malheureusement que des facteurs difficiles à contrôler, tels l'annihilation, la concentration en certaines impuretés, l'élimination du brome jouent un rôle fondamental avec d'autres que nous n'avons pas encore réussi à identifier. L'amélioration de la méthode repose donc entièrement sur la fabrication des cristaux et nous attendons avec anxiété les efforts dans ce domaine de chercheurs tels que Childs, Silfvin et bien d'autres encore. Cette méthodologie est difficile mais il est indispensable de l'aborder si nous voulons un jour rendre cette méthode si prometteuse utilisable.
Bogoslov: Do you use any technique for relaxation of crystals for using them once more, or perhaps the relaxation occurs spontaneously? How many times could a crystal be used with a suitable relaxation technique?

Childs: It is expected that the silver chloride crystals could be used many times by annealing in chlorine to redisolve the silver. At the same time, the imperfections would presumably be annealed out. Before trying the re-use of crystals, however, the more basic problems of track decoration should be solved.
II. CHARGED PARTICLE TRACKS IN SOLIDS AND THEIR APPLICATIONS TO NUCLEAR PHYSICS AND GEOPHYSICS PROBLEMS

R.M. Walker
General Electric Research Laboratory, Schenectady.
II. CHARGED PARTICLE TRACKS IN SOLIDS AND THEIR APPLICATIONS TO NUCLEAR PHYSICS AND GEOPHYSICS PROBLEMS

R.M. Walker
General Electric Research Laboratory, Schenectady.
CHARGED PARTICLE TRACKS IN SOLIDS AND THEIR APPLICATIONS
TO NUCLEAR PHYSICS AND GEOPHYSICS PROBLEMS*)

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Heavy charged particles leave trails of radiation-damaged material in many different types of insulating solids including natural minerals, glasses, and plastics. These tracks can either be observed directly in an electron microscope or they can be developed and studied in an optical microscope. In this paper we first give a resumé of the basic experimental phenomena and then discuss the mechanism of formation of tracks and of their revelation. The special advantages of these new particle detectors for nuclear physics studies are then summarized, and illustrations of the successful use of solid-state track detectors in nuclear physics experiments are given. It is shown that natural crystals contain fossil tracks and the origin of these fossil tracks are discussed. Specific applications of fossil tracks to studies of terrestrial minerals, meteorites, and cosmic rays are presented. In conclusion, we treat briefly the future possibilities in the study of charged tracks in solids.

*) Abstract of talk given by Dr. R.M. Walker.
References to Papers by Dr. Walker and His Colleagues

P.B. Price and R.M. Walker, General Electric Research Laboratory, Schenectady, New York:

Electron microscope observation of a radiation-nucleated phase transformation in mica; Res.Lab. Reprint 4305.

Electron microscope observation of etched tracks from spallation recoils in mica; Res.Lab. Reprint 4203.


Observation of fossil particle tracks in natural micas; Res.Lab. Reprint 4418.

A new track detector for heavy particle studies; Res.Lab. Reprint 4443.

A simple method of measuring low uranium concentrations in natural crystals; Res.Lab. Reprint 4493.

P.B. Price, R.L. Fleischer, R.M. Walker and E.L. Hubbard:

Ternary fission of heavy compound nuclei; Report No. 63-RL-3355M.

R.M. Walker, P.B. Price and R.L. Fleischer:

A versatile disposable dosimeter for slow and fast neutrons; Res.Lab. Reprint 4659.

R.L. Fleischer, P.B. Price and R.M. Walker:

Method of forming fine holes of near atomic dimensions; Res.Lab. Reprint 4573.

R.L. Fleischer, E.L. Hubbard, P.B. Price and R.M. Walker:

Track registration in various solid-state nuclear track detectors; Report No. 63-RL-3503M.

R.L. Fleischer, P.B. Price and E.M. Symes:

A novel filter for biological studies; Report No. 63-RL-3483M.

* Compiled by the Editor from material supplied by Dr. Walker.
R.L. Fleischer and P.B. Price:

Charged particle tracks in glass; Res.Lab. Reprint 4644.
Fission track evidence for the simultaneous origin of tektites and other natural glasses; Report No. 63-RL-35011M.
Tracks of charged particles in high polymers; Res.Lab. Reprint 4610.

R.L. Fleischer and P.B. Price:


R.L. Fleischer and P.B. Price:

Decay constant for spontaneous fission of U$^{238}$; Phys.Rev. 133, 1B, B63 (1964).

R.L. Fleisher, P.B. Price, E.N. Symes and D.S. Miller:

Fission-track ages and track annealing behaviour of some micas; Science 143, pages 349-351 (1964).

M. Dobeauvais, M. Maurette, J. Hory and R.M. Walker:

Registration of fission fragment tracks in several substances and their use in neutron detection; Pergamon Press, London, to be published.

M. Maurette, P. Pelles and R.M. Walker:

Etudes des traces de fission fossiles dans le mica; Laboratoire de Chimie Physique, Faculté des Sciences, Orsay.

M. Maurette and R.M. Walker:

Etudes des traces de particules induites par les interactions de protons de 3 GeV dans différents minéraux; Laboratoire de Chimie Physique, Faculté des Sciences, Orsay.

Donald S. Burnett, Raymond C. Gatti, Franz Plasil, P. Buford Price, Wladyslaw J. Swiatecki and Stanley G. Thompson:

Fission barrier of thallium-201. UCRL-11079.
Discussion after the invited paper by R.... Walker

Other : It seems that when the total ionization is decreasing, as for fission tracks, we are sure to see all of the tracks except for the very last part, where dE/dx is too low to produce a developable track. But in the case where the Bragg curve increases, the tracks are not visible at the beginning and often it is necessary to place Al foils on top of the detector to be sure that one is at the maximum of the Bragg curve, so that one can be sure that the surface is sufficiently disturbed, so that the developing acid can penetrate.

Walker : It depends very much on the material one is looking at. With the fission fragments one is coming down in dE/dx and in mica what you say is true, that is, one essentially sees the whole range. But if you are talking about a crystal of olivine for example, this is not true, because the critical dE/dx for track registration is higher and one only sees about half to two-thirds of the true range. This quantity dE/dx varies from one crystal to the next and must be determined for each crystal.

Colle : How could the sensitivity be improved so that singly charged particles can be recorded using such techniques?

Walker : One way of improving the sensitivity is to go to a different technique of revealing the tracks. As long as one is talking about etch revelation, one has to have a more or less continuous region of damage, so that the acid penetrates the whole length of the track without running into any barrier. In mica, for example, one can see discontinuous tracks on the electron microscope scale which however cannot be revealed by the etching technique. Hence we need a new method and one obvious way to increase the sensitivity is that of depositing
metal in the particle track. We have tried several methods of doing so, using electric fields and various heat treatments. We have succeeded in one special case with one special glass. We have succeeded very nicely in decorating dislocations in a variety of things, quartz for example, but not yet tracks. So one way of improving the sensitivity is to have a better method of revelation. What is not clear is whether the cut-off in sensitivity is of a fundamental nature or if the limitation is that of the etching technique. There is evidence that something qualitatively different happens at the sensitivity limit - if so, there is not much hope to improve the sensitivity of these materials. However, I am convinced that by one way or another it will be possible to improve the sensitivity of these systems.

Colle : Have you not mentioned something about the presence of oxygen in plastics?

Walker : In one variety of plastic if you irradiate it in vacuum the registration of tracks is not as good as when you irradiate it in air. We did a series of experiments in which we went to high vacuum, added nitrogen first, studied the registration and then did the same thing with pure oxygen. It seems that it is the oxygen which plays the important rôle. This is not at all surprising. It is known that the presence or absence of oxygen, which acts as a scavenger for free radicals, plays an important rôle in radiation damage studies. What is surprising is that the temperature effects in oxygen are rather small.

Colle : In radiation protection studies, the importance of the presence of oxygen on the site at the moment of irradiation was recognized. The oxygen is supposed, I think, to create oxygen bridges linking the two parts of the broken long chains; as a consequence, the chain cannot further be cured.
I think one could think of an oxygen donor mixed with organic material and of a specific reagent used to "etch" the material by reacting on the weakened chains.

Winzeler: Did you think how to scan 'large areas', say one cm$^2$, for rare events?

Walker: Yes, we have done this for thin films of plastic irradiated, for example, to fission fragments which leave a micro-hole through the film. We then evaporate a thin layer of aluminium on one side of the plastic and pour sodium hydroxide on the opposite side. The solution which passes through the micro-holes reacts violently with the aluminium making a hole which is big enough to be seen by the naked eye. To scale this up to find one event per square metre is difficult. We would like to use this technique to study very rare heavy ions in cosmic rays, employing different plastics of various thicknesses and sensitivities.

Filz: It seems you could improve this technique by using very thin sheets of plastic and making stacks of many sheets. Then all points of a track will be at the surface. Thus even protons might possibly be observed.

Zakreowski: At the CERN PS we have exposed sheets of natural mica interleaved with metal foils to large doses of high-energy protons. After processing, the mica sheets were examined under an ordinary optical microscope. It was found that the passage of the high-density proton beam through the mica sheets does not produce excessive background of tracks in the mica itself unless the total proton dose exceeds $10^{12} - 10^{13}$ protons/cm$^2$. Full details and photographs can be found in CERN Report 64-49 by R. Brandt, Ch. Gfeller and myself. These tests were made in preparation for an experiment to study high-energy nuclear fission that has recently been proposed by the CERN-Naples-Warsaw collaboration (CERN/Emc/64-17).
III. NOUVEAUX MATERIAUX PHOTOGRAPHIQUES
POUR LES RECHERCHES NUCLEAIRES

C.S. Bogomolov
NIKFI, Moscou.
NOUVEAUX MATERIAUX PHOTOGRAPHIQUES

POUR LES RECHERCHES NUCLEAIRES.

C.S. Bogomolov,
NIKFI, Moscou.

Au IVe Colloque de photographie corpusculaire nous avons parlé des résultats obtenus dans l'application de différentes méthodes de préparation des émulsions nucléaires.

Un degré très élevé d'homogénéité granulométrique des microcristaux des émulsions nucléaires a été obtenu par la méthode de récristallisation progressive employée par Markocki et Romer et par Klein et Moiser. Pour obtenir des émulsions de grande sensibilité il est nécessaire d'avoir non seulement l'homogénéité granulométrique, mais aussi surtout l'homogénéité cinétique c'est-à-dire d'avoir une grande quantité de microcristaux d'émulsion avec le même degré de maturation chimique [principe d'homogénéité]. Nous ne sommes pas encore au courant des propriétés cinétiques des émulsions de nos collègues polonais et allemands, mais ceux-ci ont obtenu dans leurs recherches une meilleure homogénéité granulométrique que certains autres spécialistes.

Les recherches dePerfilov et ses collaborateurs discutées à Munich ont servi de base aux études des émulsions à grains fins que je veux citer ici et qui seront examinées dans les communications de ces auteurs. L'émulsion à grains fins de type M que nous avons réalisée à NIKFI, a fait l'objet d'un exposé lors du Colloque précédent.

Dans la présente communication nous allons examiner les recherches effectuées dans le domaine de la réalisation de nouveaux matériaux photographiques pour les recherches nucléaires, en particulier les matériaux qui ont déjà été employés par les firmes connues au cours des années 1962-1963; nous parlerons aussi des recherches effectuées en Union Soviétique et dont les résultats sont bien connus de l'auteur.
A l'heure actuelle Eastman-Kodak produit des matériaux photographiques de grande sensibilité type NTB-4. L'analyse des propriétés de ces émulsions, effectuée dans notre laboratoire, a montré un certain nombre d'avantages. On peut croire que ces matériaux ont permis à Eastman-Kodak de mettre au point ces nouvelles couches, car la Maison Kodak s'occupe de recherches de ce type depuis longtemps. Les couches photographiques enregistrent les traces des particules relativistes avec une densité de 43-45 grains par 100 microns. Le voile est égal à 2,7 - 2,9 grains par $10^{-9}$ cm$^3$, il est donc un peu élevé, mais avec des traces aussi denses il n'empêche pas l'observation. L'émulsion NTB-4 ne contient pas d'iode. Pour le reste il semble que la composition élémentaire ne diffère pas essentiellement de celle des émulsions nucléaires usuelles.

Les couches photographiques type K-5, produites régulièrement par les usines Agfa-Wolfen, ont une faible concentration d'halogénure d'argent propre aux émulsions obtenues sans précipitation de la phase solide. La densité des couches d'émulsion K-5 n'est égale qu'à 3,38, ce qui correspond approximativement à une concentration en poids de 75-76%. On a effectué des essais sur certains lots de pellicule K-5 à l'Institut des Recherches Nucléaires de Dubna. On peut conclure d'après leurs qualités photographiques que certains lots parmi les meilleurs étaient comparables aux couches photographiques de type BR NIKFI de 1956-1962.

Gevaert produit deux types d'émulsions nucléaires. Le plus intéressant est l'émulsion NUC-715 avec un diamètre moyen de microcristaux de 0,15 micron. L'émulsion à grains fins NUC-307 avec un diamètre des microcristaux d'environ 0,07 micron a quelques défauts et contient une grande quantité d'agglomérats d'halogénure d'argent plusieurs fois plus gros que les microcristaux individuels.

En ce qui concerne les matériaux photographiques japonais, nous n'avons eu à essayer que les plaques avec couches minces. Les dernières que nous avons eues enregistraient les traces des particules relativistes en donnant 38 grains par 100 microns et un voile de 2,3 grains par $10^{-9}$ cm$^3$. 

9748/p/ im
Comme on le sait, en Union Soviétique les travaux sur les nouvelles émulsions nucléaires sont effectués par le laboratoire du professeur Perfilov à Leningrad et par notre laboratoire. Les spécialistes de Leningrad ont présenté un rapport sur le travail qu'ils ont effectué dans ce domaine. Cependant, la présente communication ne serait pas complète sans mentionner que le professeur Perfilov et ses collaborateurs ont obtenu une émulsion enregistrant les traces des particules relativistes avec densité de 45 grains environ par 100 microns sans hypersensibilisation par triéthanolamine.

Cela est très important puisque la triéthanolamine a un pH élevé, ce qui diminue la durée de l'utilisation de l'émulsion hypersensibilisée. On ne produit pas encore une telle émulsion à grande échelle.

Nous allons donner un aperçu plus détaillé des émulsions NIKFI, étudiées entre la IVᵉ et la Vᵉ Conférence et que l'on produit maintenant; nous parlerons aussi d'autres matériaux photographiques bien connus dans les recherches nucléaires. Avant de passer à cette partie de la communication j'aimerais faire une remarque générale.

En même temps qu'on élabore de nouveaux matériaux photographiques on a commencé ces derniers temps à utiliser d'une manière plus rationnelle les couches photographiques existantes. Parmi les auteurs de ces méthodes on trouve des utilisateurs ainsi que des émulsionneurs.

A Moscou le docteur E. Dahl-Jensen nous a aimablement parlé de la méthode utilisée au CERN pour faire les piles d'émulsion. Ces piles sont soumises à une pression assez élevée (mais inférieure à une certaine valeur critique), ce qui permet d'éliminer la couche d'air. Il semble que l'humidité des pellicules doit être répartie régulièrement sur toute l'épaisseur des couches d'émulsion.

Les flancs des piles sont fraisés pour obtenir une géométrie bien définie de l'ensemble. Les bords de ces couches fondent légèrement ce qui empêche l'accès d'air du dehors. Ces éléments de la méthode CERN et d'autres procédés expérimentaux permettent de diminuer considérablement la régression régulière sur toute l'épaisseur d'émulsion. La conservation d'une pile irradiée sous pression permet en principe d'exécuter son développement par parties sans diminution de la densité de grain des traces.
Une autre méthode d'augmentation de la stabilité des matériaux photographiques proposée par K.M. Romanovskaya a été réalisée dans notre laboratoire. Cette méthode consiste à sécher très fort l'émulsion qui est soumise ensuite à une température de 60-80°C. La sensibilité de l'émulsion est ainsi augmentée et la régression est réduite. Naturellement, le chauffage sans élimination préalable de l'humidité ne pourra pas améliorer les qualités photographiques puisque l'humidité détruit successivement les centres de sensibilité et l'image latente. Le mécanisme de l'augmentation avec la température de la sensibilité des couches photographiques sèches est dû aux électrons des petits centres de sensibilité qui sont libérés par l'énergie thermique et qui ainsi facilitent l'accroissement des gros centres. Bien entendu, les électrons peuvent être libérés des gros centres de sensibilité mais toute la multitude de centres de sensibilité formés au cours de la maturation prend part au regroupement et les plus gros centres "survivent".

La communication de Romanovskaya et de ses collaborateurs donne des faits expérimentaux qui démontrent que la régression de l'image latente et la décomposition des centres de sensibilité dépendent surtout de l'humidité et il ne faut pas expliquer ces faits par l'excitation thermique des centres. D'autre part, on pourrait considérer la dépendance avec la température des processus indiqués par l'activation thermique de l'interaction chimique d'H₂O avec les centres de sensibilité et d'image latente.

Il semble que le modèle physique le plus précis consiste à dire que les molécules d'eau possédant un moment bipolaire important polarisent les électrons dans les pièges et augmentent le niveau d'énergie de ces électrons, ce qui facilite leur passage par effet thermique vers la bande de conductibilité photographique. Nous n'indiquerons que le résultat moyen du traitement thermique des couches du type ordinaire R.
Tableau 1

Indices moyens de 10 lots de couches chauffées et non-chauffées

<table>
<thead>
<tr>
<th>Matériaux photographiques</th>
<th>Densité des traces grains/100 µ</th>
<th>Densité du voile grains/10⁻⁹ cm³</th>
<th>Estimation de la non-homogénéité de la densité des traces en profondeur</th>
<th>Perte de sensibilité au cours de 90 jours de conservation</th>
<th>Régression au cours de 45 jours de conservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sans traitement thermique</td>
<td>32,4 ± 1,0</td>
<td>1,8 ± 0,4</td>
<td>5%</td>
<td>22%</td>
<td>40%</td>
</tr>
<tr>
<td>Avec traitement thermique</td>
<td>48,8 ± 5,2</td>
<td>2,2 ± 0,3</td>
<td>5%</td>
<td>12%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Il est à souligner que l'effet de l'augmentation de la sensibilité dépend du type d'émulsion mais l'homogénéité de la sensibilité photographique en profondeur est assez satisfaisante. Les matériaux photographiques chauffés peuvent être employés dans les expériences où ils se trouvent longtemps dans des conditions défavorables. Dans notre laboratoire V.M. Ovcharova et al. ont élaboré les couches photographiques pour les recherches nucléaires où la gélatine a été partiellement remplacée par les substances à activité superficielle.

A Doubna on cherche actuellement à comparer ces matériaux photographiques (type RS) avec ceux contenant de la gélatine pure. Mais les organisations scientifiques de l'Union Soviétique qui utilisent à l'heure actuelle les couches du type R sont en général satisfaites par les caractéristiques des émulsions produites; une exception doit être faite pour les défauts dus aux variations de la composition élémentaire.
Il serait très intéressant de comparer les variations de la composition, en particulier de la concentration de l'halogénure d'argent et de la densité de l'éмуlsion, avec les données correspondantes pour les éмуlsions Ilford.

Le meilleur résultat dans l'élaboration des matériaux photographiques pour les recherches nucléaires mis au point à NIKFI est la création d'un nouveau type d'éмуlsion R-2 ou BR-2. L'éмуlsion ancienne de type R est nommée R-1 et les couches sans support avec éмуlsion du type R-1 sont indiquées par BR-1.

Les éмуlsions R-2 sont sensibilisées par un colorant qui leur donne une grande sensibilité à l'action des particules chargées.

Le sensibilisateur employé pour ce but est un des dérivés du styryl. Sa synthèse a été réalisée par R.A. Guerschtein au Laboratoire de synthese organique à NIKFI dirigé par le professeur I.I. Levkoév.

Un colorant ayant une structure semblable n'a pas encore été employé dans les recherches publiées sur la sensibilisation des éмуlsions nucléaires.

Jusqu'à présent le meilleur résultat a été obtenu à l'aide du colorant bien connu employé par Jenny³⁷ pour ses éмуlsions expérimentales et par Zhdanov, Kartoujansky et Chour³⁷ pour l'éмуlsion type R. La formule de ce colorant est citée dans l'oeuvre de P. Demers "Ionomgraphie", page 93. L'éмуlsion de type BR-1 ne contient pas de sensibilisateurs organiques.

Un avantage du nouveau sensibilisateur consiste en ce qu'il ne donne pas d'accroissement du voile, tandis que celui de Jenny augmentait le voile de 40-50% environ. Le principal avantage du nouveau sensibilisateur consiste en ce qu'il donne la meilleure reproductibilité des résultats sans exiger des variations dans la technique de préparation de l'éмуlsion type R. Par exemple, on n'est pas obligé de changer les conditions optimales pour l'éмуlsion non-sensibilisée comme le pH, le pH, le pAg, etc.

⁹⁷⁴.⁸/p/ im
A l'heure actuelle on peut donner les indices moyens des couches BR-1 et BR-2 mesurés lors de la production parallèle des deux types d'émulsion.

### Tableau 2

Indices des couches photographiques BR-1 et BR-2

<table>
<thead>
<tr>
<th>Types d'émulsions</th>
<th>BR-1</th>
<th>BR-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couche</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nombre de grains dans une trace de particule relativiste par 100 µ</td>
<td>33,1</td>
<td>32,8</td>
</tr>
<tr>
<td>Nombre de blobs par 100 µ</td>
<td>26,4</td>
<td>26,3</td>
</tr>
<tr>
<td>Nombre de grains du voile par 10⁻⁶ cm³</td>
<td>2,1</td>
<td>1,9</td>
</tr>
</tbody>
</table>

La réduction de la sensibilité lors de la conservation des couches non-sensibilisées BR-1 et des couches sensibilisées BR-2 pendant 90 jours dans les conditions naturelles est égale à (dans trois couches d'émulsion):

- BR-1 14%, 11%, 11%
- BR-2 11%, 4%, 7%

La réduction de la densité des traces après la conservation des couches irradiées pendant 45 jours dans les conditions naturelles est respectivement:

- BR-1 35%, 30%, 33%
- BR-2 39%, 34%, 31%
Kartoujansky et Chour\textsuperscript{12}) lient le mécanisme de la sensibilisation par les dérivés du styryl à la capacité de réduction de ces composants et comparent l'action des colorants à celle de la triéthanolamine.

En tout cas, le sensibilisateur employé a un avantage indiscutable, si on le compare à la triéthanolamine. Son application n'exige pas l'augmentation du pH et ne trouble pas les paramètres physico-chimiques optimums de l'émulsion.

Le problème des émulsions à grains fins pour les recherches nucléaires existe, mais l'application de telles émulsions dans la physique nucléaire est encore assez limitée. Une émulsion de type \textsuperscript{7}NIKFI à diamètre moyen des microcristaux de 0,1\textsubscript{h} micron, enregistrant les particules d'ionisation minimale n'a trouvé d'application qu'en autoradiographie.

On a produit une certaine quantité de couches du type BM-2, c'est-à-dire d'émulsions à grains fins sensibilisées d'une manière analogue au type BR-2. Les lots expérimentaux de telles couches sans support ont donné une densité de 56-38 grains par 100 microns.

Pour détecter les gerbes d'énergie $5 \times 10^{11} - 10^{12}$ eV on a employé la pellicule RT-6 qui, d'après sa sensibilité et le contenu d'halogénure d'argent, ressemble à la pellicule Sakoura de la firme japonaise Konishirokou.

De l'assortiment actuel des émulsions nucléaires on peut tirer les conclusions suivantes:

À l'heure actuelle la tendance est de produire des émulsions nucléaires de grande sensibilité enregistrant les traces des particules relativistes ayant 40-50 grains par 100 microns sans hypersensibilisation.

D'autre part, parmi les émulsions employées pour des expériences figurent en grande quantité les mêmes types: K-5 ou même G-5 Ilford et BR-1 NIKFI.

L'avenir montrera comment les émulsions ordinaires et les émulsions de grande sensibilité seront réparties dans les différentes expériences physiques. De plus, il est à souligner un grand succès des méthodes expérimentales
basées sur l'influence sur les émulsions de facteurs tels que la tempéra-
ture, le séchage supplémentaire, l'hermétisation pour éliminer la régression
d'une image latente et augmenter l'homogénéité des propriétés des piles d'émul-
sion.

Les progrès dans le domaine des émulsions nucléaires indiqués dans cet
exposé ont été obtenus sur deux années de recherche. C'est le résultat du
développement de la science ionographique dans un certain nombre de pays,
participant activement à la mise au point de l'équipement et des matériaux
destinés aux recherches dans le domaine de la physique des particules élémentai-
taires.
REFERENCES


3) C.S. Bogomolov, Troudi NIKFI, No. 11/21/6,1957.


Discussion after the invited paper by C.S. Bogomolov

Guer : Je voudrais demander au Dr. Bogomolov si le sensibilisateur qu'il utilise dans la fabrication des émulsions R2 et (BR2) peut être employé (comme autrefois le colorant sensibilisateur de Jenny) et concurremment la TEA en trempant les émulsions avant utilisation ce qui permettrait d'hypersensibiliser les pellicules juste avant utilisation et de reconnaître éventuellement les anciennes traces du fond. Dans une méthode de "datage" des événements cosmiques comme celle employée à Strasbourg, un tel "trempé" serait utile.

Bogomolov : Nous considérons comme l'avantage le plus important du nouveau sensibilisateur le fait qu'il peut être introduit dans l'émulsion liquide, ce qui n'est pas le cas de la triethanolamine. Ainsi nous avons jugé inutile de l'introduire par "trempé".
IV. QUELQUES PROPRIÉTÉS DES EMULSIONS NUCLEAIRES

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QUELQUES PROPRIÉTÉS DES EMULSIONS NUCLEAIRES

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I. INTRODUCTION

Malgré les "faire-parts" d'issue fatale qui se sont multipliés ces dernières années, les émulsions nucléaires se portent bien. Leur utilisation, notamment auprès des grands accélérateurs, comme celui du CERN, atteint un rythme inégalé rendant essentielle une planification de production presque aussi serrée que celle d'une grande machine.

Après une période d'évolution rapide et de mise au point entre 1945 et 1950 permettant leur utilisation quantitative et les enregistrements au minimum d'ionisation, la plupart des émulsions nucléaires concentrées ont été dotées de caractéristiques fondamentales à peu près stabilisées depuis notre première réunion à STRASBOURG en 1957. Il peut donc paraître fastidieux, voire prétentieux, d'en parler encore après tant de travaux et d'excellents ouvrages écrits sur le sujet, notamment par le très regretté YAGODA, par DEMERS, par FOWLER, PERKINS, POWELL, par BOGOMOLOV, PERFILOV, BARKAS...... Aussi, quand les Drs LOCK et DAHL-JENSEN m'ont chargé cet exposé, malgré leur expérience très profitable pour la communauté, d'organisateurs des Comités et d'Ecoles de printemps, indiquant que beaucoup d'utilisateurs ne connaissent pas toujours les possibilités des émulsions, j'ai été bien tenté de ne pas accepter.

La conception de ce 5ème Colloque à GENEVE que nous avons voulu centrer étroitement sur l'utilisation la plus efficace de notre outil en physique des hautes énergies, les difficultés rencontrées dans l'utilisation des monocristaux de chlorure d'argent et dans l'augmentation de la sensibilité des autres matériaux solides, les progrès récents de beaucoup d'émulsions m'ont finalement convaincu qu'un résumé succinct de quelques caractéristiques les moins répondues dans la littérature, pouvait être encore utile à quelques utilisateurs.
En nous plaçant dans l'optique de ces utilisateurs nous allons tout d'abord nous efforcer de rappeler quelques notions de photographie corpusculaire pratiquement utilisables.

II. PROPRIÉTÉS OPTIQUES

Les propriétés optiques des émulsions nucléaires fixées et séchées sont évidemment celles des gélatines ou plutôt des glycéro-gélatines utilisées additionnées d'adjuvants non éliminables qui occupent approximativement dans les émulsions concentrées courantes le même volume que la suspension de BrAg. Les innombrables propriétés des gélatines font l'objet d'ouvrages, même de colloques spécialisés qu'on ne peut résumer en quelques lignes, mais soulignons au passage un premier aspect privilégié des émulsions (que nous retrouverons sous une autre forme avec BrAg) puisque l'indice de réfraction moyen des mélanges de gélatines de très bonne provenance utilisées, varie peu autour de 1,5, indice qui est justement celui des combinaisons optiques aprochromatiques et des huiles à immersion. Les discriminations optiques fines très précieuses sont ainsi facilitées par rapport à des émulsions à liants plastiques et surtout par rapport aux monocristaux de ClAg (n ~ 2) pour lesquels les problèmes d'immersion ne sont pas encore bien résolus.

Le facteur de transparence aux photons lumineux des émulsions fixées et séchées joue un rôle important pour l'observation instrumentale des émulsions épaisses, mais ici, l'élimination des colorations variables apportées par le processus physico-chimique dont d'autres parleront (en utilisant, par exemple, des révélateurs et fixateurs protégés) reste primordiale.

III. PROPRIÉTÉS MECANIQUES

L'hystérésis importante, la contraction durant le séchage produisent des tensions mesurables que les spécialistes du "spurious scattering" connaissent
bien et qu'ils éliminent partiellement pour ce qui provient du processus, par
des procédés de compensation délicats (séchage ménagé, glycérol, résine,
traitement isotherme au point isoélectrique...) Un modèle de contraction et
de plissement de feuillets fictifs juxtaposés, tel celui préconisé par ADITYA,
produisant des zones locales de distorsion en corrélation avec le "spurious
scattering", zones d'autant plus importantes que la pellicule est libre et
irrégulière, semble actuellement rendre compte des principaux résultats et
permet certaines corrections.

Les émulsions modernes, stables, ne contenant pas d'eau libre
peuvent être exposées librement plusieurs heures jusqu'à t ~ 100°C et à
la température de l'air, l'hérogène ou l'hélium liquides en pellicules
libres enveloppées ou couchées sur nitrat de cellulose, l'équilibre thermi-
que demandant déjà plusieurs minutes pour une couche de 50 µ d'épaisseur sur
nitrat de cellulose.

IV. NOTIONS SOMMAIRES DE PHOTOGRAPHIE GÉNÉRALE

La photographie a pu naître et se développer rapidement, rappelons-le,
grâce à la présence dans BrAg et ClAg de deux facteurs exceptionnels dans les
solides, l'un électronique, l'autre ionique, qui lui valent encore après plus
d'un siècle, une place privilégiée. Du point de vue électronique, l'écart de
2,5 eV et la nature des bandes 4 P et 5 S, l'absence de niveau d'excitation,
permettent une énergie moyenne de création électron-trou positif par une
particule chargée de ~7 eV rendant ces cristaux utilisables même comme cham-
bres d'ionisation. La structure cubique ouverte, les petites dimensions et
les faibles énergies d'extraction et d'activation de Ag⁺ permettent une migra-
tion interstitielle appréciable à la température ambiante de l'Ag⁺ interstitiel
des défauts de FRENKEL. La gélatine, grâce à ses fonctions multiples et
essentielles d'absorption, de milieu diffuseur, de gonflement, d'acceptateur,
de brome d'amphotère... parachève ce caractère exceptionnel.
Résumons très brièvement quelques éléments essentiels les plus vraisemblables dans la formation de l'image latente corpusculaire d'après les travaux de DEMERS, SCHMITT, BOGOMOLOV, SCHOPPER, MORAND, BRAUN, DEBEAUVAIL, RECHENMANN et SIMON, GEGAUFF, CUER, utiles pour choisir un protocole expérimental donné.

V. PHOTOGRAPHIE CORPUSCULAIRE - IMAGE LATENTE

La particule chargée effectue un certain nombre de collisions électroniques extrayant tout au long de son passage un spectre δ dépendant de sa charge et de sa vitesse. Au-delà d'un seuil qui se situe en moyenne dans un grain d'émulsion ionographique très sensible vers 80 eV (comme pour les photons U.V. de la lumière brève) une partie de la bouffée des électrons secondaires dégradés finalement dans la bande de conduction est captée temporairement dans les divers défauts cristallins (dans la masse et la surface) et les germes de sensibilité positifs créés chimiquement à la surface du grain. Dans les émulsions nucléaires modernes, sensibles au minimum, ces germes dorés sont petits et nombreux, dans les émulsions moins sensibles (plus discriminatoires) ils sont moins nombreux et parfois plus volumineux (comme dans l'ancienne émulsion C 2 très étudiée), donc thermiquement plus stables. (Par exemple, eu égard le défaut de réciprocité pour la lumière à grand temps de poso).

Durant la phase ionique, plusieurs groupements argentiques comprenant chacun 2 à 3 atomes d'argent se forment à la température ambiante sur les germes de sensibilité et les défauts en t ~ 10⁻² sec, ces amas se coagulant ensuite en image latente stable. L'arrangement définitif peut durer quelques minutes ou plus selon les cas à la température ambiante. Cette ou ces images de quelques atomes d'argent provoquent et catalysent la réduction révélatrice.

Durant la phase électronique, une partie de l'énergie moyenne de création d'une paire d'ions est cédée au réseau cristallin sous forme de phonons, qui, dans des cas favorables où la localisation est possible, le perturbent
irréversiblement, créant ainsi pour des pertes d'énergie spécifique malheureu-
sement élevées, des pièges électroniques "décors" comme dans le ClAg, le 
mica, le nitrocellulose, certains alliages et d'autres composés d'avenir étudiés 
au début de ce Colloque.

VI. SEUIL DE SENSIBILITÉ

Le seuil d'une dizaine d'électrons par grain pour les particules 
chargées est encore loin de la sensibilité à la lumière ordinaire des meilleures 
émulsions commerciales (2 à 3 photons) mais il paraît difficile à abaisser en 
raison du mode de distribution instantanée des électrons dans les petits grains 
réguliers des émulsions ionographiques à germes petits et dispersés destinés à 
éviter le voile chimique durant le temps de développement nécessaire à la 
"sortie" du minimum d'ionisation. Ce facteur est très important pour l'utili-
sateur, car il est en corrélation étroite (presque linéairement pour les 
émulsions d'0,2 à 0,3μ) avec le nombre de "blobs" au minimum d'ionisation qu'on 
a souvent intérêt à augmenter pour favoriser les mesures de diffusion et des 
très petits angles pour lesquelles la méthode photographique présente encore 
de sérieux avantages. Le problème de l'abaissement de ce seuil paraissait 
encore plus ardu il y a quelques années, car on pensait alors que des "blobs" 
représentaient le nombre de β énergiques primaires émis au minimum. Depuis, 
des calculs détaillés admettent une statistique plus moyenne favorable à 
l'accroissement du nombre de "blobs" pour des grains de 0,2 à 0,3μ. Pour les 
grains fins de 0,07μ il semble qu'il y ait une limite absolue de 100 grains 
pour 100μ. Par exemple, la dispersion définitive des petits amas dans des grains 
peu impressionnés, suivie de recombinaisons, empêchant la développabilité peut 
éventuellement être, en partie contrée par une hypersensibilisation convivable. 
La TEA, bien adsorbée sur les grains durant l'exposition dont la fonction 
esentielle consiste probablement à réduire, donc stabiliser ces sous-amas 
transitoires, est jusqu'ici le seul composé pour jouer ce rôle par imprégnation. 
Dans beaucoup d'émulsions courantes (Ilford, NIKFI, Perfilov), le nombre de
grains au minimum est doublé par imprégnation à la TRA. Par exemple, de 20 à 30 grains pour 100\(\mu\) pour les Ilford K 5 à une quarantaine pour les hypersensibilisées.

VII. TOPOGRAPHIE DE L'IMAGE LATENTE

La connaissance topographique de l'image latente d'une particule donnée, à vitesse déterminée, est importante, car on pourrait espérer obtenir une meilleure utilisation de l'énergie spécifique perdue, voire une meilleure discrimination en développant correctement l'image corpusculaire interne éventuelle. Parmi les effets photographiques classiques utilisés en photographie générale pour différencier les images internes et externes par les Ecoles de BERG et HAUTOT, repris en détail pour la photographie corpusculaire à STRASBOURG, trois principaux: Dispersion et coagulation de l'image latente par diverses qualités de photons, étude des défauts de réciprocity, stabilisation des sous-images par basse température peuvent à première vue, comme en photographie classique, s'interpréter, soit par le dualisme des images internes-externes, soit par la dispersion superficielle plus ou moins grande.

Rappelons que l'étude attentive de ces effets, jumelée avec l'utilisation de révélateurs non solvants et solvants à développabilité variable mis au point à STRASBOURG, a définitivement montré que dans la plupart des cas, l'image corpusculaire était superficielle et sous-jacente plus ou moins dispersée en amas de dimensions croissantes avec l'énergie spécifique dépensée et que sa localisation dépendait essentiellement de celle des germes de sensibilité introduits dans l'émulsion vierge. Par contre, l'impression d'ions lourds dans des grains peu sensibilisés superficiellement est favorable à une localisation au long du passage de l'ion, grâce aux déformations cristallines irréversibles mises en évidence, notamment pour les traces de fission dans toute une gamme de solides, déformations créant des pliages électroniques efficaces. Il est donc assez facile de discriminer les traces de fission par attaque de surfaces ou révélateurs discriminatoires, comme cela a été fait pour de nombreux expérimentateurs.
Il est de même possible en utilisant des révélateurs non solvants à
développabilité critique (Hg - Erodox de -100 à -400 mV, au fer, par
exemple selon les images et les émulsions) de révéler et sélectionner les ans
selon leurs dimensions, ce qui a été pratiquement utilisé, par exemple, à
STRASBOURG et à BUCAREST pour la discrimination α (p) γ .

VIII. ACTION SUR L’ÉDIFICATION DE L’IMAGE LATENTE EN VUE D’APPLICATIONS

Dans un but de meilleure discrimination, on peut agir, du reste, et
nous l’avons fait extensivement à STRASBOURG sur les différentes phases de
l’édification de l’image latente et de sa coagulation par des facteurs physi-
ques convenables déjà utilisés en photographie scientifique: Par exemple, la
température, le rayonnement vert, rouge ou infra-rouge durant ou après exposi-
tion. La basse température stabilise la capture électronique et ne permet
l’édification et la coagulation que durant les réchauffements, ce qui peut être
judicieusement réglé et peut être précieux pour la conservation de faibles images
dans le temps. Cette stabilisation permet curieusement aux émulsions sensibles au
minimum d’ionisation de présenter un maximum de sensibilité pour la lumière longue
vers -40° C, la sensibilité à la lumière brève (t ≤ 10^{-3} sec) et aux particules
restant malheureusement inférieure à celle à 20° C. En l’absence de migration
assez rapide d’Ag⁺ et d’agitation thermique, un certain nombre d’électrons se
placent sur des pièges de fluorescence (iode, certains adjuvants adsorbés en
surface...) et se recombinent avec des trous positifs (non "acceptés" comme
à cette température). La sensibilité décroît donc graduellement jusqu’au zéro
absolu. À la température de l’hydrogène liquide intéressant les utilisateurs,
toutes les émulsions sont encore pratiquement utilisables. À celle de l’hélium
liquide, le minimum d’ionisation est seulement visible dans celles à grains
assez gros (Ilford G5, NIKFI R sans iode) ou hypersensibilisées, ou encore
préparées sans iode et sans composé fluorescent. La haute température
(jusqu’à 110° C) disperser et coagule rapidement les ans, ce qui peut permettre
t’à l’expérimentateur d’agir volontairement sur la sensibilité très accrue pour
la lumière brève et les β dans les émulsions Ilford C 2 de 20° . à 110° avec
tous genres de révélateurs et dans Ilford G 5 pour des révélateurs non solvants

9748/p/08
faibles. Très diminuée pour Ilford G 5 dans un révélateur total.

IX. EVOLUTION SPONTANEE DE L'IMAGE

A la température ambiante, l'image continue à évoluer du reste spontanément: avec une courte période pour la dispersion et la coagulation des petits amas; le "vieillissement" supprimant donc, d'une part, certains grains développables mais rendant les autres plus rapidement réductibles (Effet visible par l'effet Cabannes-Hoffmann). Avec une longue période (heures à mois) pour l'oxydation chimique de l'image, bien étudiée sous le nom de "fading", certains chargements en sels (de lithium, par exemple) produisant une corrosion éventuelle supplémentaire à la température normale.

L'utilisation judicieuse de basse température, d'hypersensibilisation et de stabilisateurs chimiques permet de freiner efficacement cette régression. On peut également utiliser la latensification par lumière actinique, malheureusement l'absorption de ces photons est fort importante dans les émulsions épaisses.

X. DATAGE DES EVENEMENTS

Comme application pratique d'action sur l'image, citons un procédé de datage des événements nucléaires dans les émulsions ionographiques, sans doute d'avenir pour les expositions spatiales qui a commencé à être mis au point à STRASBOURG(x) et qui utilise l'effet Herschel et les basses températures, d'une part, la latensification et l'effet Herschel, d'autre part.

(x) Communication au Congrès de Photographie Scientifique de TURIN, 1953.
XI. VARIÉTÉS D'ÉMULSIONS IONOGRAPHIQUES

Quelles sont les émulsions ionographiques pratiquement utilisées?

Aux hautes énergies et en physique cosmique où chaque empilement coopératif requiert rapidement au moins une dizaine de litres de pellicules, et les expositions mesurées et coûteuses, une fabrication régulière normalisée, fidèle, irréprochable, est indispensable.

Par histoire, tradition (Bristol), compétence, pour une connaissance plus complète des caractéristiques essentielles beaucoup de pays utilisateurs voisins de la Grande-Bretagne, utilisent les émulsions Ilford. Les émulsions Demers, première réalisation remarquable de l'artisanat ingénieux ont été indispensables. Les émulsions NIKFI et PERPÎLOV également très utilisées, sont décrites dans la littérature, les nouvelles variétés disponibles fort intéressantes, ont été détaillées ici même par C. BOGOMOLOV, nous n'en parlerons donc pas ici. Les émulsions Kodak Eastman utilisées dans les spectrographes nucléaires aux basses énergies et pour certaines applications ont été améliorées récemment. Les émulsions Gevaert qui ont pris un bon départ, excellentes pour la sensibilité sont en voie d'amélioration pour les qualités mécaniques. Les émulsions roumaines utiles jusqu'ici aux basses énergies, en biologie et médecine, qui commencent à être employées aux hautes énergies. Nous n'avons pas assez de renseignements sur les émulsions japonaises et chinoises qui semblaient prometteuses il y a quelques années, couches minces, 38 "blobs"/100μ ainsi que sur les émulsions Agfa, Leverkusen et Wolfen conc. 75%, meilleurs lots comparables à NIKFI-R qui étaient en bonne voie.

Rappelons que l'essor de l'ionographie est, en grande partie, dû dès 1946 à la concentration en BrAg des émulsions à grains fins dont la valeur a été empiriquement arrêtée à 80% permettant avec un révélateur dit "nucléaire" (initiallement à rayons X, physico-chimique un peu solvant) de doubler à peu près les dimensions des grains viérges et de rendre donc les traces "solides" donc bien mesurables.
Pour de nombreux travaux n'exigeant pas un grand nombre de "blobs" les concentrations peuvent être diminuées par dilution dans la gélatine ou par gonflement dans l'eau lourde à condition de redéterminer soigneusement les caractéristiques, dont le pouvoir d'arrêt.

XII. TENDANCES À ENCOURAGER

Sommes-nous parfaitement satisfaits des émulsions nucléaires actuelles, souhaitons-nous encore certaines améliorations? Que conseiller aux émulsionneurs pour le futur en dehors d'une standardisation toujours plus rigoureuse et des qualités irréprochables de gélatine?

L'évolution des fabrications et des émulsions expérimentales ces deux dernières années, indiquent une nette tendance à la diminution des grains vierges et à l'hypersensibilisation et nous devons bien sûr encourager cette tendance puisque plusieurs caractéristiques encore très favorables des émulsions ionographiques (faibles angles, discrimination des ions lourds, hyperfragments de faible vie, spectres de très faible énergie) exigent des grains petits et très sensibles.

Remarquons cependant que jusqu'ici aucune firme n'a produit en quantité et en pellicules épaisses des émulsions genre Perfilov à grains très fins, très sensibles au minimum, hautement désirables.

Ne croyons pas cependant que cette recherche dans la finesse des grains théoriquement séduisante soit illimitée. La solution n'est certainement pas l'observation au microscope optique d'émulsions du genre Schumann concentrées comme nous l'avons cru en 1946 avec BERG et BURTON puisque le développement en quintuplant les dimensions linéaires des grains pour les rendre visibles détruit toute précision. Pour des mesures ultrafines et atteindre la limite d'utilisation de la méthode ionographique pour les mesures des faibles vies moyennes, il devient indispensable de dépasser la résolution optique de 0,2μ et d'effectuer certaines mesures délicates en couches minces au microscope électronique.
XIII. MESURES FINES AU MICROSCOPE ELECTRONIQUE

Des résultats encourageants dans cette voie ont été obtenus par ROBERTS, RIEDEL et STRASBOURG et doivent être soutenus par un effort particulier des émulsionniers: deux fabrications (Gevaert et Bucarest) ont déjà étudié une émulsion expérimentale.

Le meilleur pour l'immédiat serait de disposer d'émulsions à grains ultra-fins (Perfilov ou mieux), encore plus concentrées (environ à 92%) très sensibles, développées par des révélateurs non solvants n'affectant pas la forme granulaire. Peut-être, dans certains cas, devrons-nous orienter vers un dépouillement intégral au microscope électronique, mais ici, j'anticipe et mon temps est fini puisque je dois traiter du présent.
QUILQUES DOCUMENTS POUVANT COMPLETER CE RESUME

- Notices des émulsions actuellement fabriquées et disponibles par les Éts. ILFORD, EASTMAN, KODAK, GEWAERT et l'Institut de Physique Atomique de BUCAREST aimablement adressées par les Drs. EHRlich, MILLikan, FAELENS, NIColaE.


Et avec P. CUER: Réunion de travail sur l'enregistrement des traces de particules chargées dans les cristaux, STRASBOURG 1963.


LECENDES DES FIGURES

Fig. 1 : FORMATION DU CORPS D'UNE TRACE (Thèse WINTER, GEGAUFF).

Ion de 20Ne dans deux émulsions : Ilford K5 (sensible au minimum d'ionisation) et Ilford K2 (pour Ions lourds).
L'ionisation primaire (K2) est encore en course de Bragg; le spectre et le nombre de 6 émis sont seuls responsables de l'amincissement de la trace (K5).

Fig. 2 : TOPOGRAPHIE DE L'IMAGE LATENTE (Thèse SCHMITT).

Les effets de renforcement ou d'affaiblissement par rayonnement infra-rouge dépendant de la nature et de l'intensité du rayonnement actinique, de la longueur d'onde post-exposition infra-rouge et de la nature du révélateur (solvant ou non solvant) et plus ou moins actif.
Avec un révélateur non solvant développant les amas superficiels de dimensions différentes, on peut obtenir à volonté des effets d'affaiblissement ou de renforcement (jusqu'ici attribués au dualisme image interne, image externe).

Fig. 3 : DISCRIMINATION α,β(γ) DANS UNE ÉMULSION ILFORD G5 EN UTILISANT UN RÉVELEUR DISCRIMINATOIRE AU FERRO-OXALATE DE POTASSIUM Thèse BRAUN).

Apparition des "spots" α (horizontaux) et β (verticaux) pour des potentiels E = Eα - Erodox (genre, groupe) différent (20 mV) permettant de révéler les α dans un voile γ important.

Fig. 4 et 5 - BASSE TEMPERATURE (Thèse DEBEAUVAIS-WACK).
Sensibilité des émulsions Ilford G5 pour différents rayonnements en fonction de la basse température.

Fig. 6 : HAUTE TEMPERATURE (Thèse RECHENMANN).
Comportement différent des émulsions Ilford G5 et Ilford C2 à haute température.

Fig. 7 et 8 - (Thèse RECHENMANN).
 Vieillissement de l'image latente en fonction du temps et de la température.

Fig. 9 : (BRAUN, DEBEAUVAIS-WACK).
Stabilisation de l'image latente par conservation à basse température.
<table>
<thead>
<tr>
<th>Marque</th>
<th>Type</th>
<th>Concentration en Br2 en poids en %</th>
<th>Dimensions moyennes des grains vivants (µ)</th>
<th>Sensibilité limite en énergie de particules (donnée par le fabricant) minimum = sensible au minimum d'ionisation</th>
<th>Nbre de &quot;blocs&quot; au minimum d'ionisation, Développement standard : acétate sans THA, exposition à température ambiante</th>
<th>Commentaires des utilisateurs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILFORD</td>
<td>G5</td>
<td>80</td>
<td>0,27</td>
<td>minimum</td>
<td>20 à 30</td>
<td>Encore utilisée depuis 1949. Très reproducible, sensible à la liquide hyperremplissable à THA</td>
</tr>
<tr>
<td></td>
<td>K-2</td>
<td>80</td>
<td>0,2</td>
<td>fission et ions lourds</td>
<td></td>
<td>plaques, gel, pellicules</td>
</tr>
<tr>
<td></td>
<td>K-1</td>
<td>&quot;</td>
<td>a (70)</td>
<td></td>
<td></td>
<td>comparable à l'ancienne Q mais moins discriminatoire</td>
</tr>
<tr>
<td></td>
<td>KU</td>
<td>&quot;</td>
<td>p(7 MeV)</td>
<td></td>
<td></td>
<td>La plus utilisée actuellement. Pellicules très reproduibles (1200 µ)</td>
</tr>
<tr>
<td></td>
<td>K1</td>
<td>&quot;</td>
<td>p(80 MeV)</td>
<td></td>
<td></td>
<td>Bonne discrimination.</td>
</tr>
<tr>
<td></td>
<td>K2</td>
<td>&quot;</td>
<td>minimum</td>
<td></td>
<td></td>
<td>Parfois image, vie d'émulsion expirée, mais sens. à grains plus fine et concentrée</td>
</tr>
<tr>
<td></td>
<td>K5</td>
<td>&quot;</td>
<td>minimum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>L2</td>
<td>&quot;</td>
<td>0,14</td>
<td>p(90 MeV)</td>
<td>18 à 25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L4</td>
<td>&quot;</td>
<td>minimum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NIEKFI</td>
<td>R₄</td>
<td>85</td>
<td>0,28</td>
<td>minimum</td>
<td>25 à 30</td>
<td>Ancien R (depuis 1953 très utilisée)</td>
</tr>
<tr>
<td></td>
<td>H₂</td>
<td>&quot;</td>
<td>0,28</td>
<td>minimum</td>
<td>25 à 30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BR₄</td>
<td>&quot;</td>
<td>0,28</td>
<td>minimum</td>
<td>25 à 30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BR₈</td>
<td>&quot;</td>
<td>0,28</td>
<td>minimum</td>
<td>35 à 40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N₂</td>
<td>&quot;</td>
<td>0,14</td>
<td>minimum</td>
<td>30 à 40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HN₄</td>
<td>&quot;</td>
<td>0,14</td>
<td>minimum</td>
<td>30 à 40</td>
<td></td>
</tr>
<tr>
<td>PERPILOV</td>
<td>FR</td>
<td>85</td>
<td>0,06</td>
<td>minimum</td>
<td>30</td>
<td>Révél. acétate et pyrogallol II</td>
</tr>
<tr>
<td></td>
<td>F₂</td>
<td>73</td>
<td>0,12</td>
<td>minimum</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>EASTMAN KODAK</td>
<td>NTA</td>
<td>84</td>
<td>0,22</td>
<td>a (et fission)</td>
<td></td>
<td>Plaques et emulsion en gel</td>
</tr>
<tr>
<td></td>
<td>NTR</td>
<td>80</td>
<td>0,29</td>
<td>&lt; 30 keV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NTRB</td>
<td>80</td>
<td>0,26</td>
<td>&lt; 30 keV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NTR3</td>
<td>80</td>
<td>0,34</td>
<td>minimum</td>
<td>&lt; 20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NTR4</td>
<td>80</td>
<td>0,56</td>
<td>minimum</td>
<td>20 à 30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NTR5</td>
<td>80</td>
<td>0,2</td>
<td>minimum</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NTR</td>
<td>80</td>
<td>0,6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GEAERT</td>
<td>MOC</td>
<td>70</td>
<td>u, u₁</td>
<td>p(100 MeV)</td>
<td>40 à 50</td>
<td>Très bonne discrimination.</td>
</tr>
<tr>
<td></td>
<td>MOC</td>
<td>76</td>
<td>0,15</td>
<td>minimum</td>
<td>60</td>
<td>Excellent sensibilité mais qualité mécanique et reproductions inégales</td>
</tr>
<tr>
<td></td>
<td>MOC</td>
<td>87 à 92</td>
<td>0,15</td>
<td>minimum</td>
<td>60</td>
<td>Expérimentale pour observation au microscope électronique.</td>
</tr>
<tr>
<td>PHYSIQUE ATOMIQUE BROCAERT</td>
<td>IFA EN 1</td>
<td>85</td>
<td>0,2</td>
<td>p(80 MeV)</td>
<td>30</td>
<td>Utilisée en haute énergie.</td>
</tr>
<tr>
<td></td>
<td>IFA EN 2</td>
<td>85</td>
<td>0,2</td>
<td>minimum</td>
<td>30</td>
<td>Très utilisée pour autoradiographie dans biologie et médecine.</td>
</tr>
<tr>
<td></td>
<td>IFA EN 3</td>
<td>86 à 92</td>
<td>0,07</td>
<td>minimum</td>
<td>30</td>
<td>Expérimentale pour observation au microscope électronique.</td>
</tr>
</tbody>
</table>

La production mondiale des émulsions ionographiques, après une nette décroissance de 1956 à 1961-1962, reprend rapidement.

La production volumétique d'émulsions abordées des deux principaux fabricants atteint en 1964 de 160 à 200 litres pour Ilford et de 50 à 60 litres pour Nieft, cette capacité pouvant être, si besoin, triplée.

La production Eastman Kodak et Geaert, en pleine évolution, peut atteindre rapidement quelques dizaines de litres.
Fig. IV.1
Les trois plaques ont reçu les mêmes expositions
Bandes horizontales : exposition actinique - durée variable
Bandes verticales : effet Herschel
\(
\begin{align*}
&H_1 \text{ exposition inactinique - infra-rouge } \lambda \text{ mi-hauteur 75Om} \\
&H_2 \quad \quad \quad \quad \quad \quad \lambda \quad \quad \quad \quad \quad 95Om \\
&T_2 \text{ témoin - sans effet Herschel}
\end{align*}
\)

Révélateur à la pyrocatechine (non solvant de BrAg)
Potentiel \( F = F_{Ag} - F_{\text{redox}} \) variable \( E_1 > E_2 > E_3 \)

Fig. IV.2
Fig. IV.3
SENSIBILITE DES EMULSIONS NUCLEAIRES EN FONCTION DE LA TEMPERATURE

EMULSIONS ILFORD G5

<table>
<thead>
<tr>
<th>Lumière brève 10^-6 s.</th>
<th>Lumière longue 10 s.</th>
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<tbody>
<tr>
<td>+20°</td>
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<td>0°</td>
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<td>-150°</td>
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<td>-180°</td>
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Fig. IV.4
LOGARITHMES DE LA SENSIBILITÉ (S) EN FONCTION DE L'INVERSE DE LA TEMPERATURE ABSOLUE POUR UNE EMULSION G5 ET LES RAYONNEMENTS SUIVANTS:

- Photons lumineux 10 sec
- Flash 10⁻⁶ sec
- β
- α

Fig. IV.5
EMULSION G 5
VEILLISSEMENT DE L'IMAGE LATENTE
EXPOS LUMIERE BREVÉ A 20° – DEV ID 19
A : PLAQUES CONSERVÉES A 5°
B :       A 20°

Fig. IV.7
Fig. IV.8

VIEILLISSEMENT DE L'IMAGE LATENTE A 90°
EXPOSITION A 20°
LUMIERE BREVE
G5 - DEV: PYROCATCHEINE
DENSITE GRANULAIRE EN FONCTION DU TEMPS DE CONSERVATION.

- conservation azote liquide
- conservation température ordinaire

Fig. IV.9
V. DATA HANDLING IN EMULSION EXPERIMENTS

Walter H. Barkas,
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University of California, Berkeley, California
DATA HANDLING IN EMULSION EXPERIMENTS

Walter H. Barkas,
Lawrence Radiation Laboratory,
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I have been asked to introduce this session on automation and measurement by discussing methods to facilitate emulsion data handling — both by those with modest equipment, and those possessing the resources of a large laboratory. Accurate measurements and records are always important for good scientific work. Now automation in addition may be important or even decisive for the success of certain experiments. I can discuss with authority only my own experiences, because Berkeley is so far away that I was unable to attend the recent specialized meeting on automation of emulsion measurements at Amsterdam.

For the work my group has been doing during the past six or eight years, digitized co-ordinate microscopes, several types of which were described at previous meetings, have been the single, most important aid for data taking. They are used for range and angle measurements, multiple scattering measurements, neutron spectroscopy, track reconstruction, and coplanarity measurements. In some laboratories a digitized co-ordinate microscope means one which prints the co-ordinates of points. We mean here one that punches the numbers into IBM cards or otherwise prepares the data for use by a computing machine without any further translation.

Good over-all planning of the work for efficient data reduction and record keeping is as important as the development of automatic methods. It is something that every laboratory can do, whether or not mechanical aids for computations are employed.
Many items require attention in order to ensure the integrity of the data. The instructions given to the scanner often are of paramount importance for the reliability of the data. The physicist in charge should first fully acquaint himself with the problem by doing a considerable amount of scanning himself. He should then write out the scanning and measuring instructions with the utmost care, anticipating problems and scanning biases that may intrude, while providing means for making checks. In this connection it is necessary to remember psychological factors. It is important that the scanner be unaware of the result that is expected in a measurement or observation. It is very human to try to obtain the answer that pleases. Some of the false "discoveries" made in emulsion experiments may have had such a cause.

We often take many days to prepare the scanning instructions for an experiment, which then remain unchanged except for very good reasons, and with careful notation of the circumstances. It is not then a matter of memory to use data years later. Some K mesons found in scanning carried out in 1956 are currently being analysed, and no difficulty in interpreting the old records has been encountered. Along with scanning instructions, forms for recording the information should be carefully worked out. For K mesons we have made much use of edge-punched cards, with each hole labelled, and the centre area of the card reserved for data forms, and aids for diagramming events. A card contains information pertaining to only one meson. It is the master record. Everything significant about the event is on the card. Often the data are entered over a period of several years, as a variety of measurements are made.
Such a card for $K^-$ mesons has been developed. A similar card for $K^+$ mesons is shown in my book on Nuclear Research Emulsions. There are many minor ideas which can make for greater efficiency. For example, we solved the storage and access problem of a large emulsion stack very simply using a correspondence filing cabinet. The plates are dropped into legal-size file folders of the type that are suspended in the cabinet. The number of the plate appears on a tab at the top.

For processing emulsion, improved methods are also being developed. I shall mention only one or two, because here we are getting rather far from the topic of discussion assigned to me.

We recently developed 15 litres of Eastman Kodak NTB5 emulsion in a single operation. The mounting of these pellicles was greatly facilitated because the instructions for mounting prepared by the Eastman Kodak Company are practical. The results are superior to those of older methods, and blisters are practically eliminated. For these pellicles we also developed a type of frame which left the emulsion with just the desired margin of glass on each edge.

In the most important area of all—improved efficiency in the analysis of particle tracks—I shall mention a few examples from recent experience.

As the first one, I take the identification\(^1\) of the new decay mode, $K_{\mu 4}$. [I may remark, incidentally, that the $K_{\mu 4}$ mode of K-meson decay was found not long ago also in emulsion by Koller, et al.\(^2\).] It and the $K_{\mu 4}$ mode represent the seventh and eighth types of decay known for the charged K mesons. All modes have been definitely identified by means of the emulsion instrument. That the two most recently discovered modes have been found first by means of emulsion in competition with many other instruments, indicates the unique advantage that emulsion, even today, has as an instrument of discovery.]
Our experiment was rather simple, but without the co-
ordinate microscope it would have been rather laborious. In a
large emulsion stack about 4000 three-prong decay events were found
by area scanning. Then two points near the beginning of each
secondary track were punched into IBM cards. A programme was
prepared to determine the unit vectors along the tracks. The
triple scalar product of these vectors was then calculated. For
a $\tau$ meson decaying at rest, this quantity vanishes because the
vectors are coplanar. In general, for a four-particle decay
it will not vanish. It had a magnitude suggesting non-coplanar
decay in about 100 cases. Automation thus enabled us to select
from the much larger sample, those events in which there was pion
scattering, errors of measurement in which the $K$ meson decayed
in flight, or in which there were neutral decay products in
addition to three charged particles. Only the much smaller sample
selected in this way required closer examination. Several
interesting events have been found among them, including the above-
mentioned example of the mode:

$$K^+ \rightarrow \pi^+ + \pi^- + \mu^+ + \nu_\mu.$$  

As a second example, I shall describe neutron spectroscopy
as applied using emulsion detection by William Simon of my research
group. He showed\(^3\) that the compound nucleus produced in the
bombardment of gold by oxygen ions often evaporates several neutrons
before fissioning, contrary to current theory.

The internal radiator method was employed for neutrons of
1–12 MeV. Above 12 MeV an external radiator of polyethylene was
used. Automation was employed in the scanning, recording of data,
and data reduction. His instrument was a type of co-ordinate
microscope developed at the Lawrence Radiation Laboratory for this
purpose. Figure 1 shows a recent model. The procedure was as follows: the scanner first records the z co-ordinates of the two surfaces of the emulsion at a standard point by punching the digitized readings into IBM cards. This measurement relates the thickness of the emulsion at the time of scanning to that at the time of irradiation. A fiducial point, which is the point where the normal from the target to the plate edge intersects the emulsion is also recorded.

The scanning proceeds by "fields of view", outlined by a square on the eyepiece reticle. What is really scanned are volumes of emulsion equal to the area of the square projected on the emulsion times the emulsion thickness. Each is numbered sequentially and automatically recorded on IBM cards. Every proton track starting in the volume of the field of view is measured. The measurement consists simply of recording automatically the point at the origin of the track, a second point on the initial straight portion of the track to give track direction, and as many subsequent points as are necessary to determine the range. The range and direction are calculated automatically.

As a third example, I shall mention our study of the stopping power difference of matter for particles of opposite electric charge.

The earliest indication of the effect was found more than 10 years ago while measuring meson ranges without the benefit of automation. In a later experiment for which $\Sigma^-$ ranges were measured, we became convinced of its existence. The effect is so small, and the experimental verification of it so difficult, that only now with automatic equipment have we been in a position to undertake a study of it. As everyone knows, the path of a low-energy meson in emulsion is not a straight line. Because of their small mass, $\pi$ mesons of low velocity are strongly scattered. This makes the measurement
of their ranges very tedious and subject to error unless one has mechanical aids for the measurement. By means of the co-ordinate microscope mentioned in connection with the neutron spectroscopy, points on the path are recorded on IBM cards. Then the range and initial track direction are automatically calculated. With this equipment, we have now studied the effect, using positive and negative pions of one to three MeV energy, in ordinary emulsion, in gold with emulsion detection, and in four times diluted emulsion. The first results as they existed several months ago, are presented to this conference in another paper.

As a fourth example of automation in emulsion measurements, I shall mention some of our recent work on the decay of the $\pi^0$ meson, the initial results of which I discussed at the Munich conference two years ago.$^4$ The problem is the evaluation of the error in determining the point of origin of the Dalitz pair. As we have described earlier, the estimated point of origin is found by first measuring the coordinates of the centres of the first six grains of the tracks. Then a least squares fit is made of each track to a straight line, and the point of intersection of the straight lines calculated. The vector connecting the actual point of origin of the pair with this intersection is the error vector. The distribution of its magnitude and direction has been the purpose of a recent study. By introducing the scattering, grain noise, and grain spacing as random variables with known distributions into a Monte Carlo programme, we were able to generate artificial tracks which start at the origin of co-ordinates in any prescribed direction. The calculations are described in Lawrence Radiation Laboratory Report UCRL-11624. Pairs of tracks were generated repeatedly in order to obtain the distribution of the error vectors as a function of opening angle and electron momenta. The process, of course, would have been too time-consuming to carry out without high-speed computing machinery.
I have expressed the opinion before that it is probably wisest to approach automation of emulsion track analysis cautiously. Finding means to carry out reliably even a single operation with reduction of error and fatigue is already a considerable accomplishment. We are not interested in the development of equipment as a mere "stunt". Complicated, costly but unreliable, apparatus is worse than useless.

In this respect our "Video Track Analyser" described in Munich remains marginal. We have, as yet, failed to consummate any important research project with it, but recently we have been encouraged to believe that the electronic instabilities, which thus far have kept it from functioning reproducibly, can eventually be cured. An instrument of this type probably can be useful only in a large institution, where expert maintenance is available, and it is not recommended to be used generally. For most grain density measurements, reliance on blob counting, simple lacunometers, and uncomplicated track-width instruments is suggested.
REFERENCES


3) W.G. Simon, UCRL 11088.


Discussion after the invited paper by W. Barkas

Filz: Have you tried flying-spot scanner devices?

Barkas: We have developed the photoelectric detector which scans with a photomultiplier rather than with a television-type system. If enough effort is put into the problem, a flying-spot scanner can be developed, but I am not sure these efforts are worth while.

Gottstein: Would you include three-dimensional track-following devices among the technical developments which you consider not really worth while because of the degree of electronic complication?

Barkas: We have not thought that it was worth trying to do, but I can see instances where it could have been very useful, e.g. in the case where a primary beam is very flat in the emulsions.
VI. MEASUREMENTS IN NUCLEAR EMULSIONS

INTRODUCTORY TALK FOR SESSION IX

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MEASUREMENTS IN NUCLEAR EMULSIONS

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Most of the session to which this talk was intended to be an introduction has unfortunately evaporated because many of the colleagues whom we had hoped to welcome here were unable to come. Thus my subject has become less extensive, and I shall take the opportunity to give you some of my own opinions instead of the ones we shall not have the pleasure to hear today.

Let me go back thirty years, to the time when most physicists who worked in nuclear physics thought that the period in which emulsions were useful had come to an end. An example of that type of thinking was in a paper by H.J. Taylor¹, where it was said that:

"In the writer's opinion this photographic method of investigating the ranges of fast particles involves inherent uncertainties which may give rise to large errors, and which may limit seriously its applications. It must be admitted, however, that this view is not held by those who have worked most on the subject. Fr1. Blau and other workers appear to have regarded the method as capable of giving more accurate results than would seem justifiable if the considerations of the preceding paragraphs are valid."

In those days it was almost solely the Vienna group, under Marietta Blau, which continued to improve the technique, used it and maintained faith in it. It is a great pity that Miss Blau was unable to come to this conference to see the enthusiasm of her youth justified once more.

Since the days of that controversy very many things have happened; techniques and materials have improved, and quite a few important discoveries have been made with the aid of nuclear research emulsions. Yet, whilst the
limits of what is possible have been pushed back a great deal since the pio-
genning work of Miss Blau and her collaborators, the causes of our difficul-
ties are still the same. Nuclear emulsion is still an inhomogeneous medium, and it is still sensitive to humidity which causes fading and affects its
density and shrinkage factor. The sensitivity of emulsion is still not a
very well defined quantity. Our tracks, like those of Reinganum in 1914\textsuperscript{2}),
are subject to distortion that can be confused with scattering, and, like all
the emulsion workers for more than fifty years, we have to be very careful in
our processing if we are to obtain reproducible results and uniform sensiti-
vity.

The word "reproducible" brings me to a point which is rarely made,
perhaps because it is so obvious, but which is of great importance to all our
work. It is that there are very few people indeed who know how to make
nuclear research emulsions in large quantities in a reproducible fashion.
That it is possible to obtain good results in such a messy medium is indeed
a miracle, and we should never forget to give credit to the manufacturers,
especially to the Ilford group of Dr. Waller and Mr. Vincent and, now,
Mr. Ehrlich, and to Professor Bogomolov, who have succeeded in giving us a
product of almost constant properties in which precision measurements can be
made.

In all our work we rely on the Principle of Uniformity of Nature; that
is, we believe that if the same experiment is performed several times in exactly
the same way, then the results will be the same. However, I do not believe
that there is also a Principle of Uniformity of Nuclear Emulsion, except by the
grace of the manufacturers. Today there are physicists who have spent an
appreciable part of their working lives investigating the properties of this
medium. It is true that important results in physics have come out of such
work, but I think it is useful to remind ourselves from time to time that
nuclear emulsion is not a phenomenon of nature; it is a very powerful tool
that we must apply to justify its existence.
Let me now come to the topics on which papers will be given. First there is the range-energy relation, which many of us took almost for granted even fifteen years or so ago. Others, fortunately, were more demanding and continued to investigate its dependence on emulsion composition, structure and the fundamental mechanisms involved. Professor Barkas and his group in particular have been most prominent and successful in this field and have made steady improvements in the precision with which the momentum of a particle, can be established from measurement of its range in emulsion. Their methods, applied to the determination of the masses of unstable particles have provided us with the best available values for the charged K meson and the \( \Xi^- \) hyperon, and discrepancies in this work led to their suggestion that there is a difference between the ranges of positive and negative particles of the same momentum. A paper in which experimental results on this difference are given will be presented at this session.

A related topic is the rate of energy loss in the extreme relativistic region. At the Munich conference, Professor Zhdanov's group reported that beyond the minimum of the energy-loss curve there is a maximum in \( \frac{dE}{dx} \) at a value of \( \gamma = E/mc^2 \) in the region of 100 to 300, predicted by Tsytovich and confirmed by Alekseyeva et al. Since then, a number of experimental groups have worked on this problem, for it has a bearing on the theory of energy loss as well as on measurements in nuclear emulsions, and we shall hear some of the results. The effect predicted by Tsytovich is not large, and to check it the rate of energy loss, or a quantity proportional to it, has to be measured with an accuracy of 1% or better. Such precision has not been required in ionization measurements in emulsions up to now, and extreme care and many precautions are needed to reduce the effects of inhomogeneities in the emulsion and of variations in space and, in some experiments in time, of sensitivity and fading. It is well to realize that when one speaks of a 1% change in blob density, one speaks of \( \frac{1}{4} \) blob in each 100 micron interval, a change that would be quite unnoticeable in the experiments in which one normally uses emulsions.
Extreme care and precautions cannot eliminate unsuspected sources of error, of which, it seems, some still remain. For example, the other day I was talking to Mr. Ehrlich of Ilford Limited, and I told him that we take great care to keep the emulsion packages well sealed, so that we can be sure that the water content is always that which corresponds to the relative humidity of 50% at which the emulsions are dried and packed at Ilford's. "Oh," said Mr. Ehrlich, "but we don't have the time to let the emulsions reach equilibrium ...". So the water content of the emulsions may vary from batch to batch, or even package to package and pellicle to pellicle. This is something I had not thought of before, and it seems to me that there may well be high-precision experiments in which one should let all the emulsions reach equilibrium at the same known relative humidity before they are used.

Then there is the question of temperature equilibrium. Emulsion is not a good conductor of heat, and it may take quite some time before a stack reaches temperature equilibrium. As far as I know, the temperature coefficient of sensitivity has not been measured with very high precision, but there is evidence to show that temperature non-uniformities affect results at the 1% level. Even if there are no temperature gradients, there still remains the possibility of variations in sensitivity from place to place, even in the same plate, and some years ago I heard of evidence that two regions only about 1 cm apart may exhibit detectable differences.

The next topic of interest is spurious scattering. At Munich, and at the meetings at Copenhagen and Lausanne, there was much discussion not only about the phenomenon itself but also about its definition. It now seems to be agreed generally that the mean second difference due to spurious scattering is defined by the relation

\[ D_{ss}^2 = D_{corr}^2 - D_{th}^2 \]

where \( D_{corr} \) is the observed mean second difference corrected for noise, distortion and other known spurious effects, and \( D_{th} \) is the mean second
difference calculated from the theory. Thus spurious scattering is given by the difference between two quantities both of which are subject to some doubt. The first, $D_{\text{corr}'}$, is affected by the level of distortion in the region of measurement, and by the method by which a correction is made for it. It is my personal opinion that, except in rare cases, the distortion corrections made by means of the usual methods are quite unreliable, for either they involve the assumption of a specific distortion contour (mainly the "C" shape), or the contour is determined by subjective comparison of the shapes of tracks in the same region of the emulsion. Thus it seems to me that the only way of obtaining good values of $D_{\text{corr}}$ is to have emulsions with negligible distortion. Alternatively one may restrict attention to closely parallel neighbouring tracks and work with relative scattering measurements. The value of $D_{\text{th}}$ one uses depends, of course, on the value of the scattering constant one chooses to adopt, and here, too, there is uncertainty; I shall return to that question a little later.

A quantity so ill-defined is difficult to discuss, and the best one can do may well be to determine its average value empirically and use it for correction. An alternative method, and perhaps a better one, is the one due to the Hungarian group, presented by Dr. Fenyves\textsuperscript{5}). They divide spurious scattering into two components, one of which can be estimated by statistical techniques and used as part of the correction which leads to $D_{\text{corr}}$. In this way, the remaining "truly spurious" scattering is reduced, but an average correction may still be required for it.

Closely related is the problem of the value of the scattering constant. Some time ago, Hossein et al. here at CERN made measurements with very long cell lengths on tracks of particles of known momentum, and they found that the scattering was less than expected from theory\textsuperscript{6}). Since then, several more experiments have been performed to find the behaviour of the scattering constant at long cell lengths, and the results are still conflicting. What is found is, essentially, that at very long cell lengths the spurious scattering becomes very small or imaginary (according to the definition I gave a while ago), and as consistently imaginary values seem absurd one has begun to suspect the theory. However, the situation is far from clear, and it may be that here, too, the answer will have to come from measurements of scattering which are free from the disturbing effects of emulsion distortion.
REFERENCES


2) M. Reinganum, Phys. Zeitschr., 11, 1076 (1911).


VII. SOME ASPECTS OF APPLICATIONS OF PHOTOGRAPHIC EMULSIONS

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SOME ASPECTS OF APPLICATIONS OF PHOTOGRAPHIC EMULSIONS

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The results of the recent Conference on High-Energy Physics held in Dubna have shown that in the investigation of such phenomena as elastic p-p scattering, inelastic p-N and π-N interactions at about 20 GeV, the double charge exchange of pions on nuclei, positron asymmetry in π⁺ → μ⁺ → e⁺ decays, muon polarization in K⁺μ decay, etc., the emulsion technique proved to be successful to get some experimental data which could not be obtained by other methods or, at least, the data which have the same degree of accuracy. It should be emphasized that these experiments yielded quantitative results. In the future development of the emulsion technique, one has to take into account essentially the progress of other types of nuclear instrumentation, especially that of spark chambers in which the main properties of track detectors and electronic counters are combined. However, there is good reason to believe that the emulsion technique will prove to be successful along many lines of research having in mind some of its well-known advantages:

i) high angular (< 1 mrad) resolution and good energy resolution at the same time;

ii) possibility to measure small lifetimes (~ 10⁻¹⁶ sec);

iii) portability;

iv) comparative insensitivity to the background;

v) possibility to use different targets which are put inside the emulsion blocks, or are in contact with them, or are located at some distance. As an example, the experiment on the Z⁺ magnetic moment now being performed at CERN could be mentioned.

*) Presented by E. Fenyves

9748/p/acl
In the following we shall discuss three lines of research:

i) the enrichment of emulsions with hydrogen;

ii) the use of emulsion stacks with hydrogen targets;

iii) some problems of application including the combination of nuclear emulsions with other methods.

i) Hydrogen targets are a reliable means in investigating elementary particle interactions. Successful results have been obtained with liquid hydrogen chambers, and by means of electronic counters. However, the discrimination of particles having momenta of more than 1.5 GeV/c is very difficult in bubble chambers, if at all possible. The counter technique is less suitable for investigating interactions in which many particles with different masses, energies, and lifetimes are produced. It is well known, however, that in this field interesting results have been obtained by means of nuclear emulsions. Nevertheless, an essential improvement in the experimental facilities for investigating the interactions in hydrogen with emulsion technique seems necessary and possible. This will allow us to get experimental data which are difficult to obtain with other techniques.

The emulsion pellicles are enriched in hydrogen by being soaked with lithium acetate, ethyleneglycol (CH₂OH)₂ or water, which increases the hydrogen content twofold or even more. An increase in the amount of light nuclei increases the number of interactions on free and quasi-free protons in the emulsions up to \( \sim 0.3 \). This means that, in this respect, the emulsions are practically equivalent to propane chambers. The freezing of soaked emulsion stacks\(^1\) makes it possible to reduce deformations and to simplify the handling of emulsion stacks in the course of the experiment.

We have worked out an effective method of hydrogen enrichment\(^2\). Hydrogen is introduced in the emulsion with a certain substance which is washed out during the development. These methods permit us to expose pellicles of about 1000 \( \mu \), while their shrinkage factor is \( \sim 5 \); hence the observed pellicles have the usual thickness, which simplifies the ionization and multiple scattering measurements. Then the number of particles whose momenta
can be measured is increased by a factor \( \bar{W} \). This factor is equal to the following ratio of the corresponding solid angles:

\[
\bar{W} = \frac{\arcsin \left( \frac{\sin (1/\bar{K}) a}{\sin \bar{\varphi}} \right)}{\arcsin \left( \frac{\sin a}{\sin \varphi} \right)}
\]

where \( \varphi \) is the angle with the beam direction, \( a \) is the maximum angle of the track inclination with respect to the plane of normal emulsion in which the multiple scattering measurement is possible, and \( \bar{K} \) and \( K \) are the shrinkage factors for normal and impregnated emulsions.

We have found\(^3\) an appreciable increase of the ratio between the blob densities at the plateau and at the minimum in the NIKFI BR emulsions soaked with ethyleneglycol as compared with the normal emulsions. The discriminating properties are improved in this case and the momentum range in which \( \pi \), \( K \) and \( p \) are difficult to be distinguished from each other becomes smaller. If very large emulsion stacks are not used, for example, \( 10 \times 20 \times 30 \) cm\(^3\), or one uses stacks of smaller thickness, a certain part of the volume being in a magnetic field of about 100 kgauss, it is possible to measure the momentum and identify the mass of the majority of secondaries produced in \( p-p \) and \( \pi-p \) collisions even when the energy of the primary particle exceeds that attained with modern high-energy accelerators. (An increase in the energy of the primary particle leads to a narrowing of the cone of the secondary particles, which makes easier the measurement of the multiple scattering, the magnetic deflection, and the ionization.)

To summarize: an increase in the hydrogen content, in the thicknesses of pollicies and in the sizes of the stack, the growth of the ratio \( I/I_{\text{min}} \), as well as the application of magnetic fields, will allow one to obtain, with much less effort, a great number of completely analysed events of multiple particle production in the collisions of fast particles with protons. Moreover, an emulsion stack of the given dimensions is the so-called "strangeness detector": the kaons generated in the primary collision preserve their strangeness in subsequent collisions, and observation of the decays and interactions of secondary particles gives information about the generation of kaons in the primary collisions\(^4\).
It is of interest to investigate the production of strange particles by p, π, e and γ quanta when the velocities of the corresponding centre-of-mass systems are close to each other. In loaded emulsions the average atomic weight is about 12.5, and the probability for the kaons to undergo a secondary collision in the nucleus in which they are produced is about 0.3\(^5\)). Hence, the strange particle production, in this case, is not very different from that when a pure hydrogen target is used. These experiments can be performed fast enough and give information within a wide range of angles and energies of strange particles.

ii) Hydrogen targets, outside or on the surface of the emulsion stack can also be used. Such experiments combine, on the one hand, the advantages of the hydrogen target and, on the other, the possibility of using intensive beams, carrying out accurate angular and range measurements, and discriminating between particles in the nuclear emulsions. In investigating the small-angle elastic p-p and p-d scattering, good results have been obtained by applying a thin polyethylene film (CH\(_2\)) as an internal target and by detecting the recoil protons of 30 MeV/c momentum. The effectiveness of this method even for very high-energy primary particles is proved by Nikitin et al.\(^6\)).

The method proposed by the author\(^7\)) permits the performance of several precision experiments with a hydrogen jet target which crosses the proton beam at the accelerator orbit. A hydrogen jet having the density of \(10^{-6} - 10^{-5}\) g/cm\(^2\) may be used in the experiment. For example, at the 10 GeV synchrophasotron in Dubna the accelerated protons pass through the jet, for about 0.2 sec, more than \(10^5\) times, and most of them interact with the target protons. The \(10^{-6}\) g/cm\(^2\) density is reached at the jet diameter of 41 \(\mu\). Hence, the jet is a point-like target which creates perfect angular conditions in photoemulsion experiments. The application of this method has the following advantages:
a) in the investigation of elastic p-p and p-D scattering it is possible to measure smaller scattering angles than those given by Nikitin et al.\textsuperscript{8} and to remove completely the background of nuclear interactions;

b) the kinematic conditions allow the investigation of proton resonances in p-p collisions by detecting the range and the angle of the secondary protons in the photoemulsion\textsuperscript{9};

c) it is possible to investigate the elastic p-D scattering with a high momentum transfer (~ 1 GeV/c) to the deuteron as well as to investigate the charge exchange in the p+D→n+2p reaction;

d) it is also possible to investigate the spectra of secondary particles including the gamma ray production in direct p-p interactions, etc.

A liquid hydrogen target being near or in contact with the emulsion block enables us to investigate thoroughly the spectra of secondary particles given rise to in π-p, π-D, γ-p, and other collisions. Let the flux of the strongly interacting particles be equal to 10\textsuperscript{9}/cm\textsuperscript{2}. Denote the beam radius by r, the side of the square target by a, and the length of the target by \ell. If the length of the emulsion stack is also equal to \ell (\ell >> r), the average number of secondary particles per 1 cm\textsuperscript{2} of emulsion is given by:

\[ n \sim \frac{\pi r^2 \rho \sigma}{4a} \]

where ρ is the number of hydrogen atoms in 1 cm\textsuperscript{3}. If \( r = a \times 0.3 = 3 \text{ cm}, \ s = 10^8/\text{cm}^2 \text{ and } \sigma = 10^{-27}/\text{cm}^2, \text{ then } n = 3 \times 10^2. \text{ The investigation of strange particle production by gamma rays and electrons with } s = 10^{10}/\text{cm}^2 \text{ is possible if the production cross-sections are about } 10^{-30}/\text{cm}^2. \]

The method permits us also to investigate the momentum distribution of secondary protons as a function of their emission angle; the soft part of the proton spectrum can be detected, if the emulsion is submerged into hydrogen. It is shown by Zavaritskij et al.\textsuperscript{9} that in Ilford G5 and special NIKFI emulsions the grain density of relativistic particle tracks slightly decreases (about 20%) at a temperature equal to 0.1\textsuperscript{0}K. Deformations in the emulsion are not too serious and allow one to
irradiate emulsion stacks embedded in liquid hydrogen and helium or in contact with a solid hydrogen layer on the emulsion surface. In view of this, it seems feasible to do experiments with polarized protons. The application of polarized pure hydrogen targets requires very low temperature (< 0.01°K) and strong magnetic fields which are difficult to reach in a considerable volume. Therefore, a polarized hydrogen layer on the surface of the emulsion having a small volume is expedient, especially in experiments with unstable particles, for example, hyperons.

The dynamic polarization method described in a paper by Steiner et al. makes it possible to accomplish a proton polarization of about 70% in the crystal $La_{2}Mg_{3}(NO_{3})_{12} \times 24H_{2}O$, where about 16% of the total interaction cross-section belongs to free protons. Thus, the experiment for the determination of the relative parity of $\Sigma$ and $K$ in the reaction $\pi^{+} + p \rightarrow \Sigma^{+} + K^{+}$ which we are now preparing, becomes possible. It is a very convenient method to observe the kaon decays in nuclear emulsions and to detect the right-left asymmetry of the $K^{+}$ emission in the reaction. We should note in this connection that a possible $CP$ violation reported at the recent International Conference on High-Energy Physics at Dubna, opens a new chapter in these investigations.

Further, it was shown by Gaillard that it is possible to determine the spin and parity of baryon and kaon resonances with polarized protons, for example, in reactions of the type:

$$\pi^{+} + p \rightarrow \Sigma^{+} + K^{+}, \quad \pi^{+} + p \rightarrow \Lambda + K^{0}.$$  

It was also shown in our paper that the dynamic polarization method can be used when emulsion pellicles are put into the cavity in an immediate contact with the crystal in which the protons are polarized.

The emulsion stacks, together with the liquid or solid hydrogen targets, can be an effective means in investigating cosmic-ray interactions at energies of $>10^{12}$eV. The application of hydrogen targets is necessary for the following reasons: the large multiplicity of particles produced in the primary collision with the nucleus leads to the fact that a considerable number of them undergo secondary interactions in the same nucleus,
which distort the original properties of the primary interaction. In the superhigh energy region a "tunnel mechanism" of the interaction is possible, but it is difficult to detect this phenomenon if the energy of the primary particle is not known. It is also interesting to investigate the interactions of fast multi-charged particles with protons at rest.

Successful experiments carried out by Powell et al., with large emulsion blocks flown in the stratosphere, and similar investigations done at the Physical Institute of the USSR Academy of Sciences with emulsions in liquid hydrogen\(^{17}\), provided the possibility for making the following experiments. A cubic emulsion block with an edge of about 30 cm is put inside a solid hydrogen sphere, 1 m in diameter. Solid hydrogen is more preferable than liquid, since no container and emulsion-supporting material are required. The weight of the emulsion is \(\sim 100\) kg and that of the hydrogen about 65 kg. In winter, especially at high latitudes, the sun is absent for more than 16 hours. If the sphere is covered with a thin coating having a reflection factor \(K = 0.9\) (larger values are also possible), the heat flux is given by: \(Q = \pi r^2 c(1-K)t\), where \(c = 2\) cal cm\(^{-2}\) min\(^{-1}\). In 10 hours of flight \(Q = 10^6\) cal (owing to the air thermal conductivity, the flux will be less) and only 10 kg of hydrogen will evaporate. According to "Cosmic-ray physics"\(^{18}\), the flux of particles of energy \(\geq 10^{12}\) eV is \(s = 3 \times 10^{-5}\) cm\(^{-2}\) sec\(^{-1}\) sr\(^{-1}\). The average path length of primary particles, whose interaction products penetrate into the emulsion, is in hydrogen \(< \ell > \sim r - (r/2) = 35\) cm. The number of their interactions in hydrogen is given by: \(N = 4\pi^2 r^2 \rho \sigma < \ell > st\) where \(\rho = 0.5 \times 10^{23}\). If \(t = 10\) hours, \(\sigma = 30 \times 10^{-27}\) cm\(^2\), one obtains \(N = 5700\). The number of showers given rise to by secondary particles, \(\Delta N\), which enter into the emulsion block, is less than \(N\) approximately by the ratio of the surface of the emulsion cube to that of the hydrogen sphere, from which \(\Delta N = 10^5\). The average multiplicity of the showers \(q\), is, according to Dobrotin\(^{19}\), \(q = 1.2 (E/\text{me}^2)^{1/2} = 22\), and the average angle in radians\(^{20}\) is \(< \Theta > = (2\text{me}^2/E)^{1/2}\). The lateral width \(\delta\) of the shower, if initiated at a distance \(< \ell >/2\) from the emulsion, is \(\delta = 8\) cm. A knowledge of the above values allows one to calculate the co-ordinates of
the origin of the shower, i.e. to prove whether the shower was originated in hydrogen or not (for energies of $> 10^{14}$ eV we have $\Delta N = 10$, $q = 70$, $< \Theta > = 1.5'$).

Observation of the electromagnetic cascades and nuclear interactions in the emulsion block as well as multiple scattering measurement gives us a possibility of studying the primary interactions on protons.

iii) Nuclear emulsions were also applied together with other methods. In Grigorov's investigations $^{21}$ on cosmic rays of $10^{14} - 10^{14}$ eV energy an arrangement was used which involved ionization chambers, counters, absorber, and two pollices of emulsions with an effective area of 0.6 m$^2$.

Takibayev$^{22}$ suggested the use of nuclear emulsions together with a cloud chamber.

In a paper$^{23}$, reported at the Instrumentation Section of the International Conference on High-Energy Physics at Dubna, an arrangement was described which consisted of a 125-pollicle emulsion stack (400 microns thick, 3 cm in diameter), a spark chamber, as well as Čerenkov and scintillation counters. This arrangement was irradiated in a beam of positive particles with momentum of 3.2 GeV/c. The contamination of protons was 67%, that of positive pions 34%, and that of kaons 1%. It allowed one to separate positive pions and to determine the place of their entering the emulsion. The difference between the track co-ordinates measured in the emulsion and that calculated by means of spark chamber tracks was, on the average, 0.8 mm.

Successful investigations were carried out recently on neutrino interactions with photoemulsion nuclei at CERN$^{24}$.

In Gurevitch's works$^{25}$ a pulsed longitudinal (parallel to spin) magnetic field of 140 kgauss was used to eliminate the depolarization of muons coming to rest in the emulsion. This permitted one to measure the asymmetry of the positron decay in the reaction $\pi^+ \rightarrow \mu^+ \rightarrow e^+$. The asymmetry coefficient $a$ in the formula $dN/d\omega = 1 - a \cos \Theta$ turned out to be: $a = 0.323 \pm 0.009$ which is in good agreement with the "V-A" theory.
The muon polarization in the $K^+_{\mu 3}$ decay at rest was investigated by irradiating a 1-litre emulsion stack with $5 \times 10^5$ kaons incident perpendicular onto the surface of the stack. A 6 kgauss magnetic field directed perpendicular to the $K^+$ beam was used to preserve the pion polarization. The value of the positive muon polarization was found to be $P(K^+_{\mu 3}) = 0.68 \pm 0.28$.

The emulsion technique has particularly large advantages in investigating hyperfragments, nuclear fragmentation processes, nuclear reactions when the number of secondaries is great or their energies are low, as well as nuclear reactions occurring via several channels. The loading of nuclear emulsions with suspensions of certain elements makes it possible to study reactions on light nuclei with different excitation levels.

The application of fine-grain emulsions which improve discriminating properties is very prospective. Using such emulsionPerfilov studied, for example, the angular correlation between fragments in their multiple production.

$\pi^-$-meson absorption processes and especially double charge exchange $\pi^+ + (\text{nucleus}) \rightarrow \pi^- + (\text{nucleus})$‘ reactions enable us, according to Ericson to produce and investigate isotopes which cannot be studied otherwise. In papers by Batusov et al. investigation of the double charge exchange of $\pi^+$ and $\pi^-$ on photoemulsion nuclei is described. The investigation was carried out at the JINR synchrophasotron. The cross-section for $\pi^+ + (\text{nucleus}) \rightarrow \pi^- + (\text{nucleus})$ was found to be $(5 \pm 1) \times 10^{-28} \text{ cm}^2$. Recently at the Paris Conference it was emphasized that we can obtain further new information on nuclear structure from nuclear reactions. It was also calculated that the study of the complete disintegration of nuclei in collisions with fast particles is important.

In our work it was found that 10 GeV/c protons induce in $(2.0 \pm 0.3)\%$ of events the decay of $\text{Ag}$ and $\text{Br}$ nuclei accompanied by the emission of more than 28 charged particles. The emission of 40 particles was also observed, i.e. a complete decay of a nucleus predominantly into nucleons. The excitation energy was 2-3 times above the binding energy of the nucleus. The detailed study of such excitation processes should be very interesting. The main problems are the following: by which mechanism and for what time the nucleus acquires the excitation energy, how this energy depends on the mass and energy of the primary particle, and what are the dynamics of the complete disintegration of the nucleus.
REFERENCES


3) L. Bokova, L. Kreevenzova, L. Popova and K. Tolstov, Vth Int. Conf. on Nuclear Photography (1964).


6) V.A. Nikitin, V.A. Sviridov, L.N. Strunov and M.G. Shafranova, JETP 46, 1608 (1964).


9) G. Boszki and E. Nagy, Report at the Xth Meeting of the Emulsion Committee of the JINR, May 1964, Dubna.

10) N.V. Zavariskij, V.A. Sviridov and K.D. Tolstov, PTE Nr. 5, 131 (1960).


14) I. Cronin and V. Fitch, Report at XIIth Int. Conf. on High-Energy Physics in Dubna, 1964.


16) V.I. Lushchikov and K.D. Tolstov, Vth Int. Conf. on Nuclear Photography (1964).

9748/p/acl


28) P.A. Gorichev, O.V. Lozhkin and A.A. Perfilov, JETP 46, 1897 (1964).


Discussion after the invited paper by K.D. Tolstov

Barkas: The paper of Tolstov is imaginative, but I believe most of the experiments proposed are either too difficult to carry out at present, or are better done with other instruments.

Cuèr: Je voudrais signaler que le groupe de Strasbourg, à part ses recherches de base sur la comparaison de la fragmentation et de l'hyperfragmentation à haute énergie (possible grâce à la seule méthode photographique), a effectué une expérience de double échange de charge $\pi^+\pi^-$ (qui est encore en cours, pour améliorer la statistique et la précision) qui indique pour des mésons $\pi^+$ de environ 180 MeV sur $^6\text{Li}$ et $^7\text{Li}$ une section de double échange de charges de l'ordre de grandeur de celle trouvée par Batusov et al. à Dubna.

Fenyves: I would like to emphasize even stronger the importance of the nuclear emulsion method in the investigation of hyperfragments and special problems of nuclear physics where other methods cannot be applied successfully. At the same time I agree with Dr. Tolstov that the combined use of emulsions with other methods will open new fields of applications in high-energy physics.
VIII. THE FUTURE PERSPECTIVES FOR EMULSION WORK AT CERN
CLOSING TALK

B.P. Gregory
CERN, Geneva
THE FUTURE PERSPECTIVES FOR EMULSION WORK AT CERN - CLOSING TALK

by

B.F. Geyger

CERN, Geneva

My first task is a very pleasant one: to thank all those participants who came for this Conference from distant countries, from India, Pakistan and the United States, also those from Eastern Europe and the Soviet Union, and to thank them on behalf of all those Western European participants who are here in their own laboratory and, therefore, indeed were the receiving hosts and not CERN itself. We are very glad that CERN facilities can indeed provide a means of holding such conferences.

The second point is rather difficult for me: I will not try to summarize this conference, for two reasons: first, I am not of this technique; and, secondly, I did not attend this conference very much. Now this is in no way an indication that I was not interested in knowing what is the development of the technique, but I think it is true to say that technical conferences are necessary evils, since what we really want is to do the physics with the technique and not really discuss the technique as such. On the other hand, only a thorough understanding of the technical aspects enables the experimental physicists to achieve reliable results; this fully justifies this conference.

In concluding this conference, I will attempt to tackle the difficult problem of the future of the emulsion technique in high-energy physics and at CERN in particular. It is extremely difficult to be a prophet in these fields; I would like to mention what I feel have been the successful experiments of recent years and what might be the immediate future of these experiments.

What are the achievements in the recent years? One point which must be made very clear and which one should remember when looking at the results at CERN, is the fact that not more than 10% of the machine time has been used for the emulsion technique in the last few years. Let us look at
the results of these past years: I was very much impressed at the last Dubna Conference that the best result on the Λ° magnetic moment was presented by a collaboration of four European groups including the Emulsion Group at CERN. You all know that right now we are running a similar experiment on the Σ⁺ magnetic moment in which five laboratories are collaborating, and I have great confidence that this measurement will also bring, earlier than other techniques, a first good result. If one tries to look at the future of this specific technique for the determination of magnetic moments, one has to consider that, in order to get the number and the precision that was already obtained, a major scanning effort had to be done. One can probably question whether it would be worth while, in order to get a factor of, let us say, three or four in precision, to tackle the enormous task of scanning a factor 10 to 15 times the amount already done.

A second experiment that was carried out in several laboratories was to use emulsions for studies of very small-angle proton-proton scattering. One could imagine running similar experiments on π-proton scattering. Emulsion is a very good detector for observing very small ranges of protons, and, therefore, with hydrogen gas as a target, one can observe and go down to the very smallest angles or momentum transfers in the proton-proton or π-proton scattering angle. The p-p scattering experiment using a gas target, carried out by the Hamburg group, gave a good result, which came at the same time as similar results from other techniques. Nevertheless, I think that one should consider that counter or spark chambers have now managed to develop their precision in measurements, so that they can match the precision of emulsions; moreover, they have the enormous advantage of being able to collect their data directly on a computer and give the answer almost right away. Therefore, in spite of these good results recently obtained using emulsions, we are not able to foresee a very great future along this line.

The third type of data that have been obtained is in the field of hyperfragment work. This has been very much an emulsion achievement and has brought interesting results. I feel sure that this work should be continued.
It will be more precise, it will take longer; it corresponds to fairly easy operation of the machine because only a relatively small number of shifts are required to obtain the raw data. I feel that this is a subject which will be continued and which will be helpful for physics.

The last approach I have heard of is the attempt to solve the very difficult problem of scanning in emulsion. Emulsion is a technique which requires a large scanning effort, and if one could by outside means know at which point in the emulsion an interaction of interest has occurred, one would save a great amount of time. You all know that this was attempted by a British group in the neutrino experiment quite recently and that spark chambers, associated with a set of emulsions, were capable of telling the physicists where a specific neutrino interaction had occurred. I was told that the choice of the very well shielded neutrino area for a test of this technique was a very good one. I have also heard of various proposals to use this new technique, which could indeed be a very important new step in the use of emulsions around the machine. But until now I have not yet heard of an experiment using a triggering technique which seemed to be sound enough to be a definite proposal for this accelerator.

We have here a situation in which good experiments have been done in the past year, but we have no very exciting new proposals for the coming one. Of course, new ideas can come in; in fact, the triggering by spark chambers is one of them. I am also taking into account two facts: firstly, that less than 10% of the PS time is used for emulsion experiments and irradiations, and secondly, that a large number of universities in Europe profit greatly by the fact that they have some data on which to work. Nevertheless, it is my personal belief that one has to be a little careful; careful in the sense that developments of automatic measurements which would cost a large amount of money, which would be achieved only in a year from now and then would commit the group that has spent that money and started that type of work for a number of years after, should only be started after due consideration. I consider that it would not be very healthy if all the laboratories that have been associated with emulsions in the past went into expensive and long-range development of automatic measurements in emulsion.
May I repeat again that emulsion techniques have been successful in the past few years, that I hope that the $Z^+$ experiment which is just finished will be a good experiment, and that I foresee no changes in the policy of CERN in the next year or the next few years, to carry out irradiations using a small percentage of the available machine time. Nevertheless, we should consider that this beautiful technique, which has given so many very good results in elementary particle physics in the last years, does not seem to be one which, at this time, should be considered as one of the leading and growing types of techniques around a large accelerator.

I hope I have been sufficiently optimistic and pessimistic; I think that it is useful to say these things and I thank you very much for having come to CERN.
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