PART V.1

THE PROPERTIES OF PHOTOGRAPHIC EMULSIONS

E. Dahl-Jensen

University Institute for Theoretical Physics,
Copenhagen, Denmark.

I. CHARACTERISTICS OF PHOTOGRAPHIC EMULSIONS

Ordinary photographic emulsions consist of gelatine in which a very large number of silver-halide crystals are embedded. The silver-halide mostly used is silver-bromide with the addition of up to 5% silver-iodide. Silver-bromide crystals have cubic structure of the same type as sodium chloride, the distance between an ion and its nearest neighbour being 2.88×10^{-8} cm. Depending on the way the silver-bromide is precipated, the crystals grow one of the spatial structures belonging to the cubic system; the faces most commonly present in commercial emulsions are octahedral. The small quantities of silver-iodide will dissolve in the bromide without changing the crystal arrangement, apart from slightly increasing the spacing of the ions in the lattice.

The crystal size in the photographic emulsions ranges from ~ 0.03 μm in Lippman emulsion to ~ 20 μm in some high-speed optical emulsions.

Nuclear emulsions differ from ordinary optical emulsions by a higher silver-bromide content, a smaller average crystal diameter, and a very narrow spread of the crystal diameters, as shown in Fig. 1. Extensive use is made of nuclear emulsions as thick pellicles, i.e. emulsions without support of acetate or glass.

The differences between nuclear emulsions and ordinary optical emulsions are illustrated in Table 1 below.

The atomic composition of a nuclear emulsion is an important "parameter", especially when calculating the stopping power of the emulsion. The atomic composition of a given nuclear emulsion depends

Table 1

	Optical emulsion	Nuclear emulsion
Ag Br/gelatine % by weight	50/50	83/17
" " " % by volume	15/85	50/50
Average crystal diameter	0.5 - 3	0.07 - 0.3
Emulsion thickness	~ 10 μm	400 - 600 μm

on the absolute water content and is subject also to changes introduced during manufacturing. Ilford has reported the average composition of 40 batches of G5 emulsion in equilibrium with air at 58% RH. In the next table is given this mean composition together with the composition of G5 emulsions of densities (D in g/cm^3) different from the mean density of the 40 batches.

Table 2

ILFORD G5 at 58% RH		
	40 batches D = 3.828 ± 0.035	at D in g/cm^3
Ag	1.817 ± 0.029	0.7169 × D - 0.9271 ± 0.0047
Br	1.338 ± 0.020	0.528 × D - 0.6831 ± 0.0035
I	0.0120 ± 0.0002	0.0047 × D - 0.0061 ± 0.0025
C	0.277 ± 0.006	0.6871 - 0.1072 × D ± 0.0036
H	0.0534 ± 0.0012	0.1283 - 0.0196 × D ± 0.0006
O	0.249 ± 0.005	0.5613 - 0.0815 × D ± 0.0029
N	0.074 ± 0.002	0.2182 - 0.0378 × D ± 0.0011
S	0.0072 ± 0.0002	0.0214 - 0.0037 × D ± 0.0001

(The limits given are at two standard deviations.)

The density in a tiny volume is expected to fluctuate from the average density of the pellicle as a whole. However, from straggling measurements on μ-ranges from $\pi - \mu$ decays these fluctuations can be estimated to be not larger than 1%.

Some times it may be desirable to bring an emulsion into equilibrium (within 1%) with air of another relative humidity than 58%. The time required to obtain this equilibrium depends strongly on the desired humidity and on the temperature. Zero humidity (vacuum) equilibrium is achieved in a month only, 50% RH requires about a fortnight, 75% RH a few days, and 85% RH less than a day to reach equilibrium at room temperature. At lower temperatures much more time is needed.

The gain or loss in weight and volume of 1 cc of emulsion at 58% RH brought to equilibrium with air at other humidities can be read from the following table.

Table 3

% RH	mg/cc	cc $\times 10^{-3}$/cc	mg/g
15	- 69	-58	-18
32	- 45	-38	-11
58	0	0	0
72	+ 43	+36	+11
84	+112	+95	+30

(These values are measured at "room temperature" - at 25° they are approximately doubled.)

From this table it follows that 1 g of water taken up in the emulsion occupies ~ 0.84 cc, and also that the dimensions of a plate or pellicle will change with humidity. Plates kept under dry conditions (low temperature and/or low humidity) tend to strip off from the glass or to break the glass-backing, depending on the thickness of the coating. Pellicles kept dry turn brittle unless extra plastifier has been introduced in the emulsion before pouring.

Water-soaked emulsions start melting at 35°C, whereas dry emulsions stand temperatures up to ~ 60°C (95° has been reported). If emulsions are to be kept at very low temperatures, care should be taken to get rid of "free" water (not chemically bound to gelatine) before lowering the temperature. Otherwise, ice crystals may be formed and give rise to unwanted distortions [and perhaps accelerated fading if the emulsions were kept at the low temperature during exposure (see section C)].

For a water-soaked emulsion it is somewhat different, because there you have no water in gelatine but gelatine in water, and the whole mixture will freeze as one medium.

Distributed pressures up to 800 atm do not affect the emulsions, but higher pressures may give a blackening after processing due to mechanical deformations in the silver bromide crystals. A sharp pencil will give pressures of about 2000 kg/cm^2 during writing on the emulsion - this pressure exposes the emulsion locally.

If you plot as usual, the pressure on some emulsion against the compression in % you will find that it behaves elastically up to a compression of 1%, which corresponds to a pressure of about 50 kg/cm^2. If you increase the pressure, then you will have 2% compression already at 60 kg/cm^2, implying that the emulsion had started to flow.

It is often desired to have an emulsion in contact with some material or to "load" an emulsion with some substance. It should be noted, therefore, that the recording properties of a photographic emulsion

are affected by:

oxidizing or reducing substances;
acid (or alkaline) substances;
hygroscopic substances.

Example: Metals less noble than silver (iron, copper, lead, brass, aluminia, etc.), will reduce electrochemically the silver and thus cause an unwanted blackening

$$Me + AgBr \rightarrow \underline{Ag} + MeBr .$$

It has frequently been observed that an iron or brass bolt in contact with the emulsion "eats away" a large part of the emulsion.

The chemical action of the various substances decreases with decreasing temperature. So emulsion in contact with hydrogen gas (at some hundred atmospheres) at room temperature partly will be reduced at the surface, whereas an emulsion in liquid hydrogen is not damaged.

The gelatine used in photographic emulsion belongs to the group of natural proteins. It is generally made from selected clippings of calf hide, ear and cheek, or from pigskin and bone. The main action (but by no means the only) of gelatine in photographic emulsions is to keep the silver halide crystals well dispersed and, as far as possible, to prevent clumping of the crystals. Certain, less understood, properties of gelatine make it possible to prepare emulsions with very much better photographic properties than emulsions containing any other dispering medium.

Gelatine is built up from a number of amino acids - one gelatine molecule consists of 350-500 amino acid units, the molecular weight being ~ 40,000. Gelatine molecules contain both $-NH_2$ and -COOH groups at the ends and on side chains. This means that gelatine possesses acidic as well as basic properties. The mechanical and chemical properties depend, therefore, on the P_H of the surrounding medium.

At some P_H the number of $-NH_3^+$ and COO^- groups are equal - or, in other words, the molecule as a whole has no net charge. This P_H is called the isoelectric point and lies for gelatine around 4.8. At this P_H the swelling is minimum and the gelatine has the highest chemical stability. Gelatine shows hysteresis effects - the properties under some external conditions depend on the pre-history.

II. THE MECHANISM OF EXPOSURES

When photographic material receives a heavy exposure free silver and halogen will be produced. The general reaction is

$$Br + \text{energy} \rightarrow Br^* + e$$

$$Ag^+ + e \rightarrow \underline{Ag}.$$

The quantity of energy absorbed in the silver halide crystal required to make the liberated silver detectable is far above the energy absorbed during a "normal" exposure where only a latent image is formed. Provided effective methods to remove the liberated halogen are used, direct proportionality has been established between the energy absorbed and the amount of silver liberated. When these high-exposure data are extrapolated to weaker exposures the straight line passes through the origin. From this it may be assumed that free silver is formed also in the region of normal exposure. X-ray diffraction pattern analysis on exposed emulsions shows likewise the existence of metallic silver in the latent image region.

How is the energy absorbed by the silver-halide crystal, and how are the silver nuclei formed which make the crystal developable? According to the widely accepted theory of Guerney and Mott, the photochemical process occurs in two steps - a motion of electrons, followed by a motion of ions. By absorption of light quanta or by energy dissipation by a penetrating charged particle, an electron will be lifted from its usual energy level in the crystal lattice to the conductance

band where it can move around freely. In the crystal there exists a large number of imperfections - deviations from the ideal crystal lattice or impurities of silver or silver-sulphide. Here an electron can be trapped and thus form a negatively charged speck. Between the ions of the lattice exists a number of interstitial silver ions; they are the carriers of the photo-current in a silver-halide crystal measured in complete darkness. These interstitial silver ions are attracted by the negative specks and, on their arrival, are discharged and form a neutral silver atom. This silver atom is now an effective trap for the next electron. The positive hole formed when the electron was released moves to the surface, where a bromine atom escapes.

Most of the known photographic effects can be interpreted by this theory, but the weak point is that the velocity of the positive hole movement must be much less than the velocity of the interstitial silver ions. Otherwise, the negative specks will be discharged by the positive holes before a silver ion arrives at the speck. The experimental evidence, however, is that the mobility of the holes is several orders of magnitude greater than that of the silver ions (no mass transport is involved in this process, only a repeated shift of charges). It must be required, therefore, that by some mechanism the positive holes are more readily trapped than the electrons.

Most of the bromine atoms liberated will be taken up by the surrounding gelatine. Suggested reactions are

$Br_2 + H_2O \rightarrow HO\ Br + H\ Br$

$HOBr + \text{gelatine} \rightarrow \text{gel-Br} + OH^-$

$Br^* + \text{gelatine} \rightarrow \text{gel-Br}$

where gel-Br indicates an undefined bromation product of gelatine.

The bromine could migrate to the latent image centres also and rehalogenate the silver ion, or it could recapture the trapped photoelectron and again become a halide ion. At very heavy exposures the gelatine is not able to accept the large quantities of bromine; rehalogenation will take place to a high degree, reducing the photographic effect of the exposure. When less sensitive nuclear emulsions are exposed to large fluxes of particles ($> 10^{10}/cm^2$) the net result can be that no latent image is present after exposure. This effect is known as solarization.

Another aspect of interest in the work with nuclear emulsions is the recording properties at very low temperatures. From the Guerney-Mott theory it must be expected that only liberation and trapping of electrons take place - the interstitial silver ions are practically immobile at temperatures below -200° C. At these temperatures another process may occur; electrons could be trapped in "shallow" specks, where they will remain until they are released easily by thermal excitation when the temperature is subsequently raised.

When the emulsion is heated (prior to processing) the second stage in the Guerney-Mott mechanism takes place - the interstitial silver ions move to the negative specks. The latent image silver is much more dispersed at low temperature exposure than at room temperature, the reason being that when an electron is trapped the lack of ion mobility will prevent discharge of the trapped electron by an interstitial silver ion. The probability of trapping two or more electrons in the same speck is small, as the already trapped electron will repel the next one approaching the speck. The electrons trapped in shallow traps may help in building up larger latent image nuclei when they are released by thermal energy at temperatures where the mobility of the interstitial ions is sufficient to complete latent image formation.

The recording properties of nuclear emulsions at low temperatures differ from type to type. Ilford G5 is reported to yield 75% of the usual sensitivity when exposed at liquid hydrogen temperature.

Ilford C2, on the contrary, has been reported to lose its registrating power at low temperatures. The Russian NIKFI-R cannot record relativistic particles at liquid hydrogen temperature unless modifications are applied to the emulsion, such as exclusion of iodide or introduction of the hypersensitizing TEA. The lack of low temperature sensitivity of NIKFI-R has been explained by the loss of energy through fluorescence is a marked effect at low temperatures in silver bromide crystals containing iodide. The intensity and wave-length band of the fluorescence is a complex function also of the crystal size and of the degree of perfection in the crystal lattice.

III. THE MECHANISM OF FADING

The latent image is subject to changes between the time of exposure and the time of processing. Here distinction can be made between two processes, a physical and a chemical, both of which tend to decrease the number of developable crystals, the effect is usually termed fading. The physical fading is a thermal ejection of an electron from a latent image silver speck. In this way a silver ion is formed which may migrate away from the silver speck. There is experimental evidence that more than a critical number of silver atoms is required in a speck to make the crystal developable. The loss of a single silver atom can thus turn a developable crystal into a non-developable one. Consequently, specks having just the critical number of silver atoms (which almost certainly is less than 10-15 and probably is about 2-3 only) are very sensitive to this type of fading. It has been shown (Fig. 2) that the processed sensitivity decreases rapidly during the first days after exposure; the reason may be that a considerable number of crystals possess a speck of just the critical size and are thus easily faded by this thermal mechanism. According to this hypothesis emulsions exposed at low temperatures should be more sensitive to fading because of the high degree of dispersion

of the latent image silver. The rate of physical fading differs very little at normal temperatures (0 - 25°C) - reported values indicate less than 7×10^{-4} reduction per day in the processed sensitivity. To prevent thermal fading, the exposed emulsions have to be kept at very low temperatures (liquid nitrogen).

Alboy and Faraggi have suggested that the chemical fading follows the reaction

$$2\ \underline{Ag} + O_2 + 2H_2O \rightarrow 2\ Ag^+ + 4\ OH^-.$$

Alboy and Faraggi (Fig. 3) and many others have shown that the rate of fading at constant temperature increases exponentially with humidity and that fading is accelerated in pure oxygen gas but decelerated in inert gases. However, it must be kept in mind that the above-mentioned chemical reaction, although temperature-sensitive (around a doubling of the reaction speed for a 10 degrees rise in temperature), is very much more sensitive to the <u>absolute</u> water concentration. When the emulsion is in equilibrium with moist air this absolute concentration grows exponentially with temperature (at constant relative humidity).

It has been shown (Barron and Wolfendale, Fig. 5) that, if access of water to an emulsion is prevented by adequate sealing, the rate of fading (interpreted mostly as physical fading) is as low as 0.06% per day at 25°C over three months. The storage times for a 50% reduction in processed sensitivity were found to be

520 ± 50 days at 25°C and

1040 ± 200 days at 5°C.

Figure 4 (Leide) shows the dangerous fading regions (shaded) at various humidities and temperatures. It also confirms that fading is a function of the absolute water content rather than of temperature.

A surprising conclusion from the data is that the widely used storing of emulsions in refrigerators where the humidity is high results in some fading, whereas fading is lower when emulsions are stored at 20° and 50% RH!

Because of the smaller average number and size of the latent image specks in emulsions with small crystals, fading is expected to be greater than in emulsions with larger crystals; the crystals in the small crystal emulsion may be more delicate with respect to fading.

IV. HYPERSENSITIZATION OF NUCLEAR EMULSIONS

In the last years a strong interest has been attached to the study of nuclear emulsions with considerably increased sensitivity. An old, well-known treatment - hypersensitization by TEA (triethanol-amine) - has been applied and has led to excellent results. The increase in sensitivity by bathing an emulsion in a 2.5% buffered (P_H = 9.5) aqueous solution for about 40 minutes amounts to 1.7 × the sensitivity of the same emulsion without hypersensitization. The hypersensitized emulsions seem to be stable for a few months.

The hypersensitization mechanism has been explained (Idanov et al.) as a silver-catalyzed reduction of silver-bromide by the TEA, thus building up subcritical silver specks. During exposure these will more readily grow large enough to make the crystal developable than in the case of non-hypersensitization.

Ilford has recently started the production of hypersensitized emulsions - still on an experimental basis. Their sensitivity is nearly twice that of non-hypersensitized emulsions. If the emulsions are kept dry, fading is low over a few months. In the first Ilford samples the degree of hypersensitization showed a gradient from air surface of the emulsion.

V. TYPES OF NUCLEAR EMULSIONS

1. Ilford Emulsions

Most of the nuclear emulsions used today are supplied by Ilford. Ilford has succeeded in manufacturing nuclear emulsions with rather constant properties, as far as sensitivity and atomic composition are concerned. Ilford supplies three types of emulsions which record tracks of all particles at all velocities, namely G5, K5 and L4. The processed sensitivity obtainable for all three, ranges from ~ 20 - ~ 30 blobs/100 μ; the difference in the three types lies only in the silver-bromide crystal diameters - ~ 0.27 μm, 0.20 μm and 0.14 μm respectively. Under equal conditions fading is reported to increase in the order G5-K5-L4. The discrimination power for tracks of slow particles and also the accuracy in measuring angles and very short ranges increase in the same order. In addition, the visibility of tracks is improved because a general background will be less marked when the grains are smaller.

K2 and L2 are less sensitized emulsions, recording protons to about 80 MeV, corresponding to a β of 0.4 for a singly charged particle.

K1 is still less sensitized and records protons up to 7 MeV (β = 0.12).

K0 is the least sensitive emulsion, used mainly in fission studies.

Ilford emulsions are in general available as plates, pellicles, and in gel. form. They are also available diluted with gelatine, loaded with lithium or boron, and with extra plasticizer for use in vacuum or under dry conditions

2. Eastman Kodak emulsions

Kodak nuclear emulsions are rarely used in high-energy work. According to Kodak, their relativistic particle sensitive emulsion

(NTB 3) "is considered an experimental product, not subject to Kodak's regular standards of uniformity". Kodak nuclear emulsions are not available as pellicles and are mostly used for autoradiography.

Types available are NTB 3, NTB 2 (protons up to 300 MeV), NTB (protons up to 50 MeV), and NTA (protons up to 20 MeV).

3. Gevaert Emulsions

Gevaert has recently succeeded in producing a minimum ionization sensitive emulsion called NUC 7.15, whose processed sensitivity is as high as 50 blobs/100 μ. Tests have shown that fading in 100 μ test plates is negligible after a month's storage. The diameter of the silver-bromide crystals is $\sim$ 0.15 μm, comparable with those of Ilford L4 (0.14 μm). This emulsion thus possesses a very high sensitivity combined with a high discrimination power due to the small grains. In sensitivity it is comparable to the famous Russian NIKFI-R but has about half the crystal diameter of the latter.

Gevaert NUC 3.07 is a less sensitive emulsion meant for autoradiography. The crystals are exceedingly small ($\sim$ 0.07 μm) and the emulsion is able to record particles with β's up to 0.5.

4. Agfa Emulsions

A minimum sensitive emulsion is hoped to be put on the market some time this year. The crystal size distribution will be extremely sharp - the grains will be cubic and the emulsion will contain 82-84% silver bromide.

5. Russian and Japanese Emulsions

For the sake of completeness two of the most outstanding nuclear emulsions from other countries should be mentioned, namely the Russian NIKFI-R and the Japanese FUJI ET-7A. Both of them are

minimum sensitive, the crystal diameters being 0.28 μm and 0.27 μm, respectively. NIKFI-R records relativistic particles with blob densities around 50/100 μ. In case of hypersensitization, NIKFI-R yields up to 100 blobs/100 μ.

The properties of the above-mentioned nuclear emulsions are compiled in Table 4.

VI. LOADING OF NUCLEAR EMULSIONS

Nuclear emulsions can be loaded with practically all elements. In this presentation, the technique of loading will be described in two groups: heterogeneous (the loading phase is visible after processing), and homogeneous (the loading phase is so dispersed in the emulsion that visual inspection is not possible).

1. Hetergeneous loading

Nearly all insoluble compounds can be filled into an emulsion in the form of grains with diameters larger than 1 μ. Loadings of this kind are easily mixed with a melted emulsion prior to pouring. As discussed in section I, care should be taken that the loading does not react chemically with the emulsion. Typical loadings of this category are minerals (SiO_2, diamond, graphite, TiO_2, etc.), insoluble salts ($PbSo_4$, $CoWo_4$, Wo_3, etc.), glass, plastics, protected metals, etc.

Loading by wires and tubes is often preferred as the scan for events is facilitated when it can be done along the wire. Another advantage is that thin tubes can be filled with a reactive substance. Wire thicknesses from 1-50 μm have been used. The most important problem in wire loading is to reduce the distortions around the wire, the region where one usually wants to make accurate measurements. Good results have been obtained in attempts to restore the original thickness of the emulsion after processing by resins of various kinds.

Plates, foils and powders can be placed between pellicles in a stack provided care is taken so that the material does not damage the emulsion. Likewise, pure or loaded gelatine layers can be poured on or between emulsion layers (sandwich emulsions).

Homogeneous loading. After soaking emulsions in solutions of various soluble compounds these compounds will be present in the emulsion after subsequent drying. Better control of the quantity is obtained by adding a known volume of the solution of a known concentration to a known volume of melted emulsion. In this way, Ilford prepares loaded emulsions containing 16 mg Li/cm^3 (as Li_2SO_4), 23 mg B/cm^3 (as $Na_2B_4O_7$), or 270 mg Bi/cm^3 (as Na BiO_3).

The following list may serve as a guide for the quantities of various substances which can be loaded into an emulsion by simple impregnation or addition.

H_2O	200%	(with development immediately after exposure)
D_2O	10%	
Li_2SO_4	5%	
$Li_2B_4O_7$	10%	
$Na_2B_4O_7$	10%	
NaN_3	3%	
Th $(NO_3)_4$	0.3%	
$UO_2(CH_3\ COO)_2$	2%	

The list can be extended to include almost all soluble compounds - provided adequate care is taken to prevent chemical destruction of the emulsion (by buffering or by complexing). Strong complexing agents (e.g. versenates) enable us to load emulsions with large quantities of heavy elements such as UO_2, Th, Bi, etc. (de Carvalho).

It is possible to add up to 50% of insoluble compounds as colloidial particles to an emulsion, but this procedure requires rather sophisticated methods. For example, $PbSo_4$ and $CoWO_4$ can be precipitated together with silver-bromide during the manufacture of the emulsion, the loading consisting of submicroscopic particles protected by gelatine.

* * *

BIBLIOGRAPHY

GENERAL

Mees, The Theory of the Photographic Process, New York, 1954.

James and Higgins, Fundamentals of the Photographic Theory, London, 1949.

Joos and Schopper, Grundriss der Photographie und Ihrer Anvendungen besonders in der Atomphysik, Frankfurt am Main, 1958.

Demers, Ionographie, Ottawa, 1958.

Mitchell (editor), Fundamentals of Mechanisms in Photographic Sensitivity, London 1951.

I. CHARACTERISTICS OF PHOTOGRAPHIC EMULSIONS

Swinnerton and Waller, Photographie Corpusculaire, Strassbourg 1957, p. 183.

Oliver, Rev. Sci. Instr. 25, 326 (1954).

Leide, Arkiv för Fysik, 11, (1957).

Barkas et al. Nuovo Cim. 8, 185 (1958).

Tretiakova, Int. Sym. Nucl. Phot., Moscow 1960.

Waniek, Bull. Amer. Phys. Soc. 1, 219 (1956)

II. THE MECHANISM OF EXPOSURES

Debeauvais-Wack, Phot. Corp. I, 126 (1957)

Bogomolov et al., Phot. Corp. I, 203 (1957)

Bogomolov et al., Phot. Corp. II, 124 (1959).

III. THE MECHANISM OF FADING

Alboy and Faraggi, I. Phys. Rad. 10, 105 (1949).

Barron and Wolfendale, Brit. J. App. Phys. 8, 297 (1957).

Leide, Arkiv för Fysik 11, 344 (1957).

Bogomolov, Phot. Corp. I, 195 (1957).

Debeauvais-Wack et al., Comptes Rendus 253, 2517 (1961).

IV. HYPERSENSITIZATION OF NUCLEAR EMULSIONS

Idanov et al., Phot. Corp. II, 91 (1959).

Bogomolov et al., Phot. Corp. II, 128 (1959).

Faraggi and Garin, Hypersensibilization des Emulsions Nucléaire Ilford par la Triettanolamine, Saclay 1959.

Dahl-Jensen, Supp. Nuovo Cim. 16, 245 (1960)

V. TYPES OF NUCLEAR EMULSIONS

Booklets and private letters from the various manufacturers.

Bogomolov et al., Phot. Corp. I, 133 (1957).

Imaeda et al., Phot. Corp. II, 109 (1959).

VI. LOADING OF NUCLEAR EMULSIONS

Yagoda, Radioactive Measurements with Nuclear Emulsions. New York, 1949.

Silver and Waniek, Rev. Sci. Instr. 25, 1119 (1954)

de Carvalho and da Silva, Notas de Fisica 4, 12 (1958).

Bytchenkov et al., Int. Sym. Nucl. Phot. Moscow 1960.

Table 4

Manufact.		ILFORD							KODAK				GEVAERT		NIKFI	FUJI
type		G5	K5	L4	K2	L2	K1	K0	NTB 3	NTB 2	NTB	NTA	NUC 7.15	NUC 3.07	R	ET-7A
diam. μm		0.27	0.20	0.14	0.20	0.14	0.20	0.20	0.25	0.25	0.25	0.15	0.15	0.07	0.28	0.27
highest β record.		1			0.40		0.12	0.10	1	0.65	0.32	0.21	1	(?) 0.50	1	1
P	T MeV	all			80		7	5	all	300	50	20	all	150	all	all
	R mm.	all			20		0.3	0.2	all	200	9	2	all	60	all	all
K	T MeV	all			40		3.5	2.5	all	150	25	10	all	80	all	all
	R mm.	all			10		0.15	0.08	all	100	4.5	1	all	33	all	all
π	T MeV	all			13		1	0.7	all	45	8	3	all	20	all	all
	R mm.	all			3.5		0.04	0.02	all	30	1.5	0.3	all	8	all	all
e	T KeV	all			40		4	2	all	150	25	10	all	80	all	all
α	T MeV	all			all		140	110	all	all	800	300	all	all	all	all
	R mm.	all			all		5	3	all	all	100	20	all	all	all	all
Particles of higher charges are always recorded.																

3348/NP/smg

DISCUSSION

Combe : Now there are some emulsions recording particles up to $\beta = 0.40$ (K2 Ilford), some up to $\beta = 0.65$ (Kodak). How difficult would it be to produce emulsions recording up to a β between 0.65 and 1? Such a property could be used in experiments where the wanted particles have a β between 0.65 and 1, and are produced with a lot of unwanted particles with $\beta = 1$.

Dahl-Jensen : Dr. Vanderhaeghe has described an excellent method of mixing two types of emulsion of the same grain size but different sensitivity to get an emulsion with a sensitivity which is about the mean of the two. You can also hypersensitize a less sensitive emulsion to obtain the desired sensitivity.

E. Fletcher : Does the treatment of the emulsions before exposure (e.g. the temperature at which they are kept) affect their sensitivity?

Dahl-Jensen : Barron and Wolfendale again exposed some of the emulsions, which had been stored both at 5° and 25° C for 500 days, and found no decrease of sensitivity for either temperature.

Heckman : Could you tell me why processed L4 emulsions often have large, amber-coloured crystals? These crystals are difficult to remove and seriously affect particle tracks which enter them.

Teucher : It can be prevented by refixing; L emulsions should always be refixed.

Heckman : I wonder if you could account for the varying degree of success one has when one tries to hypersensitize emulsions. In particular, I know that emulsions have been useful several months after they were sensitized, yet I have experienced cases where the rise in the single-grain background has made the emulsion useless in about 24 hours.

Dahl-Jensen : If you use too high concentrations of TEA you will expose your plates by the hypersensitization. My only experience is with two stacks of K5 emulsion which could be kept for about three months before the hypersensitization disappeared. It is reported by Faraggi and Garin (see bibliography) that you can reproduce the hypersensitization by a certain procedure, getting stability for more than six weeks.

Key : You mentioned that the proportionality between the energy absorbed and the amount of silver liberated was established at very high exposures and then extrapolated to normal exposure. Why cannot you just measure the points?

Dahl-Jensen : Because these points correspond to about 10^5 silver atoms per cm^2 and you need about 10^{20} atoms to make a chemical analysis. However, you can measure such small quantities by counting the γ rays from Ag after irradiation in a reactor.

Teucher : Could you say something about attempts to manufacure emulsions without gelatine?

Dahl-Jensen : Black and white films for cinemas are very often made with polyvinylalcohol instead of gelatine, but you can only use a very thin layer because it is very difficult

Dahl-Jensen (cont.) : to get your developer into it. Attempts have been made to replace partly the gelatine of nuclear emulsions by polyvinylalcohol but for the same reason it has been very difficult to get a uniform development.

Zakrzewski : How does the emulsion change depending on the inhomogenities you introduce?

Dahl-Jensen : We have found that with, for example, diamond powder (about 8 μm in diameter) you can tolerate 50 mg/100 cm^2 emulsion (200 μm thick). A track passing through the centre of a grain or above can easily be seen, whereas a track hitting the bottom part of the grain can be examined later on after reversing the plate. The distortion of a steep track near the grain is less than 1-2 μm, which is not much compared with the distortion of the plate as a whole.

Zakrzewski : Which grain size can be used when you are to study short prongs from interactions inside a grain?

Dahl-Jensen : This is a question of compromise because you must exclude events in an outer layer of the grain where you cannot be sure whether the reaction took place in the grain or just outside. If you use smaller grains your effective target volume will decrease rapidly; if you use larger grains you will miss some of the short prongs. We have estimated that 6-12 μm grains will give you minimum distortion and maximum information.

Bovet : I would like to add a remark on the question of heterogeneous loading of emulsions. Several heavy metals can be introduced directly into the emulsion in the form of small spheres. We have succeeded in

Bovet (cont.) : producing spherical blobs of gold with a diameter of 3 μm. These blobs are easily distinguishable from the silver ones after development; such a loading, amounting to 4 mg/cm^2, does not seriously alter the transparency or optical properties of a layer of 200-600 μ emulsion.

* * *

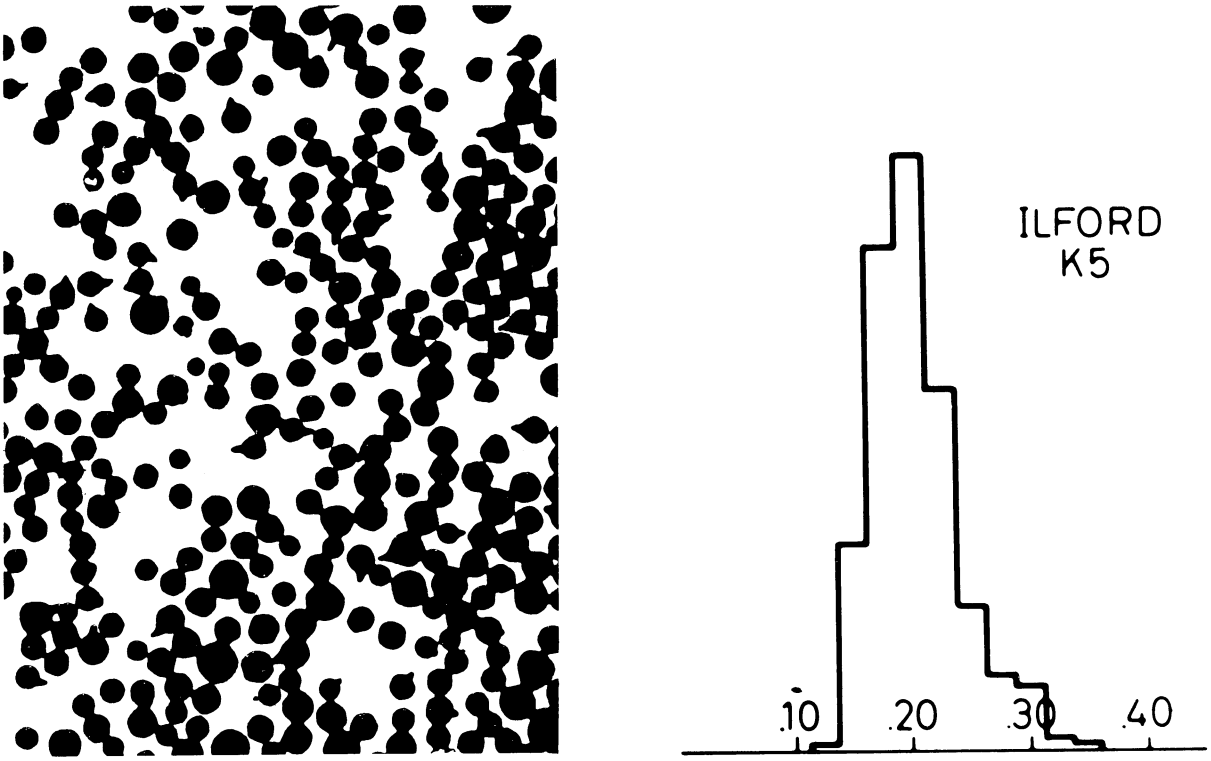

Fig. 1. a) b) The size-frequency curve of an Ilford K5 emulsion (crystal diameters in μm)

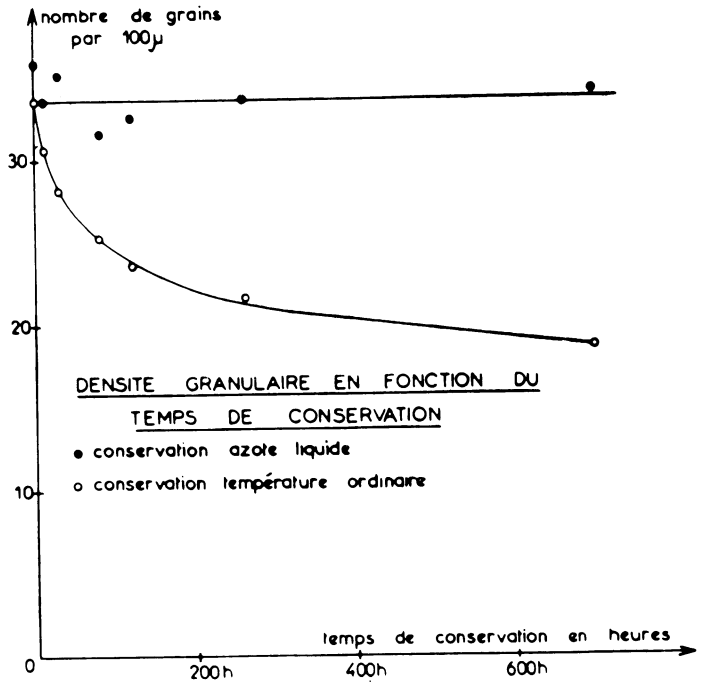

Fig. 2. (Debeauvais-Wack et.al. Comptes Rendus 253 p.2518 (1961))

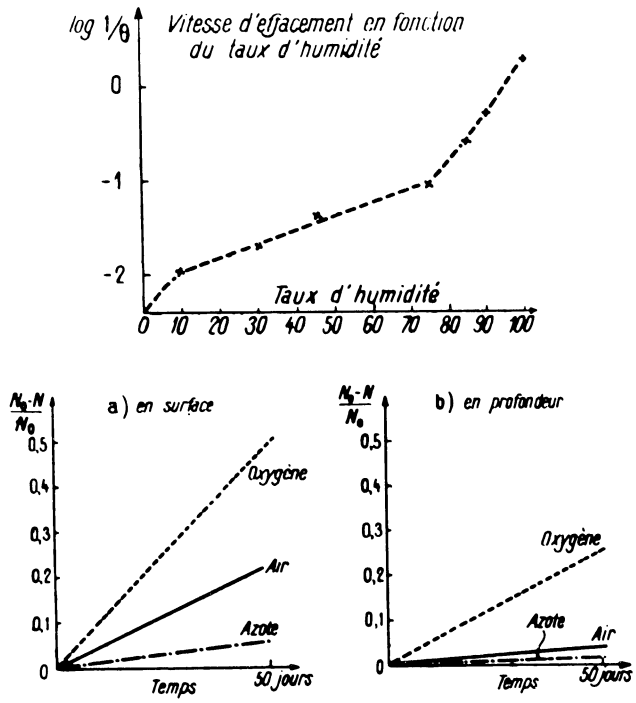

Fig. 3.

(Alboy and Faraggi, I. Phys. Rad. 10 p. 105 (1949))

G. LEIDE, *Latent image Fading in Ilford G-5 emulsions*

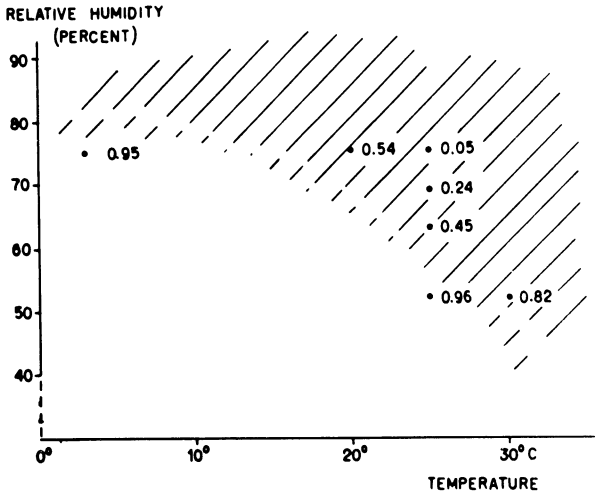

Fig. 4. (Leide, Arkiv f. Fysik 11, p. 344 (1957))

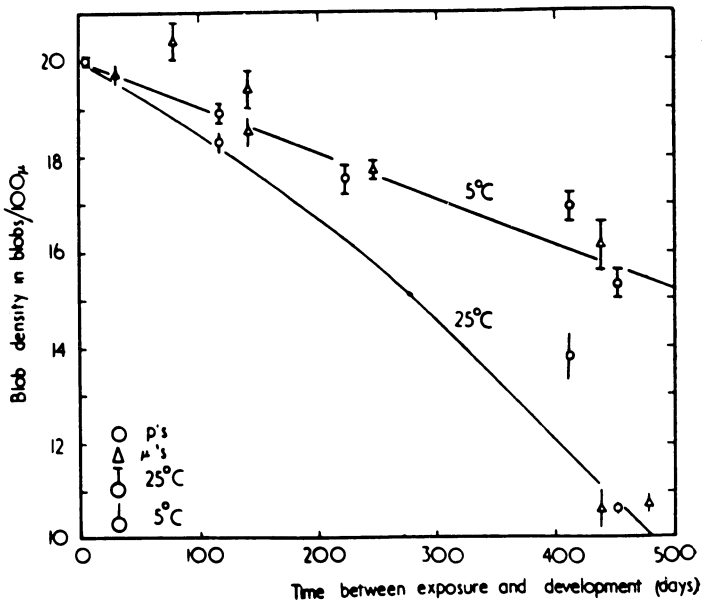

Fig. 5.

(Barron and Wolfendale, Brit. I. Appl. Phys. 8. p. 298 (1957))