INTRODUCTORY TALK

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I. THE PURPOSE OF THE SCHOOL

This is to be a "School for Physicists using the Nuclear Emulsion Technique in Conjunction with the CERN Proton Synchrotron and Synchro-cyclotron". Why has it been found desirable to set up such a school? Is it not true that the physicists using the nuclear emulsion technique have plenty of opportunities to learn all about it at their home laboratories? In a sense this is certainly true. Many of you come from laboratories that have done very valuable and famous work using the emulsion technique, and there is no better place to learn the emulsion technique than in those laboratories. Nevertheless, we think that there is a genuine need for a school of the kind attempted here. If one wants to experiment nowadays with nuclear emulsions at a large accelerator in a way which really results in revealing a new piece of physical information, then there are many things one has to know in addition to the recipes of how to process the emulsions and how to make reliable measurements in them.

To start with, the emulsion technique has no longer the outstanding position it had several years ago when many of the most important discoveries of those days were made by it. In the meantime the bubble chamber has been invented and developed into an extremely powerful tool and the electronic techniques have been much refined. The large accelerators have come into operation. New devices like spark chambers, luminescent chambers, semiconductor detectors are being applied, or are being tested for application, in high-energy nuclear physics experiments. Many experiments which could only have been done by the emulsion technique a decade ago can now be carried out faster and more conveniently by one of the newer techniques, whereas for some other experiments the emulsion is still the most suitable tool today. The emulsion worker who plans another emulsion experiment must therefore know enough of these newer techniques, and of the results obtained and obtainable by them, to be sure that he is not just attempting to do something that has already been done, or is being done, or could be done, in another and more efficient way. Of course, the mere fact that some problem has been attacked, is being attacked, or could be attacked by another technique does not mean that it is taboo to the emulsionist. If something has already been done then one may judge whether the result is clear and unambiguous, or whether it should rather be repeated, and, if so, by which technique. If something is being done, then there may be some room for doubting whether it will be finished, and lead to a clear-cut result, and it may take some knowledge not only of the experimental technique applied, but also of the experimenters involved, to form a personal opinion as to the wisdom of starting a competitive experiment using emulsions. Finally, if an experiment could be done better by, say, a hydrogen bubble chamber but no bubble chamber group plans to do it in the near future for lack of time or interest, then there might be a case for the emulsion worker to go ahead. He may find something interesting and may stimulate the appetite of the bubble chamber people who will then finish the job. But in general the emulsion worker should concentrate on those experiments which can <u>only</u> be done by emulsions because here his contribution becomes most valuable. Again, in order to find these experiments he must know not only his technique but also the possibilities and the limitations of the others.

So this is one justification for our school in which we shall try to show what the emulsion technique really <u>can</u> do, and what one should better leave to the bubble chambers, counters, spark chambers, etc.

A second object of the school is to study the particular aspects of experimenting with emulsions <u>near a large accelerator</u>. Again this is something which it is difficult to do far away from an accelerator. There are many technical problems to be overcome before the emulsion can be exposed at the accelerator, problems that do not exist in cosmic ray work. They will become evident in the lectures on the CERN accelerators and beam transport systems, on exposure techniques, and on some typical experiments.

Another field to be covered by this school are some recent advances of the emulsion technique itself. Apparatus like pulsed magnets for exposing emulsions in fields of more than 100,000 gauss have a size and complexity that make it difficult to transport them over long distances. It would also be uneconomical if each laboratory, for example, set up its own condenser bank. Therefore, large apparatus of this nature will only be constructed at a few places, preferentially near the accelerator. Physicists at the other laboratories should nevertheless know about them, and use them as far as possible.

This should be sufficient to sketch what some people would like to call the "philosophy" of the school but what -- with more respect towards philosophy -- could also be called its programme. In addition, however, the programme will also include lectures on the general foundations and methods of the emulsion technique like the photographic process, the types of emulsions available, their handling and processing, the scanning and measuring methods. We shall now look at this programme in a little more detail.

Let us consider the first mentioned point first. Let us compare the special features of the emulsion, track chamber, and electronic techniques and discuss the fields in which each has particular value.

II. COMPARISON OF THE PRESENT TECHNIQUES OF HIGH-ENERGY NUCLEAR PHYSICS

We shall not consider here those techniques which are still in the state of being tested or developed, and shall thus limit ourselves to the scintillation and Čerenkov counters, to the expansion and diffusion cloud chambers, to bubble chambers, spark chambers, and, of course, nuclear emulsions.

Each of these tools has specific properties. Therefore it is sometimes this, sometimes that technique which is better, or only applicable under the conditions of a given experiment.

Scintillation counters have a relatively high resolution in time, i.e. a short "dead" time, and are therefore of great value in all investigations which aim at precise measurements of flight and lifetimes, involve coincidences of several counters, and require large statistics. On the other hand, pure counter experiments often do not give much information on the details of the reactions studied. Frequently it is impossible to say whether one particle, or several particles simultaneously, have traversed the counter, whether secondary reactions took place inside the counter, and which were the direction of flight, the mass, charge, and velocity of the particle.

The situation is better in this respect with the Čerenkov counter. The Čerenkov counter is also well suited for use with fast coincidence circuits, and can be combined with scintillation counters. In fact, the antiproton was discovered by such a combined arrangement of scintillation and Čerenkov counters$^{1)}$. Also at CERN combinations of Čerenkov and scintillation counters have been extensively used$^{2)}$. The Čerenkov counter has the great advantage of a precise velocity resolution ($\Delta\beta \approx 0.001$) in addition to a high counting efficiency. It can also be made to have angular discriminating properties. Of course, a Čerenkov counter is much more complicated to make and to run than a simple scintillation counter.

The other detectors mentioned have one thing in common that the counters lack: they make the tracks of charged particles directly visible. This, however, is more or less the only thing they have in common. In almost all other respects they have vastly different characteristics.

The expansion cloud chamber may have large dimensions, can be triggered by counters and exposed in a magnetic field, but has a considerably longer "dead" time than any of the other types of chambers.

Compared to the expansion cloud chamber, the diffusion cloud chamber has the advantage that it can be operated with hydrogen under high pressure. The pair production of neutral V-particles in π-p reactions has been demonstrated in this manner$^{3)}$. One disadvantage of the diffusion cloud chamber is that the thickness of its sensitive layer is rather limited.

As was just said, cloud chambers can be triggered by counters so that only events of a special type are registered. This possibility does not yet exist for bubble chambers although there has recently appeared some hope that by the use of ultrasonic waves the problem of triggering bubble chambers may be solved. This disadvantage of the bubble chamber is, however, balanced by an array of important advantages. The bubble chamber has a repetition rate much higher than that of the cloud chamber, may have dimensions comparable to those of the largest cloud chambers, can also be exposed in magnetic fields and, most important, may be filled with liquid hydrogen.

On the other hand, a hydrogen bubble chamber is a device of great technical complexity and therefore expensive to build. It is also expensive to run, due to the continuous hydrogen consumption, and to the safety problem which requires constant supervision and alertness from a large crew. Much more economic in every respect is the spark chamber which has recently attracted much attention as a most welcome addition to the arsenal of detectors available for elementary particle experiments$^{4)}$. It has clearing times smaller than 1 μsec. It allows tracks to be located with an accuracy of about 1 mm. It is easy to build, inexpensive, and can be triggered. For the latter reason and for the fact that one can put 10^6 particles/sec through the chamber it should be ideal for looking at rare and complicated events. At CERN several spark chamber experiments are being planned to investigate the polarization of the recoil proton from $\pi^- + p \rightarrow \pi^- + p$, the leptonic decay modes of K^+, the interactions of neutrinos, the relative $\Sigma - \Lambda$ parity, and other problems. Spark chambers can be put into a magnetic field, and may even be combined with a Čerenkov counter and a bubble chamber, thereby making possible the identification of particles of a given mass among the tracks in the bubble chamber[4)].

The <u>nuclear emulsion technique</u> permits microscopic track measurements of high precision and reproducibility and therefore the determination of ranges and specific ionizations with an accuracy unattainable by any of the other techniques. As an example one might recall that the range of a muon from the decay at rest of a pion is 0.6 mm in nuclear emulsion and 11 mm in the liquid hydrogen of a bubble chamber. The mean diameter of a developed silver grain in G5 emulsion is about 5×10^{-4} mm, of a bubble in the liquid hydrogen chamber about 0.2 mm. The ratio (track length/unit of range measurement) is in this case about 1000 for the emulsion, but only about 50 for the hydrogen bubble chamber. Ranges and distances of the order of one micron which are quite unresolvable by other means are still easily measurable in nuclear emulsion.

If the outcome of the experiment depends less on the accuracy of measurements in individual reactions, and more on the speed of finding correlated events separated by distances of the order of 1 cm or more (like the production and decay of neutral particles) then the chambers become superior to the emulsions. The diameter of the field of view in the microscope is only fractions of a millimetre, whereas in the photographs from a large cloud or bubble chamber one can at one glance survey an area with a diameter of the order of 1 metre. Cloud and bubble chambers therefore allow investigations which are almost impossible in emulsions due to the difficulty of spatial correlation.

Scanning for events with a rather small cross-section which involves following great lengths of track is for the same reasons less time-consuming in track chambers than in emulsions even though the density of the absorbing material in the former may be smaller. One will therefore prefer track chambers to emulsions also in experiments of this type, unless measurements of extreme precision have to be performed on the events found.

Table I summarizes some of the more important features of the various techniques. From this table one gets a rough idea of the advantages and disadvantages of each of the techniques mentioned. If there is a particular physics problem to be attacked, the right technique to do the job should be carefully selected. The professional emulsion worker is particularly exposed to the temptation not to observe this rule. This is because his technique allows him in principle to do almost any experiment that the other techniques can do if one disregards the time and effort required to do it. Every reaction in which charged particles are involved is beautifully and clearly visible in all its details, and the only problem is to find enough of these reactions and make the necessary measurements within a reasonable time. The emulsion contains about as much hydrogen per cc as a hydrogen bubble chamber; there is only the problem of identifying the events with this free hydrogen. Again this identification takes time and effort but can often be done. But, as we said in the beginning, whenever an emulsion physicist thinks: "This is an experiment I can do", his immediate further thoughts should be: "Is the emulsion technique superior to the other techniques here? Is it at least likely to come up with a good result within reasonable time? Can I therefore justify the effort required to do the experiment? Or should I rather use another technique for this experiment, or do another experiment for which emulsions really are the best solution?"

As examples we shall now mention a few experiments in the cases of which the emulsion technique was indeed considered to be a most suitable, if not the only suitable, one.

III. EXAMPLES OF EMULSION EXPERIMENTS

1. The interactions of 1.5 GeV/c K^- mesons

This is an experiment proposed to be carried out by several groups in Europe, India, and the United States. Its purpose is the study of the production of hyperfragments, if possible also of Λ^0-Λ^0 and of Ξ hyperfragments, of the production and absorption of Ξ hyperons, of small angle elastic scattering of K mesons, and of related problems. It is a typical emulsion experiment in that the observations proposed cannot be made as well by any other technique because of the short hyperfragment and Ξ ranges and small scattering angles to be measured.

2. The magnetic moment of Λ^0 and Σ^+ hyperons

The groups of Bristol, CERN, Lausanne, and Rome plan an experiment by which they want to measure the magnetic moment of the Λ^0 and Σ^+ hyperons. The experiment is based on the known facts that the Λ^0 and Σ^+ hyperons produced by pions are polarized with respect to the production plane, and that the decay pions from the hyperon decays show an angular asymmetry with respect to the polarization vector. In a strong magnetic field the polarization vector will precess about the field direction by an angle which depends on the magnitude of the magnetic moment. Detailed quantitative calculations of this effect have been published, e.g. by N. Schmitz[5]. In order to obtain precession angles of a measurable order of magnitude, magnetic fields of more than 100,000 gauss are required. Nevertheless, large statistics will still be necessary. Why, then, is this an emulsion experiment? The bubble chamber technique would, in principle, be better suited for the detection and angular measurement of the hyperon decays, but there do not yet exist in a working condition bubble chambers that can operate in or near magnetic fields of that strength, although such chambers are being developed by, for example, Dr. Bergmann at Munich. Magnet coils for the exposure of emulsions in pulsed, very high magnetic fields do exist, however.

For this technical reason the experiment can probably be carried out in emulsions earlier than in bubble chambers. Quite recently, however, the magnetic moment of the Λ^0 has been measured in a spark chamber experiment at Brookhaven.

3. "Burning spot" experiment

This experiment, which was proposed by the Bern Group, takes its name from the fact that a very well-collimated pencil beam of high intensity will be directed on a small spot in one corner of the emulsion stack, or on an external target of high Z material just outside the stack. The intensity will be so high that the emulsions would be black ("burnt") in the beam region where a very large number ($\sim 10^6$) of interactions would take place. In these interactions a considerable number of baryons and antibaryons would be produced, some of which would leave the region of the "burning spot" and would produce tracks in the clear parts of the emulsions. The whole arrangement will be placed into a high field, pulsed magnet so that the tracks of positively and negatively charged baryons would be separated. If one scans at a distance of ~ 2 cm from the burning spot or target one hopes to be able to pick up easily the tracks of negatively charged baryons and antibaryons, the interactions of which can be studied.

The emulsion technique is suitable here because it allows the observation and identification of tracks close to a highly irradiated target. The experiment requires, however, a high degree of collimation. It is proposed to use a lead collimator, 2 m long, with an aperture of 5×5 mm^2.

4. Search for Dirac monopoles

This experiment was carried out recently at CERN. If magnetic monopoles exist, they may be formed by proton-nucleon collisions in a target in which they then get bound. By strong, pulsed magnetic fields they should be liberated again from the target. They should ionize heavily and therefore leave very characteristic tracks in nuclear emulsion. The experiment, which was carried out in various ways, consisted essentially in the irradiation by protons of different kinds of targets which were placed in strong, pulsed magnetic fields, either during the irradiation or afterwards. If any monopoles had been liberated some would have been guided by the accelerating fields into the nuclear emulsions which were placed, in the last version of the experiment, at a distance of a few metres from the machine. So far, none have been found. The upper limit for the cross-section is of the order of 10^{-40} or 10^{-39} cm^2.

The emulsion technique is excellently suitable here because of its simplicity, its power of integrating over time, and its distinctive power for very heavily ionizing tracks, but the experiment can, and has, also been done with counters.

IV. CONCLUSIONS

We have shown only a few examples of CERN emulsion experiments from which some of the main advantages of this technique become discernible. Of course we could have mentioned many more examples of emulsion experiments carried out or planned in various places in the world. A good one would have been the determination of the π^0 lifetime in which flight paths of a fraction of a micron have to be measured, a feat directly possible only with emulsions, although indirect ways also exist. [See talk by H. Heckmann in Part VIII.2

We summarize again: the high spatial resolution, the discriminating power (i.e. the possibility to make direct measurements on the tracks), and the relative ease of handling the emulsions are the principle assets of the emulsion technique. Whenever these factors become decisive the application of the emulsion technique is indicated. But one should, of course, never forget that there are usually several ways to the solution of a problem in physics, and that one cannot, therefore, divide up the questions of physics according to techniques which might be competent for them. There is no limit to ingenuity, and the advent of a good new idea can completely change the experimental situation.

At the end of the introduction I should like to say just a few words on some of the technical aspects which the emulsion physicist has now to face and which will be treated in greater detail in this school. I spoke before of the relative ease of the emulsion technique. This is true if one compares the mere preparation and exposure of an emulsion block with, for example, the construction and operation of a bubble chamber. But this situation is changing. The construction and use of pulsed magnets is already requiring more complete technical work from the emulsion physicist, and as far as the design, testing and monitoring of beams go, the emulsionist will now have to share fully the burden of the work required from the track chamber and electronics physicist if he does not want to remain in the position of perpetual parasiting on other people's beams. Therefore this school will stress particularly the problems of beam optics and particle separation. I only want to remind you here that, for example, the new K beam for the North Hall will consist of seven quadrupole lenses and three bending magnets. The design, alignment, and adjustment of a beam of this type is, of course, a major task that requires several months of work by a group of physicists.

I cannot go into any details here in this short introductory talk. All the details will be given to you in the sessions that follow. It was my intention only to recommend to your particular attention some points of the programme which cover aspects of modern emulsion work about which we, as emulsion physicists, perhaps still think too little. It was not necessary for me here to stress the other parts of the programme which deal with the more conventional aspects of our technique, aspects the importance of which has always been obvious. Without the knowledge of the special types of nuclear emulsion available, without the know-how of processing and measuring, no emulsion experiment is possible.

At the beginning of this school and as a member of its Organizing Committee, I should like to thank CERN and all of its members who made this School possible. I also thank all those colleagues who have agreed to lecture here and thus to contribute to the success of the school. They will now introduce you into the fields in which they are experts and which are so important for fruitful work with the emulsion technique.

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REFERENCES

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3) W.B. Fowler, R.P. Shutt, A.M. Thorndike and W.L. Whittemore, Phys.Rev. 93, 861 (1954).

4) See, for example, Spark chamber symposium, Rev.Sci.Instr. 32, 480 (1961).

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6) G. Harris, J. Orear and S. Taylor, Phys.Rev. 106, 327 (1957).

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DISCUSSION

Lock : The magnetic moment of Λ^0 has been measured by a spark chamber experiment at Brookhaven, but the error was large; the quoted value is -1.5 ± 0.5 nuclear magnetons. Therefore another experiment is planned on this machine in order to reduce the error.

Richter : I have one question about the comparison of spark chamber and bubble chamber. You have given here a resolution time of 10^{-6} sec for a spark chamber. Now I think it is rather difficult to use this resolution time for the spark chamber and to compare these two resolution times. I have the feeling it would be better to say a bubble chamber is seeing every track coming along within about 1 msec, while a spark chamber sees every track within 10^{-6} sec. But to make this track visible you cannot take this resolution time of 10^{-6} for the spark chamber. You have, I think, of the order of 50 msec to get separate tracks. The question is, how do you define this resolution time for those two chambers?

Gottstein : I think that the definition of the resolution time is the time by which you can distinguish that two events were not simultaneous. In a spark chamber you can do it with an accuracy of 10^{-6} sec because it takes about that long to clear the gas again before the next spark; whereas in a bubble chamber -- unless you use information from counters -- you know only that the event happened while you took the pictures, and a picture can be taken in intervals of ~ 1 sec. What I had in mind when I wrote 10^{-6} sec for the spark chamber was a comparison with the time resolution of the counters. I agree that the registration interval given for the bubble chamber

Gottstein (cont.) : is of a somewhat different nature and therefore not really comparable.

Teucher : I think what you have written is too favourable for the spark chamber because actually as far as I know you can not take a second picture for, let us say, 10 or 20 msec in a spark chamber. The sensitive time is of the order of 1 μsec. But if you want to compare how much data you can take I think you have to take actually the recovery time, and all these things, such as power supply and so on, go in and as far as I know this is at the moment of the order of 10 - 20 msec, so even if you have a pulse length of 100 msec which is about the best you can get at the proton machine you can take something of the order of 10 pictures per pulse with the spark chamber but not more than that. So the data collection is very good because with the bubble chamber you can take just one picture and with the spark chamber you can take ten. But if you go to electron accelerators where you have extremely short pulse lengths, then it remains at one picture per pulse for the spark chamber.

Gottstein : The figure of 10^{-6} is significant when you have to distinguish one track from the next one. It is quite true that you cannot take another photograph after 10^{-6} sec, but only after this much longer recovery time. But if you want to make time measurements, then you should use this figure of 10^{-6}.

Nikolić : Speaking about the exposure of emulsions by the 1.5 GeV/c K^- beam, you mentioned as a typical emulsion experiment the investigation on hyperfragments, and especially that of the hyperfragments with two bound Λ^0s produced by Ξ^-.

Nicolić (cont.) : Then you also mentioned a general research on Ξ^- particles to be a typical emulsion experiment. Can you substantiate the latter opinion?

Gottstein : I just reported what the people who want to do this experiment wrote specifically in their proposal. They want to study the production of hyperfragments and of Ξ^-. The investigation of hyperfragments is a typical emulsion experiment. I have not calculated the kinematics for the Ξ particles produced in such reactions so I do not know at the moment what ranges they could have. In any case, the emulsion technique would allow rather precise measurements on the Ξ tracks also, if such are found.

Nikolić : Emulsion represent, for instance, a particularly suitable technique for the study of production of short-lived charged particles, especially of Σ^-. Another advantage of this technique is the fact that it allows one to work with a very high particle intensity. For example, emulsions are and will be used in determining the pion flux in the CERN neutrino experiment.

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Table I

Comparison of the present techniques
of high-energy nuclear physics

Detector	Registration interval	Direct track visibility	Surveyable track length	Advantages	Disadvantages
Scintillation counter	$\lesssim 10^{-9}$ sec	no	-	High time resolution. Large statistics attainable.	Tracks not visible. Poor space resolution.
Čerenkov counter	$\lesssim 10^{-9}$ sec	no	-	High velocity resolution in addition to above.	As above.
Expansion cloud chamber	1 - 10 min *)	yes	~ 1 m	Large dimensions. Sensitive volume not limited as in diffusion chamber. Triggerable by counter.	Low density **). Long dead-time.
Diffusion cloud chamber	~ 10 sec	yes	~ 1 m	Large dimensions. 20 at H_2 possible. Triggerable by counters.	Shallow sensitive volume. Density still low **)
Bubble chamber	~ 1 sec	yes	~ 1 m	Large dimensions. Uniform substance of high density. Short life of bubble nuclei (~ 1 msec).	Not yet triggerable by counters.
Spark chamber	~ 10^{-6} sec	"yes"	~ 1 m	Large dimensions. High density. Simple. Triggerable by counters.	Tracks invisible inside plates. Limited spatial resolution.
Nuclear emulsion	-	yes	~ 0.5 mm	Precision measurements. High spatial resolution.	Complex composition. Small field of view. No time resolution.

*) 5 to 10 sec possible with supercompression.

**) Density of hydrogen gas: 0.09 g/litre. Density of liquid hydrogen: 59 g/litre.