REPORT OF THE QUARK SEARCH EXPERIMENT WA44

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REFERENCES
1. INTRODUCTION

1.1 A short introduction of the new particle, quark

On examining a material, several structures can be seen depending on the device with which you are looking (fig. 1).

The elementary particles, discovered by 1932, are sufficient to explain the structure of the nucleons and electrons contained by the atom (table 1)[1]. They are also sufficient for explaining the whole world; none of the other particles, which are discovered later, are useful for this.

The experiments carried out with the big accelerators showed two new kinds of interactions, the weak and the strong, so there are now four kinds of known interactions, three kinds of which make it possible to classify the particles.

(a) Strong interaction

"Strong" means that the probability of interaction is high. The life time of a particle, which can decay strongly (according to the selection of the quantum mechanics only) is about $10^{-23} - 10^{-22}$ s. Only hadrons belong to this group of particles. The strong force controls the nucleon and its stability.

b) Electromagnetic interaction

All particles with an electric charge and the photon belong to this kind of interaction. The life time of a particle, which decays in this interaction is $10^{-16}$ s. The electromagnetic force keeps the electron on its orbit around the nucleon.

(c) Weak interaction

The life time of particles, which decay weakly, is $10^{-13} - 10^{-8}$ s. Leptons also belong to the particles having this interaction, which gives an explanation of the radioactivity.

(d) Gravitational interaction

No gravitons have been seen until now.

The big accelerators showed not only the manifestation of these new interactions, but also many new particles like the strange particles and
a lot of other hadrons. Due to this big increase of hadrons a new theory arose, which states that all hadrons are built up by other, smaller particles, called quarks. Originally three, later four, kinds of quarks were assumed, as listed in table 2 [1]. This theory assumes that the proton consists of three quarks (uud) and also the neutron (udd). In fact, all baryons are built up by three quarks; mesons consist of a quark and antiquark. Today, the table of elementary particles is different (table 3).

The following report describes the set up and the tests of an experiment searching for quarks. The streamer chamber is a detector, which can show the existence of free quarks, which until now have proved to be a useful mathematical model, although a free quark has never been detected. The fractional charge of the quark (1/3 or 2/3) makes it possible to distinguish the particles, due to the lower primary ionization compared to a unit charge particle. The massless neutrino with its high energy may be able to break the proton and produce free quarks.

1.2 Streamers

If a charged particle passes through a gas, it will produce a number of primary electron-ion pairs ($t_1$) depending on its velocity, the kind of the gas and its charge. If a high electric field is applied, the electron will be accelerated and each will produce an avalanche of electrons and ions ($t_2$). In fig. 2 [2] the whole development is presented. The avalanche grows exponentially with the time and a space charge develops due to the different mobility of electrons and ions ($t_3$). After reaching a certain size, it begins to emit photons ($t_4$). The size increases very much and the avalanche develops into a streamer, where the secondary avalanches, created by secondary electrons, are grown together with the primary avalanches ($t_5$). Due to this, a plasma channel is formed in the direction of the two electrodes and this grows further until it connects both electrodes ($t_6$). But this is not obtained in a streamer chamber. The two modes, the streamer and the avalanche mode, in which the chamber can be run, are characterized in stage c and d for the avalanche and e and f for the streamer. Hence, each primary electron creates one
avalanche, which may turn into a streamer, therefore by knowing the number of avalanches (streamers) one is able to measure the primary ionization. By knowing the primary ionization per unit length one can determine the charge of the particle which passed through the gas. The aim of the experiment therefore is to determine the kind of particle with the number of avalanches produced.

1.3 Experiment WA44

Fig. 3 [3] shows the experimental apparatus of WA44 in top and side view. The neutrino beam enters from the left, passing through a lead target with scintillators which register the position of the event. $S_1$ and $S_2$ are also scintillators, at the front and back of a big magnet, to trigger the apparatus. Behind the Streamer Chamber (SC) and Wire Chambers (WC) more scintillators are mounted. These permit the detection and reconstruction in space of the event and particle track.

Fig. 4 illustrates a schematic presentation of the streamer chamber and the optical part. In the big experiment three cameras are used, two with a 105 mm objective and one with a 50 mm objective. Fig. 5 presents the view of the chamber with these three cameras. For the reconstruction of the track in space, two cameras are necessary; the better resolution photographs are for more accurate primary ionization measurements.

The report describes the optical part of the experiment, the problems associated with finding the right film and its subsequent development, the right gas mixture and the influences of the devices on the reconstruction of the number of primary electrons. During the time of my stay the big experiment was in preparation. For the previous tests, a small chamber of size $350 \times 500 \times 200$ mm was used with cosmic rays. Unfortunately, as some parts of this small system had to be dismantled for the big experiment, it was not possible to continue all the tests until the construction of the big streamer chamber itself had been completed.
2. EXPERIMENT AND OUR WORK

2.1 Introduction of the experiment parameters

To obtain the real number of avalanches is the most important problem of this experiment and this depends on a lot of different parameters, for example:

(a) kind of gas and gas mixture,
(b) high voltage pulse,
(c) delay - time,
(d) resolution of the optics,
(e) resolution of the intensifier,
(f) resolution of the film,
(g) development of the film,
(h) pressure of the gas.

All these parameters required testing, a description of which is outlined in the following sections.

2.1.1 Chamber

The small chamber is $350 \times 550 \times 220$ mm. It has two parts: an inner section filled with the gas and a body filled with freon. It can be used between 0 and 2 atm, compared with the big chamber which is $2350 \times 1250 \times 600$ mm and can only be used at atmospheric pressure. Fig. 6 [4] shows the principle build up of the small chamber. In the middle of the chamber there is the wire mesh on which the high voltage is applied (fig. 7). It lies between two other wire meshes with earth potential. In order to avoid a pulse reflection, resistances have been installed at one side of the chamber. In practice, the main pulse looks different from fig. 7. It is preceded by a small positive pulse which causes the electrons near the mesh to be attracted to it and this is seen as a gap on the tracks crossing the mesh.

2.1.2 Marx generator and Blumlein line

The Marx generator is the device which produces the high voltage pulse from a continuous DC supply. It is built up in ten stages as shown
in fig. 8 [4]. The working principle is as follows: the main parts are capacitances and spark gaps. Firstly, the capacitors are charged in parallel via resistors. Each capacitor has on one side the potential $U_E$ and on the other zero. When the spark gaps fire, the capacitors are in series and all potentials are added. Fig. 9 shows three possible methods of how the circuit of capacitors and spark gaps can be made. In the first a pulse with the sign opposite to that of the applied voltage is produced, compared with the second, where the pulse has the same sign. In the third there is a pulse with a positive and negative part. Also, twice as many capacitances as spark gaps are necessary. But the pulse which is produced by the Marx generator does not have short enough rise and fall times and this makes it necessary to use a Blumlein line to improve it. Fig. 10 shows pulses made with a polaroid camera and the difference between the ideal and the real pulse. In fig. 11 [5] the Blumlein circuit is described.

2.1.3 **Image Intensifier**

The use of an image intensifier allows the chamber to work in the avalanche mode. In the avalanche mode the light of each avalanche is not so bright and the size is much smaller than in the streamer mode. Therefore, one obtains a better resolution of the individual dots. The following description shows how the image intensifier, which is used to increase the light, functions (fig. 12). The photons of the image in the chamber go on to a photocathode, which emits a number of electrons proportional to the number of photons. These electrons are accelerated by a high voltage of 40 kV and are focused on to a phosphor screen by a magnetic or an electrostatic field. The phosphor screen then emits photons which fall on to another photocathode. In this case a four-stage intensifier with a magnetic focus is used, resulting in a gain of $10^6$.

2.1.4 **Optics**

In front of the image intensifier an objective ($OB_1$) is used to focus the image on to the photocathode. It has a focal distance of 50 mm or 105 mm, which gives a demagnification factor of 50 or 23 in this case.
Behind the image intensifier there is a transfer lens (OB₂), with a demagnification of 1, used to focus the image coming from the intensifier on to the film (fig. 13). By photographing a test pattern (fig. 14), a limiting resolution better than 25 lp/mm and 2 mm respectively, in the chamber for the 50 mm objective. The resolution of the 105 mm objective is twice as great, this is 1 mm in space. The influence of this on the track is shown in fig. 15 [6].

2.1.5 Adjustment

First the image has to be focused on to the phosphor screen of the intensifier by using the test pattern shown in fig. 14. A microscope is necessary to look at the image on the phosphor screen as it is too small to perform the adjustment by eye. It has to be done in two steps; firstly, the focus of the objective OB₁ must be adjusted and followed by the overall focus and the focus of each individual stage of the intensifier. The last is possible with four voltage dividers, one for each stage, which are adjusted to obtain the best image. Given the conditions of the small chamber, it was possible to see the seventh (i.e. the last) of the test patterns using the 105 mm objective and the fourth using the 50 mm objective on the intensifier output phosphor. The range of resolution and the large demagnification factor of about 50 make it very difficult to adjust correctly with the 50 mm objective. When this is done, the image has to be focused on the film. For this, the intensifier is fixed on to a mounting which is adjustable with the aid of a micrometer. By looking through a scoopenet the intensifier can be moved until the image is focused on the film. The scoopenet is a microscope, which is focused on the fibre optic plate (fig. 16). The distance between the mirror and the fibre optic plate has to be the same as between the mirror and the film, so that the image of the intensifier is focused on both the fibre optic plate and on the film. This completes the preparation of the optical system.
2.2 Different parameters of the experiment and their tests

2.2.1 Influence of the chamber conditions

The expression \( E^3 \cdot \tau/p^2 \), where \( E \) is the electric field, \( \tau \) the pulse length and \( p \) the gas pressure, determines the average avalanche size and is thus an important parameter, which can be used to describe the chamber conditions. It demonstrates that one can obtain big and bright avalanches either by increasing \( E \) and \( \tau \) or by decreasing \( p \). Therefore, one is able to alter the size and appearance of the avalanches by varying one of these three parameters, all of which have to be adjusted in this way in order to achieve a track with round and well separated dots on the film. If the electric field is too low, the avalanches are too small and are seen as a weak track which can also be caused by too short a pulse length or too high a gas pressure. Fig. 17 illustrates an example of weak, good and strong tracks.

2.2.2 Delay-time

The delay-time is the time between the passage of the particle causing the primary ionization and the high voltage pulse. The primary electrons may have in themselves sufficient energy to create secondary electron-ion pairs. After the passage of the ionizing particle, the electrons begin to diffuse and have the ability to recombine. By recombination one loses electrons, which results in a broader track with less avalanches. Fig. 18 [6] shows the influence of the delay-time directly on the track, where it is clearly seen that the track with the longer delay-time contains far less avalanches. It can also be seen that the diffusion in Ne is much higher than in He. The diffusion of the electrons in two dimensions follows a Gaussian law

\[
\frac{dN}{N} = \frac{1}{\sqrt{4\pi Dt}} \cdot e^{-x^2/4Dt} \cdot dx,
\]

where \( dN/N \) is a fraction of charges in the element \( dx \) of the distance \( x \) from the origin after the time \( t \); \( D \) is the diffusion coefficient for electrons in the gas.
This expression has the standard deviation \( \sigma = \sqrt{4 \cdot D \cdot t} \). Figs 19 and 20 [6] show the different rate of diffusion in He and Ne allowing D to be measured from the slopes of the plots. Figs 21 and 22 [6] describe the memory of the gases He and Ne. The memory of a gas relates information concerning the recombination, i.e. how long a track can exist in the gas without applying a high voltage. The figures show an exponential decrease of avalanches with increasing delay-time. These figures represent the same data in a graph which are illustrated on the tracks in fig. 18 [6]. The first increase of points is caused by the resolution of the optical system which does not allow the resolution of individual avalanches for a small delay-time.

2.2.3 Influence of the gas mixture

Each of the gases has a different coefficient for primary ionization per unit length (table 4).

Pure gases like He and Ne and also mixtures of them have been examined. Ne has a higher primary ionization, about 11.4 ion pairs/cm, compared with He, which has a primary ionization of 3.5 ion pairs/cm. Due to this, the dots are clustered and irregular, which complicates the counting of the dots. The average number of dots per 35 cm tracks is approximately 80 with a demagnification of 50. Fig 23 [6] shows the different size and shape of 100% He, He-Ne mixtures and 100% Ne. 100% Ne has several round dots, which are simple to both resolve and count. Their size corresponds to between 1 mm and 2 mm in space. Due to the lower primary ionization the average number per track is also lower. It is approximately 50 on a 35 cm track with a demagnification of 50. Hence, one can assume that each dot represents an individual avalanche and thus, also one or more primary electrons. The aim is now to get the maximum number of resolved dots representing individual avalanches with a limiting resolution of 2 mm in the chamber. Therefore, some tests with the following mixtures were performed:

- 100% He,
- 10% Ne - 90% He,
23% Ne - 77% He
- 35% Ne - 65% He
- 50% Ne - 50% He
- 70% Ne - 30% He
- 100% Ne.

The result was surprising, as a curve was expected where the number of points per unit length would be limited by the resolution, so that in effect the curve would become flat. However, a curve as shown in fig. 24 was obtained.

2.2.4 Test pattern

Fig. 25 shows another test pattern which is produced by the firm Dr. Johannes Heidenheim in Treunreut. The horizontal and vertical bars make it possible to see any influence of astigmatism of an optical system. Its size is 101.6 × 82.6 × 2 mm. It is made of glass and covered with an opaque reflecting layer, so that only the bars are transparent. In order to find the limiting resolution of an optical system one has to look for the bars which are just resolved. This expression gives the resolution in lp/mm.

\[ R = 2^x + \frac{y-1}{6} \cdot M, \]

where x and y are the measured values of the bars and M the demagnification factor

\[ M \approx \frac{\text{object distance}}{\text{focal length}} \]

This expression has some physical basis, but it is only relevant for this kind of test pattern.

2.2.5 Test of the objectives

To compare the resolution in lp/mm of the objectives which are used, the following test was done. The distance of the test pattern and the objective of approximately 3 m corresponds to the conditions of the experiment. The complete system is shown in fig. 26. The test pattern previously described
was focused on to the fibre optic plate by moving the objective along the optical axis. The limiting resolution was found with a microscope looking on to the fibre optic plate. In order to measure the resolution of the lens over the whole field of view, the test pattern was moved sideways up to 100 cm perpendicular to the optical axis. But the measured resolution was limited by the fibre optic plate due to the 5 μm diameter of each fibre. In order to avoid the resolution being limited by the eye, it was necessary to increase the magnification of the microscope to times 120. To focus the image without using the fibre optic plate does not offer a solution to this problem, because the image surface of the objective is not flat, but curved. Due to the chromatic aberration of the objective there exist different image surfaces depending on the wavelength (fig. 26). The image surface of the blue light is much more curved than that of the red light, because of the higher diffraction of blue light. Without using a flat screen one would focus the microscope on the curved image surface, which would distort the result, therefore, the fibre optic plate was used. The influence of this curved image surface is clearly seen in the test of the 50 mm objective with blue light. To obtain the blue light, an interference filter was put in front of the objective. On the optical axis the resolution for the blue light was much higher than that of the white light. The rapid decrease of resolution which occured as the test pattern was moved away from the optical axis, is caused by the curved image surface of blue light, resulting in the distance between the focused image and the fibre optic plate increasing. The measurements presented in fig. 27 show that the 105 mm objective has a higher resolution over all the field of view than the 50 mm objective. But the 105 mm objective gives a much smaller demagnification and hence field of view than the 50 mm objective. This test also shows the good and constant resolution of the 80 mm "Componar" which it was first planned to use in the big experiment, but it was subsequently dropped due to its higher demagnification than the 105 mm objective.
2.2.6 **Film test**

Four main criteria determine the use of the right film:

(a) The resolution should be higher than the rest of the optical system, which is restricted by the intensifier to 35 lp/mm (limiting resolution).

(b) The sensitivity should be between wavelength 400-500 nm, which is the wavelength of the light emitted by the P11 phosphor of the intensifier.

(c) A speed of approximately 400 ASA is necessary because of the low light level and the short duration of the track.

(d) Halo protection is also necessary because a halo is caused by the scattering of light through the phosphor of the intensifier and the back scattering of electrons.

Kodak SO 121 proved to be a suitable film with these properties, but because it is no longer available, a replacement had to be found. Two sizes of film have been tested, 50 mm unperforated as is used for the experiment and 35 mm perforated. Due to these different formats it was necessary to find the right apparatus for the tests.

For the 50 mm unperforated films, it was possible to use the apparatus of the experiment carried out with the small chamber. The intensifier was replaced with a box containing the test pattern and a pocket lamp. To simulate the blue light emitted by the phosphor, an interference filter was put between the test pattern and the pocket lamp. The shutter was mounted in front of the box. For the largest depth of field, the aperture of the transfer lens was put on F8. The box was situated on the support of the intensifier, so that it was possible to move it with the micrometer for focusing (fig. 28). The distance between the test pattern and the transfer lens was the same as between the phosphor of the intensifier and the transfer lens.

It was necessary to find the resolution as a function of the light brightness, so a test was realized as follows. The film was exposed
with times between 1/30 s and 32 s, always doubling the time. Three photographs were taken each time. All films were developed with a gradient of approximately 1.2 except the Kodak 5721, where a maximum gradient of 0.8 was possible and the 39D65 with a gradient of 2.98. The results of these tests are shown in fig. 29 [6] and fig. 30, where SO 121 can be seen to be the best. A montage of polaroid photos made with a microscope shows the best exposure and an overexposure in fig. 31 [6]. These photographs show something about the grain size and the resolution. The disadvantage of this test was the pocket lamp which always provided the same light conditions. This was the reason that the SO 121 was tested again in order to obtain a comparison.

For the test with the 35 mm perforated films a regulated light source was chosen. The test of these films presented some problems, because it was not possible to use the 50 mm camera due to the film size. This problem was solved by using a single lens reflex camera, where it was possible to remove the objective. Therefore, this camera was used to fix and to transport the film. With the transfer lens an image of magnification 1 was obtained on the film. The greatest depth of field was again obtained with the transfer lens to F8. Fig. 32 shows the apparatus for this test. The other films tested presented different problems, namely the size, which had to be cut down to 50 mm or 35 mm. This was possible with a special cutting machine. The results of this test are shown in fig. 33.

The last film test with two 3M films, SX-502 and GS4, and the Agfa RP1S showed that the γ is not a good criterion for the development. In this case all films were underdeveloped, which gave a wrong impression of the speed. To ensure that the development was correct, the test was repeated and the films developed by hand at 19°C for 3 min; this gave a better result. In order to find the speed, a series of photographs was taken of the output phosphor of the intensifier. This showed that the GS4 is faster than the RP1S, which was just the opposite result than that of the test with the filter. Thus, the filter has a different spectral content than the phosphor of the intensifier. So it is important to test
the films with the wavelength produced by the intensifier which is used in the experiment.

With this kind of film test it is possible only to find out the resolution and the relative speed. In comparison to the SO 121, which turned out to be good for the experiment, it can only be said that a film is similar in resolution and speed, but it is difficult to say anything about the suitability of the film for photographing streamers. The best method would be to test the film with photographs of the chamber and with the test pattern, because it is impossible to reproduce the light conditions with a test pattern.

2.2.7 Test of the image intensifier

The resolution of the experiment is restricted by the intensifier, which has a limiting resolution of 35 lp/mm. A halo is caused by the back diffusion of the electrons and the scattering of the light by the grain of the phosphor. When the electrons, possessing a high energy, hit the phosphor, they can produce not only photons but also secondary electrons. The secondary electrons, under the influence of the electric field, produce photons themselves. This process is often called back scattering of electrons (fig. 34). The diameter $d$ of the halo from the back scattered electrons is given by the following expression:

$$d = 2 \frac{V}{E} \sin \theta$$

$V$: energy of the electrons,  
$E$: value of the electric field.

Resolution test

The resolution has to be tested on all three intensifiers used in the experiment. The image of the test pattern on the phosphor is directly viewed with the microscope. The distance between the objective and the test pattern gives a demagnification of

$$\frac{2670 \text{ mm}}{80 \text{ mm}} \approx 33.$$  

The value 0/1 of the test pattern was seen on the phosphor and this corresponds to a resolution of 35 lp/mm on the phosphor. The resolution
was also measured for different apertures of the objective and several light brightnesses (fig. 35).

3. CONCLUSIONS

The results of the tests show the streamer chamber, now referred to as the avalanche chamber, combined with the optical system as a useful detector for photographing particle tracks. The quality of the tracks is now limited by the overall resolution of the optical system. This can be improved by using an electronographic camera, which makes the use of the image intensifier and the transfer lens unnecessary, because the special film is directly sensitive to electrons.

The work here gave me an impression, of how to prepare an experiment, testing devices and collating all results in order to obtain maximum efficiency for the experiment. I also realized the great importance of communicating with all those participating in the experiment in order to achieve good and effective work.

Acknowledgements

I thank all members of the group for the nice and friendly integration, specially Paul Lecoq and Christie Marrian, who spent a lot of time to give me an understanding of the whole experiment.
REFERENCES


**Crystal**  **Atom**  **Nucleon**  **Hadron**

- Ions  - Nucleon  - Protons  - Quarks
- Electrons  - Neutrons

**Microscope**  **Van de Graaff Generator**  **Accelerators**

Fig. 1

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass (MeV)</th>
<th>Mean life (s)</th>
<th>Spin</th>
<th>Q</th>
<th>B</th>
<th>E</th>
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Q: electric charge  
B: baryon number  
E: electron number  

Table 1
<table>
<thead>
<tr>
<th>Particle</th>
<th>Spin</th>
<th>Q</th>
<th>B</th>
<th>E</th>
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Q: electric charge  
B: baryon number  
S: strangeness  
C: charm

\textbf{table 2}

\textbf{particle families}

\begin{align*}
(e) & \quad (\mu) & \quad (\tau) \\
(V_e) & \quad (V_\mu) & \quad (V_\tau) \\
(U) & \quad (C) & \quad (t') \\
(d') & \quad (s') & \quad (b') \\
1 & \quad 2 & \quad 3
\end{align*}

quantum of radiation

\begin{align*}
\text{photon} & \\
\text{family 3 is only assumed until now}
\end{align*}

\textbf{table 3}
Discharge mechanism in a streamer as a function of time

fig. 2
17. Transmission Line and $C_E$, $C_{E2}$ capacitative dividers support (Ground part)
18. Transmission Line (HV part)
19. Central plane coronas
20. Central plane of the streamer chamber
21. Chamber cells (plexiglass)
22. Chamber ground electrode
23. Matching resistors
24. Scintillato, Light guide
25. Outgassing tank for the Blumlein oil (SHELL DIALA C)
26. Expansion reservoir (SHELL DIALA C)

fig. 6

\[ u(t) \]

\[ t \]

ideal voltage pulse

fig. 7
Fig. 8  2MV. Marx power supply - Schematic diagram

1. Oil tank
2. Capacitors Cogeco, 100 kV, 10 nf
3. Plexiglas Marx tube, 20cm diameter
4. $N_2$ pressurized gas -1 to +2 atm.
5. Charging 4k$\Omega$ Carbon resistors
6. Ground discharge Carbon resistors
7. Stainless steel spark gaps, 10mm gap
8. Output self inductance $L_5 + 26\mu H$
9. Trigger system
10. $\odot$ 20 kV Triggering pulse input
11. $\odot$ and $\odot$ D.C. charging voltage
12. Spark gap to condensor connection
photo of a pulse made with a polaroid camera

**Ideal pulse**

\[ u(t) \]

**Real pulse**

\[ u(t) \]

\[ \text{rise time} \]

\[ \text{decay time} \]

\[ T : \text{pulse width} \]

**Ideal Blumlein line**

\[ k \rightarrow t \rightarrow k \]

\[ V_0 \]

\[ Z_0 \]

\[ Z_0 \]

\[ u_0(t) \]

**Real network**

\[ L_0 \]

\[ S_4 \]

\[ C_4 \]

\[ C_3 \]

\[ C_0 \]

\[ V_0 \]

\[ C_2 \]

\[ T \]

\[ \text{Marx Blumlein Chamber} \]

**fig. 10**

**fig. 11**
schematic presentation of two stages

fig. 12

fig. 13
TRACKS IN HELIUM

x 50 Photo

x 23 Photo

5cm in chamber (both photos)

fig.15
scoponet

fig. 16
weak

good

strong

fig. 17
x 23 TRACKS IN HELIUM WITH TIME DELAY

minimum delay, 1 μsec

7 μsec

35 μsec

55 μs

5 cm in chamber
x23 TRACKS IN NEON WITH TIME DELAY

minimum delay, 1 $\mu$sec

2 $\mu$sec

8 $\mu$sec

15 $\mu$sec
DIFFUSION OF ELECTRONS IN NEON

\[ D_{\text{Ne}}^e = 2200 \pm 150 \text{ cm}^2 \text{ sec}^{-1} \]

fig. 19

DIFFUSION OF ELECTRONS IN HELIUM

\[ D_{\text{He}}^e = 330 \pm 20 \text{ cm}^2 \text{ sec}^{-1} \]

fig. 20
MEMORY WITH NEON IN THE CHAMBER

\[ t_m = 6 \pm 0.5 \mu \text{sec} \]

MEMORY WITH HELIUM IN THE CHAMBER

\[ t_m = 34 \pm 3 \mu \text{sec} \]
<table>
<thead>
<tr>
<th>Gas</th>
<th>electron-ionpairs/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen H₂</td>
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</tr>
<tr>
<td>Helium He</td>
<td>3.5</td>
</tr>
<tr>
<td>Nitrogen N₂</td>
<td>27.1</td>
</tr>
<tr>
<td>Oxygen O₂</td>
<td>28.9</td>
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<tr>
<td>Neon Ne</td>
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<td>Argon Ar</td>
<td>25.8</td>
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<tr>
<td>Xenon xe</td>
<td>49.6</td>
</tr>
</tbody>
</table>

table 4
x23 Tracks in Various Helium Neon Mixtures

100% Helium

10% Neon

23% Neon

35% Neon

2.3 cm in chamber
50% NEON

70% NEON

100% NEON

2.3 cm in chamber
<table>
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<tr>
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<td>8,00</td>
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fig. 25
\[ R_{ep/mm} = 2 \times \frac{r}{d} \times 14 \]

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<th>Objective</th>
<th>Distance Object</th>
<th>Distance Ob</th>
<th>Resolution</th>
<th>Magnification</th>
<th>Resolution</th>
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</table>

![Graph](image-url)
FILM TESTS

Limiting resolution [p per mm

Exposure at F8 sec

fig. 29

Kodak 2479
SO 265
SO 121
3M 911
Agfa Avi phot. pân 30
Kodak 5721
H - Appearance of halo
FILM TESTS

Kodak 5721
1/4 S

Kodak 5721
1 S

Kodak SO 265
1/4 S

Kodak SO 265
1 S

Kodak SO 121
1/15 S

Kodak SO 121
1/4 S

Kodak 2479
1/8 S

Kodak 2479
1/2 S

3M 911
1/4 S

3M 911
1 S

Agfa. Avi. phot.
1/2 S

Agfa. Avi. phot.
2 S
**fig. 34**

**fig. 35**