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APPARATUS FOR DETECTING STABLE FRACTIONAL CHARGES ON MATTER

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APPARATUS FOR DETECTING STABLE FRACTIONAL CHARGES ON MATTER

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We describe the fabrication, operation, and data analysis procedures for an apparatus using a new technique to search for stable fractional charges on matter. Our technique depends upon forming a highly uniform stream of liquid droplets using classical liquid-jet techniques. From sample data, we achieve charge resolution of 0.04e.

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INTRODUCTION

It is well-known that liquid droplets may be formed at high rates by acoustically modulating the pressure in a streaming jet of the liquid.[1] A carefully constructed nozzle to emit this jet, together with accurately maintained parameters on the fluid, allows production of a stream of droplets which are uniform in mass, equal in speed, and highly parallel.[2,3] By properly influencing the electrical potential at the point of the jet where the droplets become separated, the electrical charges may be set as desired for each individual droplet.[4]

In the absence of applied electric fields, each droplet would continue to fly along very nearly the same straight trajectory regardless of its electrical charge. If a static electrical field is maintained perpendicular to the unperturbed trajectory, the droplets with various distinct charges will follow separate paths in the plane defined by the unperturbed trajectory and the electric field vector. The net deflection is approximately qV_oL^2/mv^2b, where q is the charge on the droplet, V_o is the potential between the deflecting electrodes, L is a measure of the length of the deflecting electrodes, m is the mass of the droplet, v characterizes the velocity of the droplet, and b characterizes the separation between the deflecting electrodes. If the ratio V_oL^2/mv^2b is large enough, droplets having different numbers of elementary charges will have easily distinguishable trajectories. If fractionally charged particles exist and are present on some of the droplets being produced, they will follow trajectories lying between the integer charge droplet trajectories. Techniques similar to ours have been independently proposed by previous workers; however, no practical resolution of charges has been reported.[5]

In an earlier unpublished report,[6] we outlined the necessary operating parameters which are required to build an apparatus using this technology to search for fractionally charged particles on stable matter. Our original design suggested a charge resolution of 0.02e with 0.8 mm separation between adjacent integral charges and a mass flow rate of 5 x 10^{-5} gm/sec. In this paper, we describe the construction of such an apparatus and its initial performance. This apparatus is a prototype for more sophisticated instruments that are currently under construction.

DESCRIPTION OF APPARATUS

An overall schematic of the instrument is shown in Fig. 1. The crucial subsystems are the droplet production device, the droplet charging, aiming and sorting device, the deflecting region, the data-taking window, the electronic position encoding apparatus, the data-logging apparatus, and the off-line data analysis. Each of these subsystems will be described below.

The droplets are produced via a classical method that depends upon expelling a jet of liquid through a circular orifice. Because of the surface tension of the liquid, the resulting jet of liquid is unstable against the growth of capillary waves (corrugations that are imposed upon the surface of the stream in the direction that breaks the initial cylindrical symmetry of the stream). The corrugations grow in amplitude until the stream necks off into separated droplets. We drive this instability with a periodic perturbation applied to the driving pressure. This process is illustrated schematically in Fig. 2. The droplet pattern that emerges need not always be simple; Fig. 2 also shows a simple pattern in which more than one droplet emerges in each cycle. The larger droplets are known as the "primary" droplets, while the smallest droplet is known as the "satellite" droplet. Theoretical descriptions of the droplet formation process are rather incomplete. The basis of our understanding of the production of primary droplet streams is in the early work of Rayleigh. Modern computational techniques are now starting to open the possibility of predicting properties of the simplest stream configurations which include satellite production.[7]

Our present apparatus has the liquid supported above the orifice in a pressure reservoir. In operation, the liquid is expelled from the orifice by applying gas pressure to the top of the liquid within the reservoir. Commercial nitrogen or argon is used for pressurization. After the correct operating conditions are achieved, the reservoir is valved off to avoid any regulator pressure fluctuations. As the pressure slowly decreases during the emptying of the reservoir, the pressure is occasionally readjusted. Air pockets, trapped during introduction of liquid in the lower reservoir and droplet generator, can cause poor droplet formation. This problem is overcome by evacuating the reservoir prior to filling. Liquid is then bled in from an acrylic prefill tank through a needle valve. The reservoir is made of AISI 412 stainless steel, electron-beam welded to minimize the introduction of particulate contamination into the liquid.

The liquid is forced through a drain in the bottom of the reservoir into the throat of the droplet-generating mechanism. An exploded view of the droplet-generating mechanism is shown in Fig. 3. The piezoelectric crystals are made of commercially available lead-zirconium-titanate, which is machined to fit the apparatus using diamond tools. Electrical contact to the crystals is assured by application of a layer of silver that is thick enough to level out any physical irregularities in the top and bottom surfaces. The liquid enters the top of the throat of the droplet-generating mechanism and is forced through a 0.125-in hole along the axis of the Allen bolt into a lower chamber, which is sealed at its bottom with the orifice plate. The crystals are preloaded by applying a torque of 150-in/lbs to the Allen bolt.

Two differing types of orifice plates were employed: stainless steel foil plates and glass nozzles. The stainless steel plates were punched as discs from 0.005-in sheets. Some care needs to be exercised to select the sheet so that irregularities which are commonly present in thin sheet metal are minimized. The discs are then drilled with a mechanical fluted drill bit virtually identical to a standard twist drill except that the size is rather small. The drill bits are supported by a high-precision drill press.[8] After drilling, the orifice plates are cleaned up along the flat surfaces with several grades of abrasive ending with crocus cloth. The inside of the larger holes are than polished with a spinning brass polishing rod. The final polish is applied via electropolishing in commercial electropolishing fluid at room temperature using low current.

The glass nozzles are made from commercial 3/16-in thin wall Pyrex tubing. The end of the tubing is cut flat using a diamond saw. The tubing is clamped into the chuck of a standard hand-held electric drill driven through a Variac power supply. With the motor running at slow speed, the end of the tube is heated with a glassworking bench torch until the glass flows sufficiently to allow the surface tension of the glass to shrink the end to the desired diameter orifice. Some care is necessary to select glass tubing with a uniform wall thickness. Nonuniformities of the wall cause the hole to be formed off axis. This blunted end of the tube is cut from the rest of the tube with a diamond saw to a length of about 1 cm, and the blunt end is then polished with a standard metallurgy sample polishing wheel. Some care needs to be exercized to assure that the polished face is parallel to the cut end of the nozzle. The polishing is continued until the blunt end of the nozzle is ground down to the level where it intersects the smallest diameter of the contracted tubing, thereby giving the nozzle a right-angular edge. Operation of nozzles with non-right angular edges sometimes causes instabilities, especially with mercury. A filter of several commercial 200-mesh stainless steel screens is installed over the inlet end of the nozzle with epoxy cement. These glass nozzles are fastened into the droplet-generating mechanism with epoxy cement.

The driving signal to the piezoelectric crystals originates in a high-precision, high-stability source (Hewlett-Packard Model 3325A Synthesizer/Function Generator). This signal is boosted by a simple two-transistor, push-pull amplifier operating from a commercial laboratory power supply. It is important to minimize 60 Hz noise on the amplifier output. The bandwidth of the amplifier is about 150 kHz, but its harmonic distortion at frequencies below 10 kHz is very large. This output is stepped up by a home-wound 100:1 ferrite-core transformer and fed to the piezoelectric crystals. Signals of lower frequency are tapped in phase with the oscillator by discriminators with gates and are used to drive the diagnostic stroboscopic lights and the electrical prescaling, when appropriate.

As the stream emerges from the orifice and the droplets break off from the stream, it is necessary to control the electrical charge on the droplets. The liquid is maintained at our dc ground level. The mean value of charge on the droplets is set by influencing the electrical potential in the region where the droplets break away from the grounded stream. This is achieved by placing a voltage on the nearby charging electrode, which is made of an electrodeposited nickel mesh, and which is sufficiently sparse to allow convenient visual observation of the break-off point. The charging electrode essentially surrounds the break-off region to shield stray fields.

The aiming of the stream is accomplished by having the droplet generator connected to the rest of the apparatus via a stainless steel bellows with a system of aiming screws. This assembly can also be translated with respect to the rest of the apparatus by sliding on a vacuum-tight greased rubber gasket.

The droplets will obtain a large electric dipole moment when exposed to the deflecting field which allows charge analysis. We operate the instrument so that droplets are passing through the deflecting electric field in rapid succession. The dipole moments will, therefore, lead to a potentially troublesome interaction force between successive droplets. To reduce this dipole-dipole force to acceptable magnitude, the spacing between successive droplets must be maintained greater than some minimum value. This minimum spacing between successive droplets is greater than the interdroplet spacings that may conveniently be achieved by straightforward operation of the droplet production mechanism. For this reason, we must "prescale" the droplet stream; i.e., we must remove some droplets, increasing the separation between the survivors. This prescaling can be accomplished in two ways: electrical prescaling or satellite operation.

Electrical prescaling requires setting the potential on the charging electrode separately for each droplet produced. We thus set a very high value of the charge on, say, 30 consecutive droplets, followed by one droplet which has its mean charge set as nearly to zero as can be arranged, and repeating this sequence for each droplet to be studied. The highly charged droplets are quickly removed from the droplet stream by the deflecting field, leaving the desired widely spaced droplet stream to be studied.

Satellite operation requires operating the stream in a mode which produces satellite droplets; the satellite droplets are studied after the primary droplets have been removed. Satellite droplets are usually about an order of magnitude smaller in diameter than the primary droplets. Therefore, one produces a stream of sufficiently small droplets from a nozzle an order of magnitude larger than normally necessary. This technique has a twofold advantage: First, the larger diameter nozzle is much less prone to particulate contamination and fluttering (see below). In addition, the satellite droplets are produced sufficiently far apart so that electrical prescaling is not necessary. We achieve satellite production just as repeatedly as primary production under correct operating conditions. Electrical prescaling was abandoned early on, due to the difficulty of using small nozzles. All of our subsequent data was taken with satellites. The intervening primary droplets are removed by intruding a smooth 1 cm sphere or a razor blade barely into the droplet stream. This deflecting object contacts the primary droplets only; the satellite droplets pass by untouched. It has been found that the razor blade, directed upwards at approximately 60°, works best with organic fluids, while a mercury-wetted brass sphere works best with mercury. The deflecting object is positioned by manipulating its mount on a vacuum feedthrough. The deflecting object is held at ground potential inside the charging electrode screen. Figure 2 shows the operation of the deflecting object on a droplet stream.

While operating in the satellite mode, it is essential that the spray from the large droplets being deflected does not fall into the observation region at the end of the tube, causing spurious droplet signals. This is avoided by having the satellite droplets pass through a 2 mm aperture at the end of the charging electrode region. This aperture is at the apex of a stainless steel cone, which directs the spray of large droplets into an annular funnel. This funnel is drained through a tube that leads into a storage container outside the main vacuum chamber. When operated properly, no apparent spray is seen accompanying the satellite stream.

Having passed through the aperture, the stream of droplets to be studied passes through an observation region that surrounds the top ends of the deflecting electrodes. This observation region is a cylindrical hoop of commercial UV absorbing acrylic plastic about 1-in. long. The electrodes are split to have a slot running down their centers so as to allow free exit for any droplets that are so highly charged as otherwise to strike the surface of the electrodes. Each of the four half-electrodes was made from a single strip of commercial ground steel stock 0.125 x 1.0 x 36-in. These steel pieces were rounded on all edges using professional grinding. The electrodes were then dressed with abrasive paper to a smooth finish and plated via a standard commercial process. In plating, the electrodes were wheel-buffed on one flat surface, copper-flashed throughout, plated with "flowing" nickel, plated with "hard" nickel, and finally plated with "decorative" chrome. The electrodes are supported in their sloping configuration by long thin ramps made of commercial gray polyvinyl chloride. These ramps are in turn held rigidly in place relative to one another by machined gray PVC rings. All the supporting rings were trimmed so as to be accurately concentric, defining a cylindrical volume that contains the electrodes.

The electrode assembly slides into the vacuum chamber, supported by pins from the top. The vacuum chamber is made from a 10-ft length of commercial 3-in white PVC pipe. Several observation ports are attached to the body of the tube to allow examination of the droplets along their trajectories. The port windows are made from UV absorbing acrylic. The observation ports themselves are made of gray PVC pipe, fastened to the vacuum chamber by PVC cement. The buildup of static electrical charge on the inside walls of the vacuum chamber is avoided by a coating of graphite throughout the inside. The end-to-end resistance of this graphite layer is less than 10^7 ohms. The effect of static electrical buildup on the windows is minimized by a screen of standard steel mesh.

The vacuum chamber was evacuated in early running by a mechanical roughing pump followed by a sorption pump containing a commercial molecular sieve at liquid nitrogen temperature. Later, a mercury diffusion pump with cold trap was attached to the top of the vacuum chamber with better performance.

After emerging from the deflecting electrode gap, the droplets fall freely through the remainder of the vacuum chamber length to arrive at the data-taking port at the bottom of the apparatus.

Illumination light from a 1W argon laser ion impinges from the left of the data-taking port. The laser beam is condensed to a diameter of 0.5 mm by a standard long-focal-length lens. Other than maintaining approximately normal incidence, no particular effort was made to reduce laser beam scattering and loss while passing through the sides of the data-taking port, except that magnetically controlled wipers were installed inside the data-taking port to allow spattered liquid to be cleaned from the laser beam input and output points.

The heart of the data-taking chain is a 1728 element, linear, optically sensitive, charge coupled device camera (Fairchild Camera and Instrument Corporation, Model CCD 1400 Line Scan Camera Subsystem). This device is a linear array of tiny (0.0005-in square) photo- sensitive sites (buckets), each of which can store an amount of electric charge proportional to the amount of light energy incident upon it over a data-taking period. When the data-taking period is complete, a gate can be opened (start-of-scan signal), allowing the charge in the optically sensitive side of each of the buckets to transfer to an adjacent non-light-sensitive site; each of the 1728 packets of charge is held in a separate such site. This array of non-light-sensitive sites has its boundaries determined by externally imposed electrical potentials. By manipulating these external potentials, the charge packets may be physically shifted to the end of the array where a charge-sensitive amplifier provides a conveniently detectable analog voltage level corresponding to the amount of charge stored in that bucket that has most recently been transferred to the end of the shift-register array. Thus, in the ideal case one can receive 1728 channels of analog information from separate photosensitive sites, all passing through a single amplifier, removing the need for tedious calibration of gains, etc. While the charges from a previous frame are being shifted and read out, the optically sensitive sites remain "live," accumulating charge as light continues to impinge. Our device has two separate shift arrays--one for the even buckets and one for the odd--and these arrays feed into separate amplifiers. Our instrument can be operated at shifting frequencies from 100 kHz to 10 mHz, corresponding to frame-reading rates of about 60 Hz to 6 kHz. The instrument operates in a self-triggering mode, i.e., as soon as one frame of data is completely read, the start-of-scan signal is issued and the charges that have accumulated meanwhile in the optically sensitive sites are immediately transferred to the shift arrays. Thus, the instrument operates with essentially no dead time, providing continuously renewed snapshots of the light intensity incident upon the linear photosensitive arrays.

The CCD photosensitive array views the region of the droplet streams where the laser illumination is the brightest, through a 4X single-lens telescope made from an improvised aluminum extender tube lined on the inside with black felt and a commercial 55mm f/2 camera lens mounted backwards from its customary use on a camera. This telescope has an inconveniently shallow depth of field, so that the laser beam and camera are arranged to move together. Therefore, the camera is always focused on the droplets as long as the droplets are illuminated by the laser. This is accomplished by having the camera and the mirror, which directs the laser into the viewing region, mounted on a table that slides on a linear bearing for positioning.

The start-of-scan signal from the CCD controller defines the bucket number of the analog signal as the 0th bucket. Each cycle of the shifting clock voltage signifies that a new bucket of charge is represented at the analog output. We reset our bucket number register on the start-of-scan, and increment it once for each cycle of the shift clock. A discriminator is triggered from the analog signal; when this discriminator fires, the bucket-number-register is latched and a read command is sent to the Q-bus of our LSI-11/2 computer system. The data are read onto the Q-bus through a standard 16-bit parallel interface board and are read into the memory via a standard driver routine written commercially for the interface board. Once the data word is transferred into the memory of the computer processor, the bucket-number register is cleared and a start-of-scan signal is required to reinstate the data-taking cycle. There will occasionally be a data frame lost when the counter processor is busy and the discriminator fires on one of the highest bucket numbers only. The data words are read into memory until 8192 consecutive words have been read. When the block of data is read, the processor halts data-taking until the entire block of data is stored on the high-speed hard disc. During this writing operation, the data-taking is halted.

In summary, we record the raw data, which corresponds to the position of every bright image in the field of view of the camera in sets of 8192 points. In the pathological event that two bright images were to appear within the same data-taking frame, only the leftmost image is recorded. In particular, let us emphasize that essentially all of the raw data are recorded onto the disc permanently without preselection of any kind.

OPERATION OF APPARATUS

Mercury was initially used as the working fluid in the apparatus. While we were able to produce very high quality mercury streams of large diameter droplets, the droplet streams of low enough mass for sufficient charge separation were not of high enough precision to allow useful data collection. Charge quantization of mercury droplets was seen, but with insufficient resolution. Another problem with mercury was the tendency for the droplet streams often to start jumping with excursions of the order of a few millimeters every few seconds. This effect is possibly a manifestation of the stream instability known as "fluttering." This phenomenon has been identified previously as due to "attached flow" within the orifice,[9] yielding a sort of low Reynold's number turbulence in the jet emerging from an orifice. Whatever the origins of this effect, data taking using mercury was often very erratic and tedious.

Operation with low-vapor-pressure organic fluids was then attempted with much better results. While there are numerous organic fluids which may be utilized, triethylene glycol and tetraethylene glycol were picked for the initial work. The fluids are heated while being pumped under rough vacuum in an Erlenmeyer flask before transfer to the reservoir in order to drive off volatile impurities, principally water. Operation with the organics is almost always stable, with no fluttering problems. The droplet streams will typically drift only a few millimeters in a period of an hour. In addition, the relatively low density eases the requirement of getting very small droplets. Once the system has been evacuated, the fluid is bled from the prefill tank into the main reservoir. About 400 cc of liquid is used. Depending on the size of the orifice, liquid may drip from the orifice under the influence of gravity. When the filling is completed, the reservoir is pressurized so that a suitable stream emerges. The pressure depends strongly on orifice size, but is typically 15–25 psi (absolute pressure) with the most commonly used 100 μm diameter orifices.

Once a stream is obtained, the oscillator is adjusted in amplitude and frequency to obtain a good stream of primary droplets. The stream is then aimed with the bellows and the sliding seal to project through the aperture and down directly between the deflecting electrodes into the viewing window. Once the stream is passing through the apparatus correctly, a good set of satellite droplets is searched for. The satellite droplets must be prepared in such a manner that they are sufficiently small and are sufficiently widely spaced. This involves selecting the signal driving the piezoelectric crystals to produce a complicated pattern of droplets. Figure 2 suggests the sort of patterns that are most productive. Droplet production as complicated as this defies even the most crude theoretical understanding, so that the production of these streams becomes a matter of practice and not a matter of quantitative method. When a suitable small satellite is obtained, the deflecting object is adjusted to remove the larger droplets.

Once a good satellite stream is obtained down at the data-taking window, the stream must be neutralized. This is done by slowly turning up the deflecting field and simultaneously adjusting the charging electrode so that the stream does not move off to the side toward one of the electrodes. When a stably operating, electrically neutralized, prescaled stream is present at the data-taking port, a data file is usually taken to verify quantitatively the performance level. Then the deflecting potential is turned up to a voltage level where the dispersion of the electrical charges on the droplets is evident as a broadening of the stream into a "fan" of different trajectories. The fan is visually examined to verify that it has extension in the direction of the deflecting electric field, and that it has not broadened in the orthogonal direction. If trouble is detected at this phase, some data set may be taken to help identify its source and the signal to the piezoelectric crystals is modified. If the fan is proper, the deflecting voltage is increased to the point where the individual quantized charge streams should become separated. A data file is taken at this point. If the quantization condition is not clearly evident visually, the signal to the piezoelectric crystals is readjusted. Once the quantization condition is clearly apparent visually, data-taking continues without interruption except for the before-mentioned time out to copy the raw data onto the disc.

DATA ANALYSIS

The data are analyzed off-line in blocks of 8192 words. The graphic output of the data-analysis routine in shown in Figs. 4 through 7. The prominent problem in the data analysis is that the quantized streams are not completely steady at the level required for the desired resolution. Figure 4 shows the microscopic drifts of the streams during actual favorable data-taking conditions. Of course, the streams move in unison, but their absolute positions vary by distances corresponding to about 10 percent of the spacing between neighboring streams. The separation between the neighboring streams might also slowly drift: again, of course, in unison. The largest problem requiring attention during data-analysis is to identify the separation between the absolute location of the quantized streams. This must be done before any assignments of apparent charges on the droplets can be made.

The algorithm used in our data-reduction routine relies upon the so-called Fast Fourier Transform technique. First the data block is subdivided into "frames" of data, sets of consecutive data points where we will be able to ignore the drifts in stream locations with negligible loss of information. The usual frame contains 50 consecutive data points. The data points within the frame are histogrammed into any array of 512 bins. Because of this, histogram boundaries do not match the 1728 different possibilities for the individual data points, and counts are "shared" between neighboring bins of the 512 binned histograms, as appropriate. This compressed histogram is next complex-Fourier transformed. The transformed histogram is searched for its largest peak in complex absolute value among the bins away from the first few bins (the bins corresponding to the very largest "wavelengths" convey no information about the positions of the peaks in our "real space" data). The wave number corresponding to the position of this peak on the transformed plot corresponds to the interstream separation. A more precise estimator for the centroid of the peak results from fitting the peak to a quadratic.

This quadratic fit also yields our best estimate for the height of the peak. Our best estimate for the value of the argand of the (complex) transformed plot at its peak is obtained by linear interpolation. The argand value at the point where the Fourier transform achieves its peak provides our best estimate of the displacement of the array peaks. Quantifiable criteria could be used to exclude entire frames of data on the basis of their quality as measured by the height, position, and shape of the peak on the Fourier transformed plot. No such exclusions have yet proved necessary or appropriate. Given our estimates for the interstream separation and the overall displacement of the streams, we can assign an apparent charge to each datum within each frame. This is done by assuming that the centers of the streams each correspond to some integer number of elementary charges and then taking the obvious modulo assignments to force each apparent charge to lie within the range from -0.5e to +0.5e. The progress of our sample data set through each of these stages is illustrated in Figs. 5 through 7.

CONCLUSION

We have successfully demonstrated a new method for measuring the electrical charges on tiny liquid droplets with resolution of 0.04e, sufficient to allow fractional charges to be seen. Although our best performance to date has been achieved with certain organic liquids, we can see no fundamental limitation to the range of substances that can be searched with this method, either by liquifying the substance or dissolving it, or suspending it in some suitable liquid vehicle. Our method allows us to search materials without needing to introduce unquantifiable data-selection at any stage in the analysis. Our method is self-calibrating in the sense that we run hundreds of droplets through the same measurement procedure in a time-scale that is short compared with the time over which the apparatus may be expected to change. We believe that our technique should allow great improvement over the previously available techniques to search stable matter.

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FIGURE CAPTIONS

Fig. 1 Schematic diagram of apparatus.

Fig. 2 Schematic stroboscopic view of typical droplet stream with satellite droplets showing operation of deflecting sphere.

Fig. 3 Exploded view of droplet generator.

Fig. 4 A short segment of sample data. The abscissa is the droplet number and the ordinate is the CCD bucket number. Some charge changing event can be seen. The difference in intensity of different streams is due partly to the charge distribution and partly to an illumination artifact.

Fig. 5 Amplitude of Fourier transform as a function of time. The data are divided into "frames," each consisting of 200 droplets in time sequence. Each of these frames has its deflection measurement histogrammed and the histogram Fourier transformed. Plotted is the height of the largest peak on each of these Fourier transforms. Non-ideal operation of the instrument is indicated by the discontinuity appearing near frame number 20. The frames corresponding to the three obviously low points on this plot were excluded from the data analysis. Perfectly narrow and uniformly spaced droplet streams would lead to a value of 200 for the heights of the Fourier transform peaks.

Fig. 6 Location of Fourier transform peak as a function of time. Plotted is the wave-number of each of the Fourier transform peaks as in Fig. 5. The frame corresponding to the one obviously high point on this plot has already been removed from analysis on the basis of the height of the Fourier transform peak. Perfectly narrow and uniformly spaced droplet streams would lead to the number of streams that would occupy the entire width of the CCD data-taking field-of-view.

Fig. 7 Histogram of apparent charges. When data analysis is completed as outlined in the text, these estimates for the electric charges on the individual droplets result. The abscissa scale of 0 to 100 corresponds to a charge range of -0.5e to +0.5e.

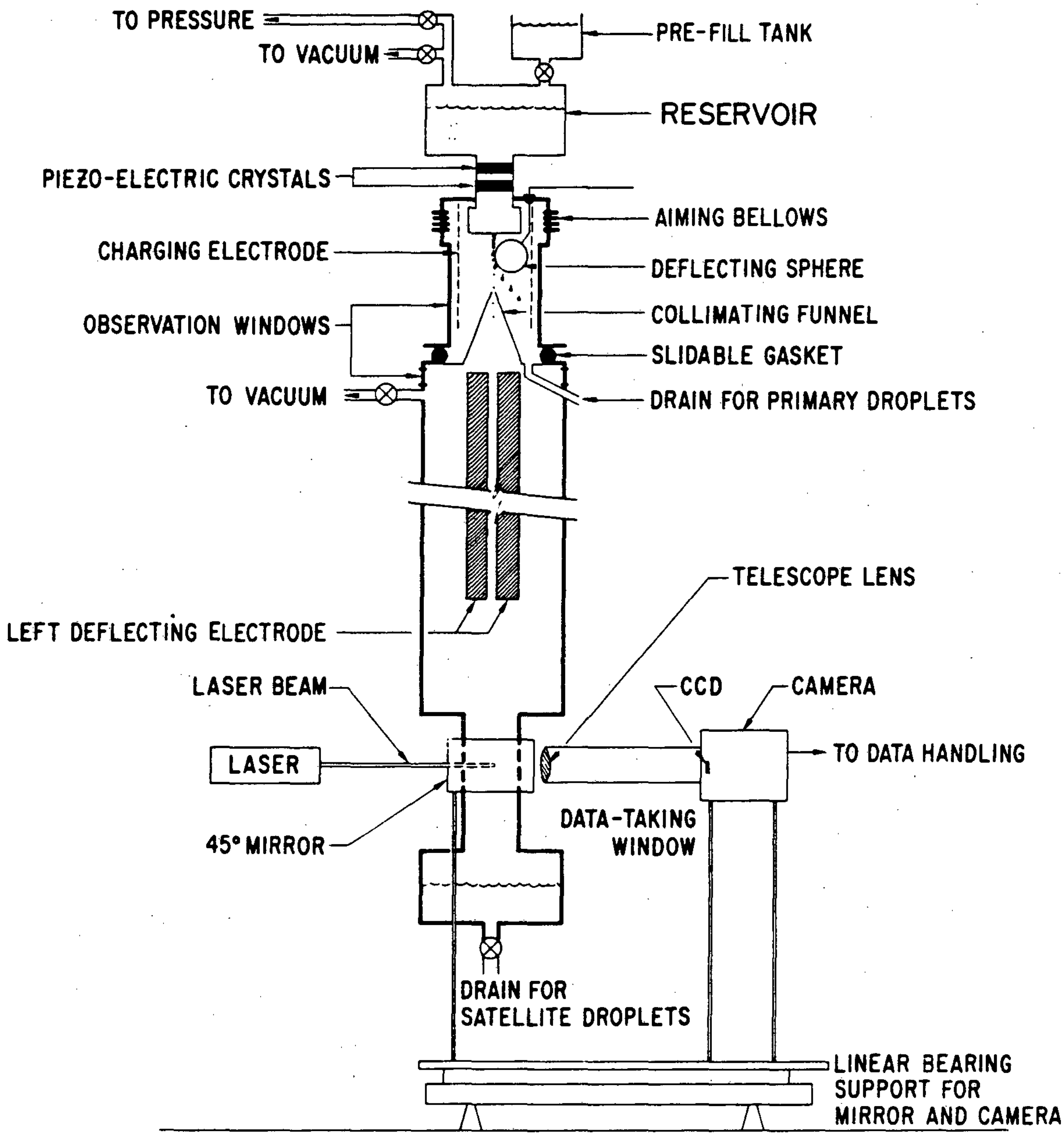

Fig. 1

XBL 824-311

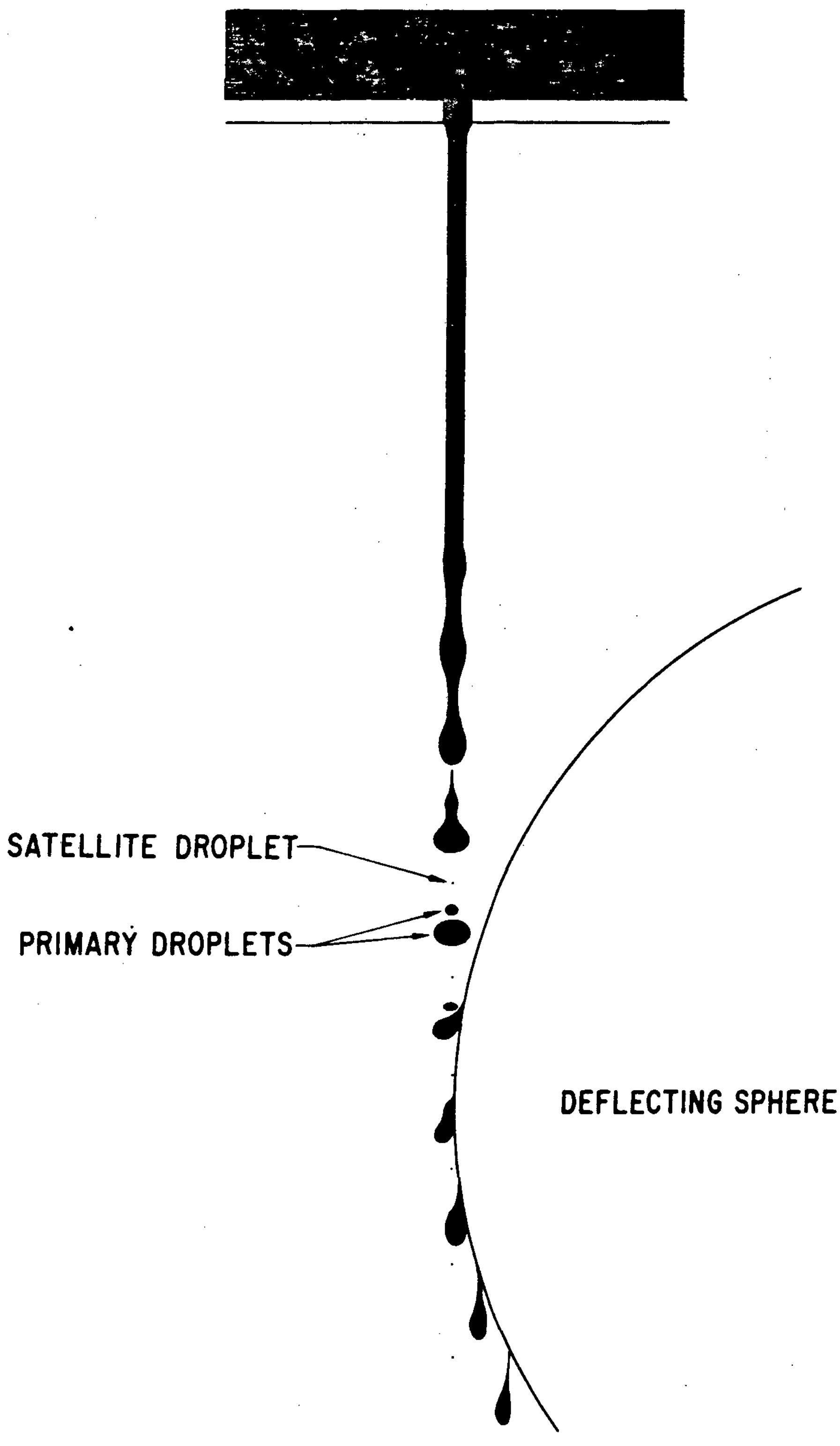

Fig. 2

XBL 824-310

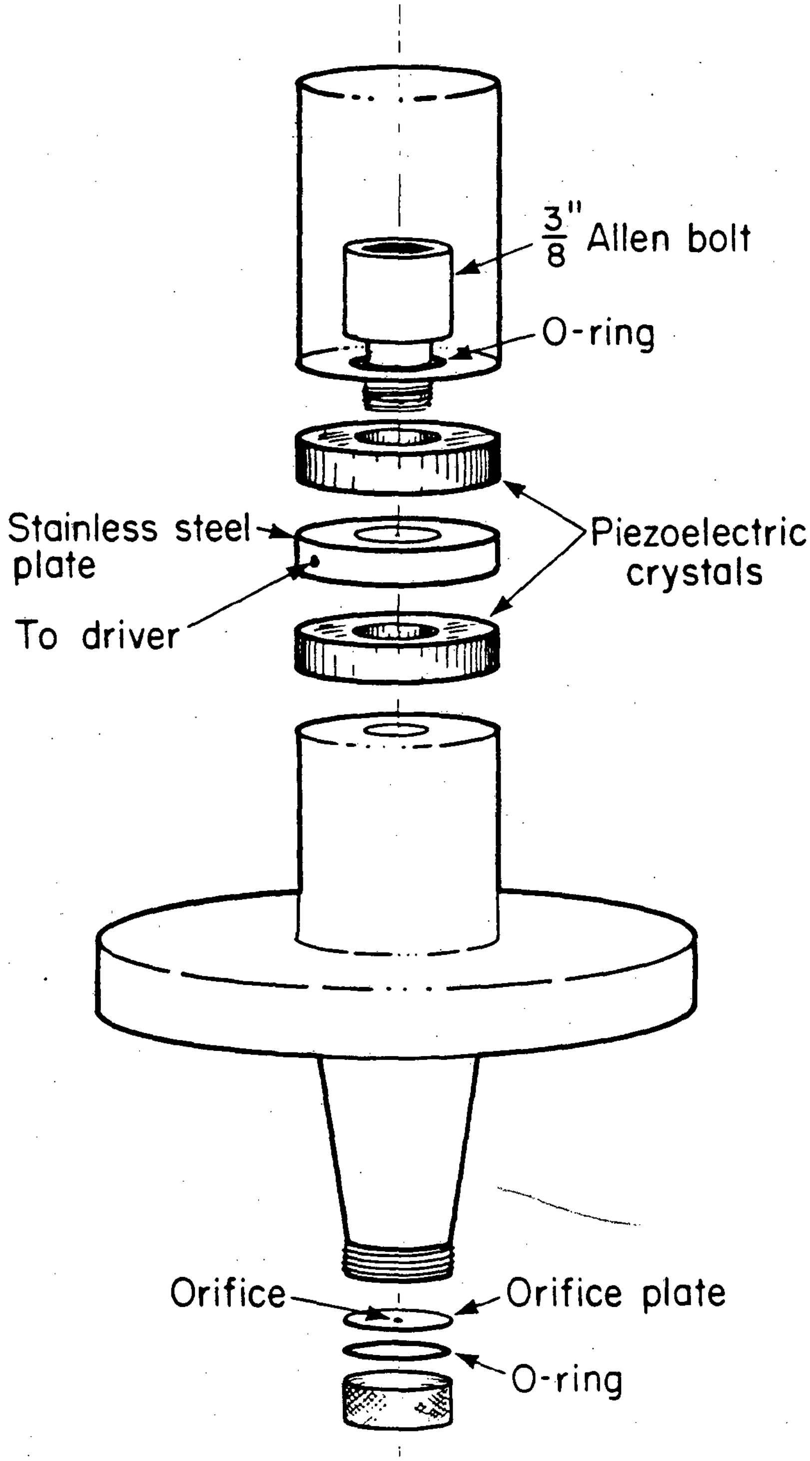

Fig. 3

XBL 802-328

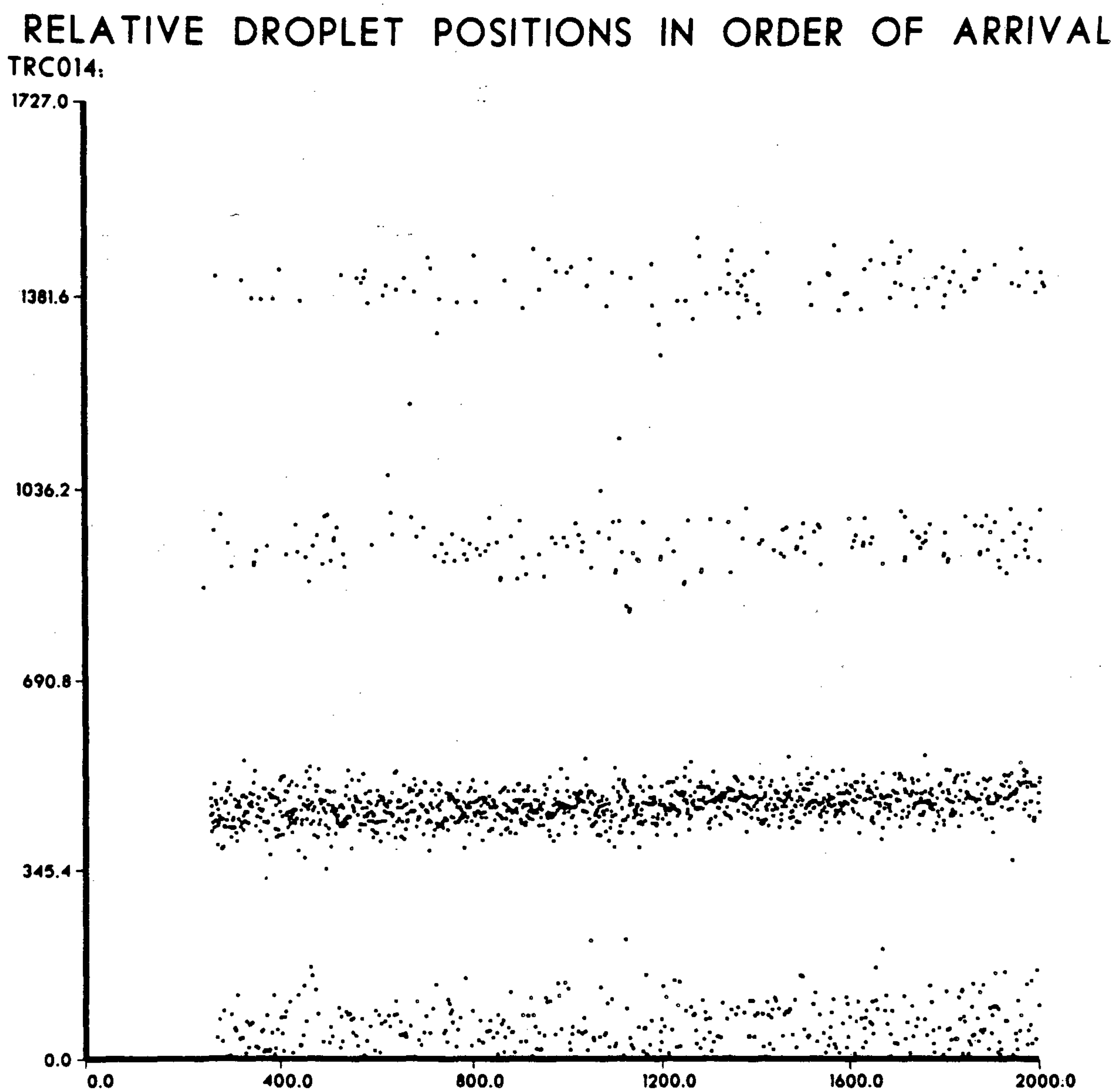

Fig. 4

XBL 824-309

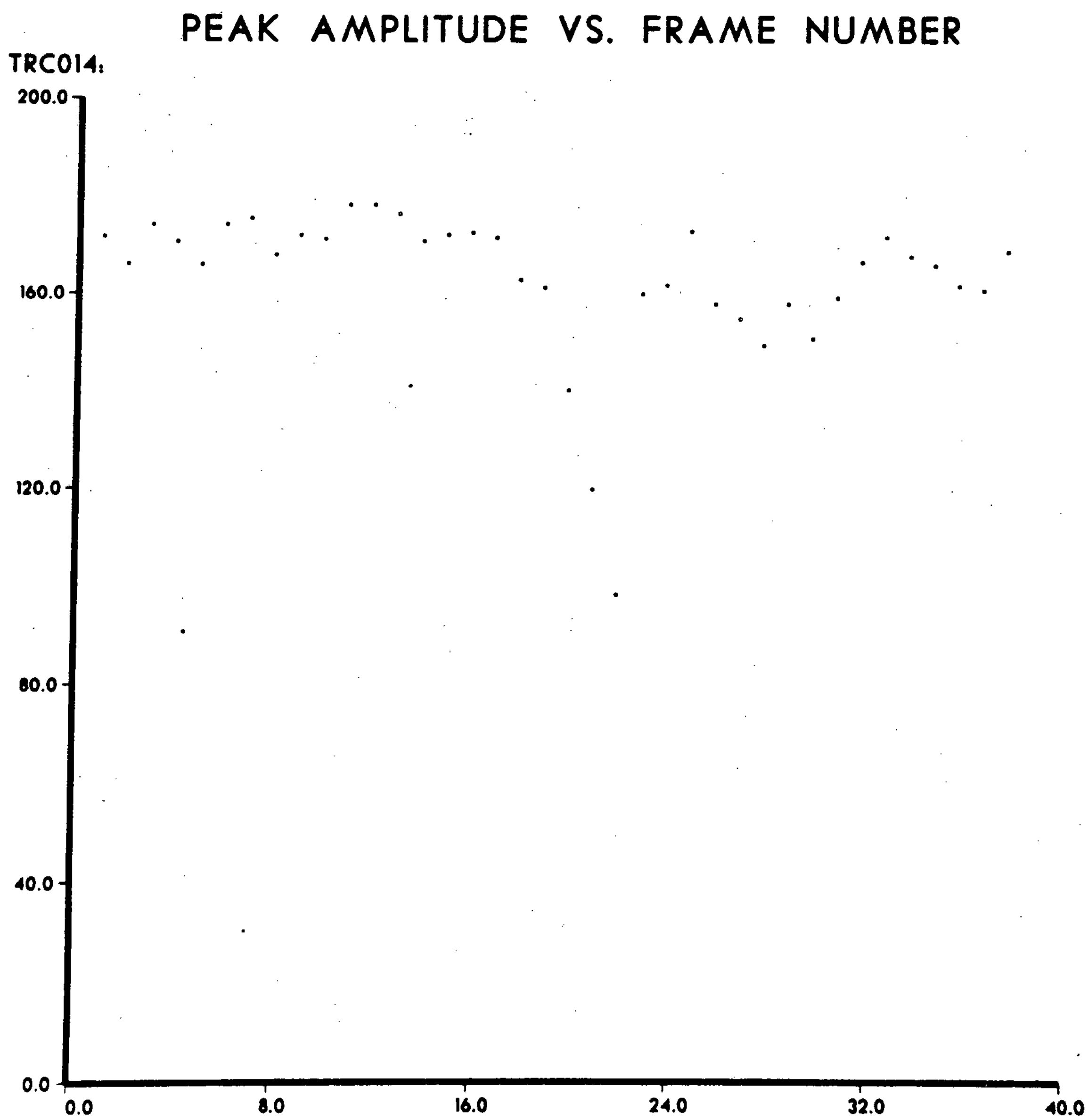

Fig. 5

XBL 824-308

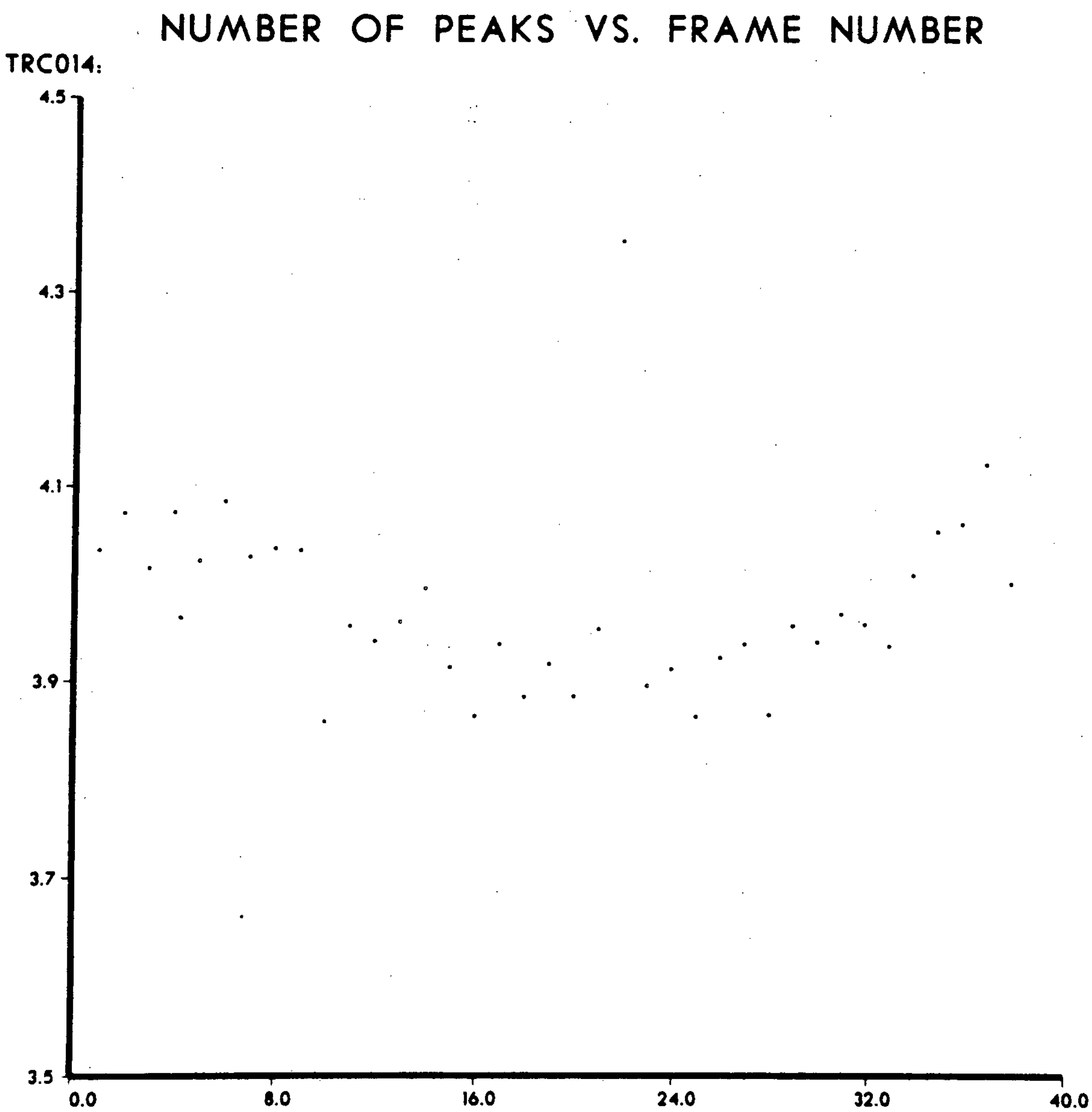

Fig. 6

XBL 824-306

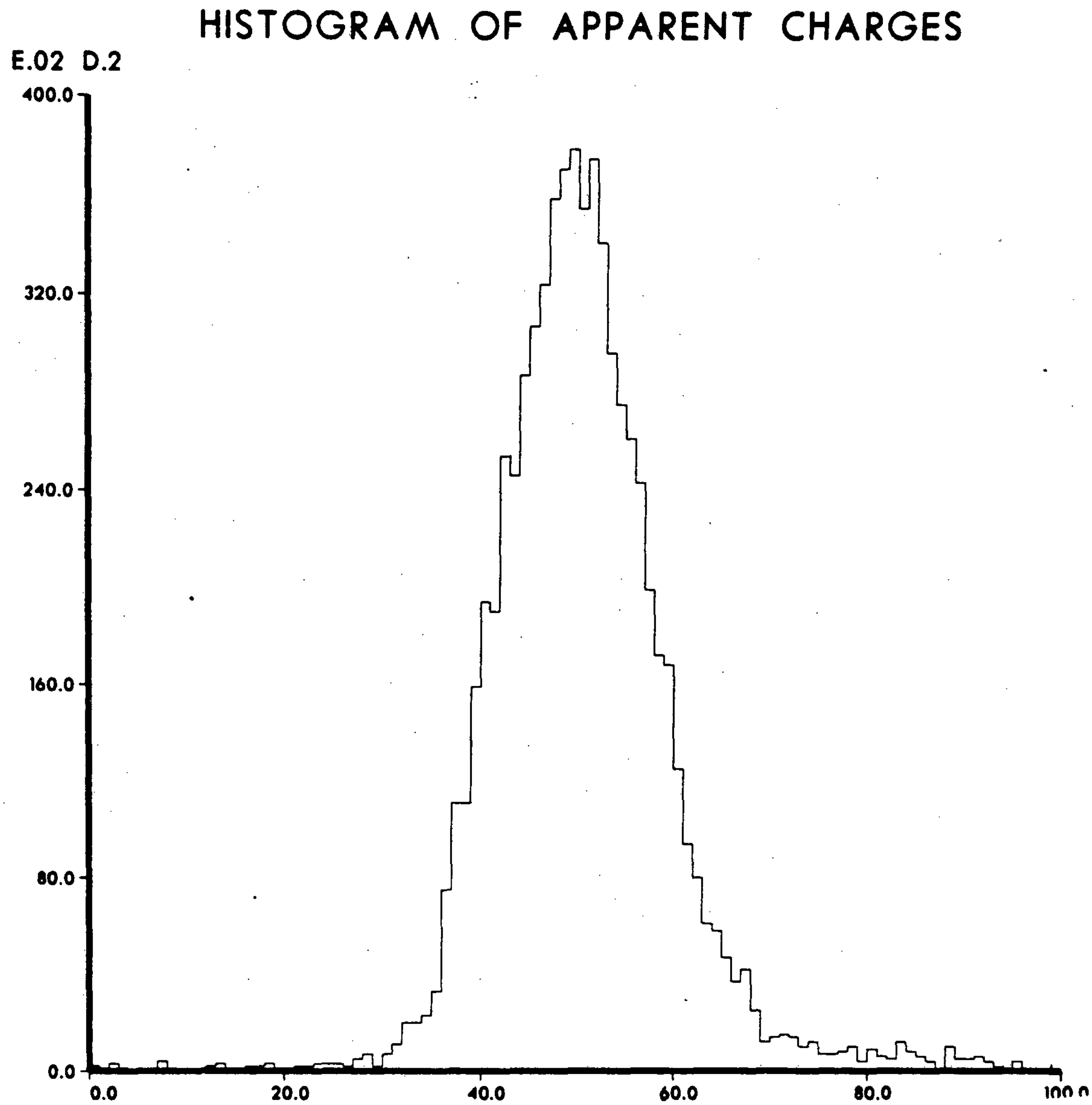

Fig. 7

XBL 824-307

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