Title
Recent Advances in Millimicrosecond Counting Techniques

Author
Chamberlain, Owen

Publication Date
1956-04-17

UCRL 3577

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

BERKELEY, CALIFORNIA

UCRL-3377

RECENT ADVANCES IN MILLIMICROSECOND COUNTING TECHNIQUES

Owen Chamberlain

Department of Physics, Radiation Laboratory
University of California, Berkeley, California

April 17, 1956

I will describe some of the changes that are now occurring or are likely to occur quite soon in our fast counting techniques. Since I have had little to do with the development of these techniques, but have rather been interested for the most part only with their application, I have drawn heavily on the information and advice of Dr. Clyde Wiegand and Mr. Quentin Kerns of the University of California Radiation Laboratory.

The techniques I wish to mention should be quite useful in several different types of experiment. The fast coincidence techniques are principally used for reducing background from accidental coincidences, for measuring times of flight of particles from one counter to another, and for measuring the life times of unstable particles.

From the start I wish to say that I shall confine my attention exclusively to the more ordinary types of coincidence technique in which the resolution time of a coincidence circuit is of the order of magnitude of the length of the pulses. In so doing I shall omit discussion of the differential coincidence circuits, in which resolving times considerably shorter than the pulse widths can be obtained. I omit the differential coincidence techniques because they appear, to me, to have severe limitations with regard to reliability and efficiency when used in applications involving high instantaneous counting rates. Those interested in the differential coincidence techniques may wish to refer to the work of Dr. Zoltin Bay (1) .

The original source of the signal is usually either light obtained from a scintillator or Cerenkov light. The time of light emission of the plastic scintillators is frequently of the order of 10 millimicroseconds (mμsec), but conventional pulse shaping techniques can presumably be used to produce useful pulses of a few mμsec duration. Particular mention should be made of gaseous xenon scintillation, reported by Northrop and Nobles to have light emission times of the order of 3.5 mμsec (2). Perhaps the most important light source will be the Cerenkov radiation, from which a useful light pulse may readily be had with duration as short as 0.1 mμsec.

Until very recently, the speed of our fast coincidence techniques was to a large extent limited by the capabilities of our photomultiplier tubes and associated amplifiers. Two new developments give promise of relief from the limitations of the past.

First, let me mention the development by E. J. Sternglass and M. M. Wachtel at the Westinghouse Research Laboratories. They have produced an experimental photomultiplier based on plane electrodes consisting of thin films giving secondary electron emission in transmission. In one design the multiplying electrodes consisted of a foil of gold 20 A thick followed by a layer of KCl 450 A thick. The experimental multipliers require a few kilovolts per stage, but give a pulse rise time (for a tube with 7 stages of multiplication) of less than 1 mμsec, with the expectation that this may be considerably reduced. Thus far the tubes have not been developed to the point of practical usefulness, especially since the present multiplying films show rather severe fatiguing effects when exposed to typical scintillation counter conditions. Nevertheless, I feel that the present difficulties will very likely be removed in the coming one or two years.

Secondly, I would like to mention the relatively new RCA photomultipliers having 14 multiplication stages. These are currently available with the tube type number 6810. Since these tubes can be used with very large values of the overall multiplication, and since the tubes can give up to 0.3 amp at the output, it is possible to use these tubes in connection with conventional coincidence circuits without amplification. While the rise time of the pulses is not as fast as that to be expected in the near future, still the pulses are about twice as fast as the output pulses from available distributed amplifiers. It is also quite a convenience to be able to do without the distributed amplifiers.

Mr. Quentin Kerns of the University of California Radiation Laboratory has made a detailed study of the factors affecting the rise time in the 6810 photomultipliers and has found that the rise time is 6 mμsec, but that if only a small area of the photocathode is used then the rise time of the output pulse is 1.5 mμsec. This indicates that it will be possible to improve the rise time quite considerably by shaping the photocathode of the tube so as to equalize the flight times of electrons from various portions of the photocathode to the first dynode. RCA physicists have indicated informally that they will try to produce such a tube as soon as possible. With this one change, the RCA 6810 appears to offer us the possibility, very soon, of speeding by at least a factor of 5 the pulses into our coincidence circuits.

One may draw a very practical conclusion from these comments concerning photomultipliers: it now seems that for fast coincidence apparatus using scintillation counters it is not necessary to make or purchase distributed amplifiers. It is, however, still necessary to have considerable amplification when Cerenkov counters are used.

Having reviewed two of the developments in photomultipliers, I would like to make some remarks about the cables that are used to carry the signals from the photomultipliers to the inputs of the coincidence circuits. We at the University of California have been used to using rather long lengths of cable between the counters and the coincidence circuits, often several hundred feet of cable. When we first started using the new 6810 photomultiplier tubes we observed that the rise time of the pulses was considerably spoiled by our connecting cables which were of type RG 63/U (impedance 125 ohms, outside diameter about 0.5 inch). Mr. Kerns has recently pointed out to us that we should have known trouble of this kind was to be expected. His argument may be outlined as follows. The loss of signal in the presently available cables is mostly due to the skin effect at the central conductor of the coaxial cable and is therefore proportional to the square root of the frequency. Thus,

$$-dE/E = \alpha f^{1/2} dL$$

or

$$-\ln (E/E_o) = \alpha f^{1/2} L,$$

where E is the output voltage and E_o the input voltage for a frequency component of frequency f, and L is the cable length and α a constant. Using the simplest ideas of fourier analysis it can be seen that the rise time of the cable (rise time of the output pulse when a very fast-rising pulse is applied at the input) is approximately equal to $\alpha^2 L^2$.

This result has been shown by Mr. Kerns to apply rather accurately to several varieties of commonly used coaxial cables. For experimental arrangements in which it is desired to have long lengths of connecting cable (and still use the fast coincidence techniques) Mr. Kerns has developed a new variety of cable with 125 ohm impedance. The dielectric is a long piece of styrofoam 2.06 inches in diameter. The outer conductor consists of copper foil wrapped around the outside. The inner conductor is copper tubing 0.25 inches in diameter. For assembly the styrofoam dielectric is made in two halves, the pieces being shaped on a carpenter's machine saw. The new cables are not flexible, so must be fitted with conventional cable lengths at each end for easy connection to other equipment, but they are remarkably inexpensive and some lengths are now being installed at the University of California.

In order to allow a comparison between the RG 63/U cable and the new styrofoam cable I will give the cable rise times for cable lengths of 400 ft. The rise time of the RG 63/U cable is 6 mμsec (observed), while that of the new cable is 0.06 mμsec (calculated). Rise times for other lengths may easily be computed since the rise time is proportional to the square of the length, to sufficient approximation.

I have no comments to offer at this time concerning advances in the techniques of the coincidence circuit itself. I feel that for the present existing techniques are adequate. I am confident that in the near future some changes will have to be made to make full use of the very short pulses that will be obtainable from future photomultiplier tubes.

To illustrate the sort of results that can be obtained with conventional techniques augmented by the new photomultiplier tubes, I will describe the arrangement used by Professor Segrè, Dr. Wiegand, Dr. Ypsilantis, and myself(3) for selecting antiprotons from among the scattered particles from the Bevatron target.

A beam of negative particles of known momentum (1190 Mev/c) was formed by a magnetic optical system consisting of analysing magnets and magnetic lenses. Then the antiprotons were selected from this beam by choosing those that had the proper velocity.

The arrangement of the parts of the apparatus is shown in Fig. 1. The 6200-Mev proton beam of the Bevatron struck a 1 in.-thick copper target. Some of the negative particles leaving the target entered the analyzing magnet M1, passed through the magnetic lens Q1, and were brought to a focus at the position of the counter S1. (Scintillation counters are indicated by S and Cerenkov counters by C.) As the particles left the counter S1 they entered the second lens Q2, passed through the second analyzing magnet M2, and again came to a focus at the counter S2.

Each of the magnetic lenses, Q1 and Q2, consisted of three successive quadrupole magnets with 4-in.-diameter aperture. The first and last quadrupole magnets extended each 8 inches along the trajectory, and the middle quadrupole was 16 inches long.

For ease in understanding the focussing properties of this magnetic system it is useful to think in terms of the optical analogs of the parts. For this purpose the analyzing magnets may be thought of as prisms and the magnetic lenses as simple thin lenses. The target would then represent the source of light. At counter S1 one would see a rainbow spectrum with different colors (different momenta) brought to foci at different points, due to the dispersion of the prism. The same process would occur between the first focus at S1 and the second focus at S2, except that the dispersion of the second part of the system just compensates for the dispersion of the first part, and all light that enters the second lens (Q2) comes to a focus at the same final point at S2. Therefore there is no dispersion of the image at S2. In terms of charged particles this means that there is a good image of the target at S2, with all momenta that can get through the system making a focus at the same point. This feature is helpful in obtaining a reasonable intensity at the counter S2.

Most of the beam of negative particles selected by the magnetic system consisted of negative pi mesons. At the chosen momentum of 1190 Mev/c these pi mesons had a speed of 0.99c, where c is the speed of light. The antiprotons had a speed of 0.78 c at the same momentum, so it was necessary to set up a velocity-selecting arrangement that would be sensitive only to particles with velocities close to 0.78 c. This has been done by using several methods of velocity selection simultaneously.

The first method I will mention involves the velocity-selecting Cerenkov counter, C2, that has been separately described in another paper at this conference. Except for some background effects, counter C2 counted only particles within 0.03 c of the velocity of the antiprotons in the beam.

The second velocity selecting method involved simply the use of an ordinary Cerenkov counter, C1, whose radiator had such a low index of refraction (1.28) that it did not register the antiprotons but did register the faster particles (mesons). This counter was connected in anti-coincidence and events were rejected if they were accompanied by a pulse in this counter. For this reason we have often referred to the counter C1 as the "guard" counter.

The third method of velocity selection consisted in the measurement of the flight time of particles between counters S1 and S2, which were separated by a distance of 40 feet. The flight time for mesons was 40 mμsec and that for antiprotons was 51 mμsec. The resolving time of our coincidence circuit was about 6 mμsec, so the circuit was capable of counting the antiprotons without counting the mesons, except for cases of accidental coincidence.

The time-of-flight counters S1 and S2 were identical to each other. The scintillator was a disc 2.2 inches in diameter and 0.7 inch thick, of plastic scintillator. These pieces of scintillator were manufactured in our own laboratory, but their characteristics are quite similar to pieces of commercially available scintillator. The discs of scintillator were inserted in lucite light pipes constructed along the lines suggested by Garwin.(4) The light pipes were in contact with the faces of the 6810 photomultiplier tubes.

In order to obtain pulses of short duration from this arrangement it was necessary to differentiate the pulses quite severely. This was done by connecting a shorted stub of 125 ohm cable, 18 inches long, at the output terminals of the photomultiplier. The shorted stub was made all the more necessary by the slowing of the pulse as it passed through some 400 feet of 125-ohm cable between the photomultiplier tube and the coincidence circuit.

The coincidence circuit was basically that of Garwin,(5) as modified by Dr. Leon Madansky. The delay curve is shown in Fig. 2. The observed resolving time of 6 mμsec is certainly not unusually short, however, I feel that it represents good present practice in a circuit of high reliability that must handle pulses varying considerably in amplitude.

The flight time between the counters S1 and S2 was also measured in another way, by combining the two pulses and displaying them both on a fast oscilloscope trace where they could be photographed. After development of the film, the flight time could be measured to about 1 mμsec on the film, even though it was necessary to pass the signals through conventional distributed amplifiers before applying them to the deflecting plates of the oscilloscope.

Fig. 3 shows histograms of the flight times of various particles. Fig. 3a shows meson flight times, observed to check the operation of the system, Fig. 3b shows antiproton flight times, and Fig. 3c shows the apparent flight times for accidental coincidences.

This may be a good illustration of a generally useful method. If one does not wish to make a large investment in an elaborate coincidence arrangement, it may frequently pay to use fairly standard techniques in the coincidence circuit, but to get the more detailed information by reading the film after photographing the pulses. The film reading requires some patience, but quite frequently the work of reading the film is much less than the work that would have to go into a very fancy coincidence circuit. Furthermore, the film often gives information that is never available from coincidence circuits, particularly with respect to pulse height and pulse shape.

I have tried to limit this discussion to developments that were either presently available, or were rather soon to become available. I hope I have succeeded in indicating my philosophy that the basic counting equipment for up-to-date work need not be too complicated. The illustration with respect to the antiproton selecting apparatus is intended to act partially as background for the talk of Professor Segrè, who will report on the present state of the physics of the antiproton.

References

(1) Z. Bay, Phys. Rev. 83, 242 (1951); Bay, Meijer, and Papp, Nucleonics 10, 38 (1952).

(2) J. A. Northrop and R. A. Nobles, Fifth Scintillation Counter Symposium, Feb., 1956.

(3) Chamberlain, Segrè, Wiegand, and Ypsilantis, Phys. Rev. 100, 947 (1955).

(4) R. L. Garwin, Rev. Sci. Inst. 23, 755 (1952).

(5) R. L. Garwin, Rev. Sci. Instr. 21, 569 (1950).

Figure Captions

Fig. 1. Diagram of the apparatus of the antiproton experiment, showing the selection of pulses to be photographed on the oscilloscope.

Fig. 2. Delay curve of the coincident circuit. The counting rate at the output of the coincident circuit is plotted as a function of the relative delay time of one counter with respect to all the other counters.

Fig. 3. (a) Histogram of meson flight times used for calibration. (b) Histogram of antiproton flight times. (c) Apparent flight times of a representative group of accidental coincidences. The ordinates show the number of events in each one mμsec interval.

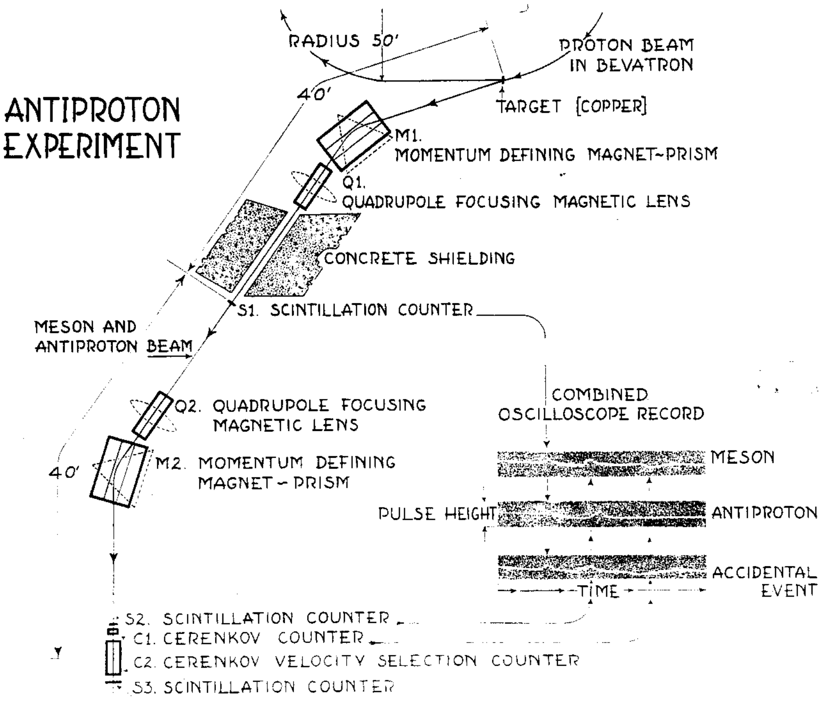
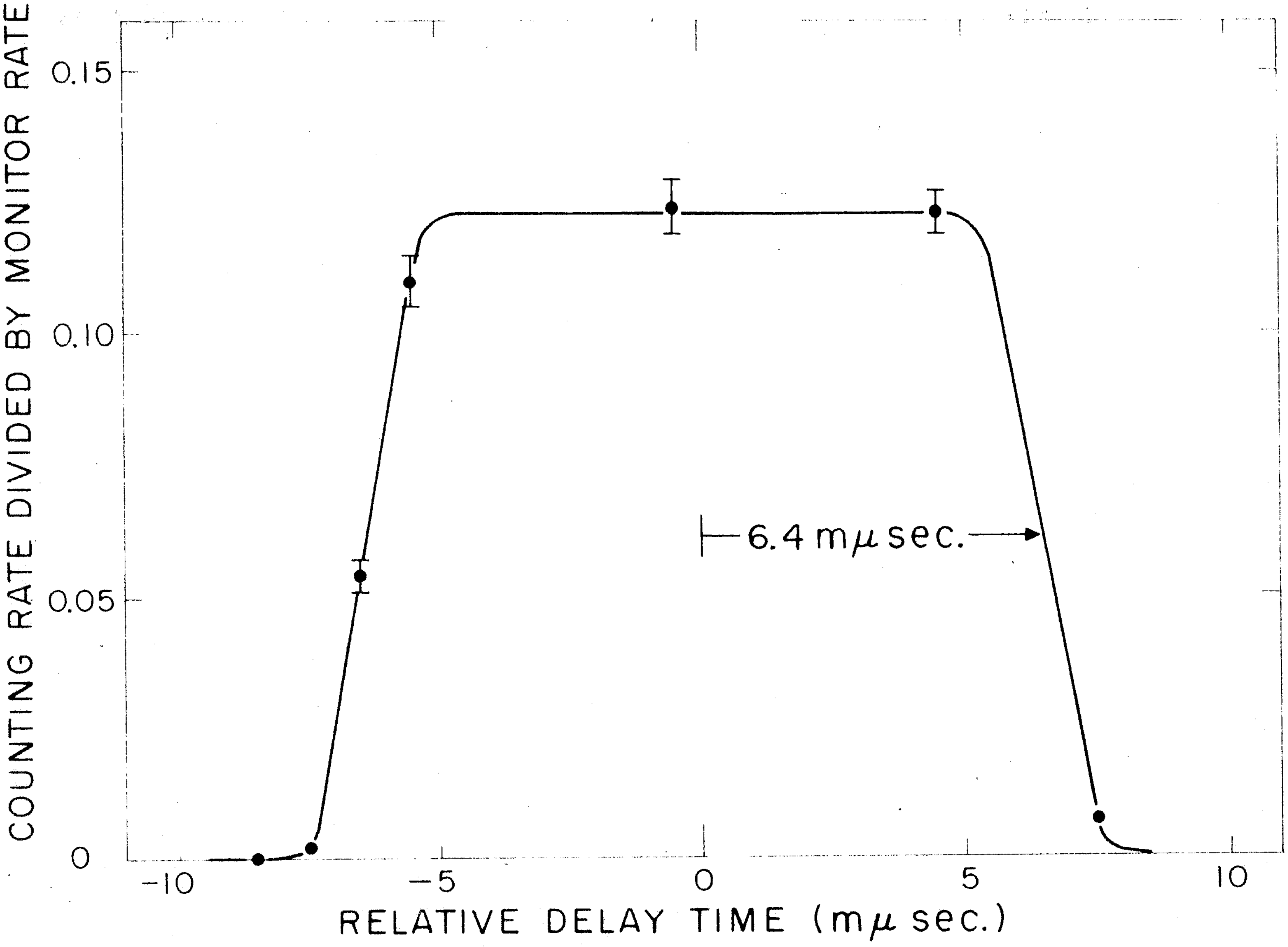

ANTIPROTON
EXPERIMENT
RADIUS 50'
PROTON BEAM
IN BEVATRON
4'0'
TARGET [COPPER]
M1.
MOMENTUM DEFINING MAGNET-PRISM
Q1.
QUADRUPOLE FOCUSING MAGNETIC LENS
CONCRETE SHIELDING
S1. SCINTILLATION COUNTER
MESON AND
ANTIPROTON BEAM
COMBINED
OSCILLOSCOPE RECORD
Q2. QUADRUPOLE FOCUSING
MAGNETIC LENS
40'
M2. MOMENTUM DEFINING
MAGNET - PRISM
MESON
PULSE HEIGHT
ANTIPROTON
ACCIDENTAL
EVENT
TIME
S2. SCINTILLATION COUNTER
C1. CERENKOV COUNTER
C2. CERENKOV VELOCITY SELECTION COUNTER
S3. SCINTILLATION COUNTER

Fig. 1


COUNTING RATE DIVIDED BY MONITOR RATE
0.15
0.10
0.05
0
−10
−5
0
5
10
RELATIVE DELAY TIME (mμ sec.)
6.4 mμ sec.

25214-1

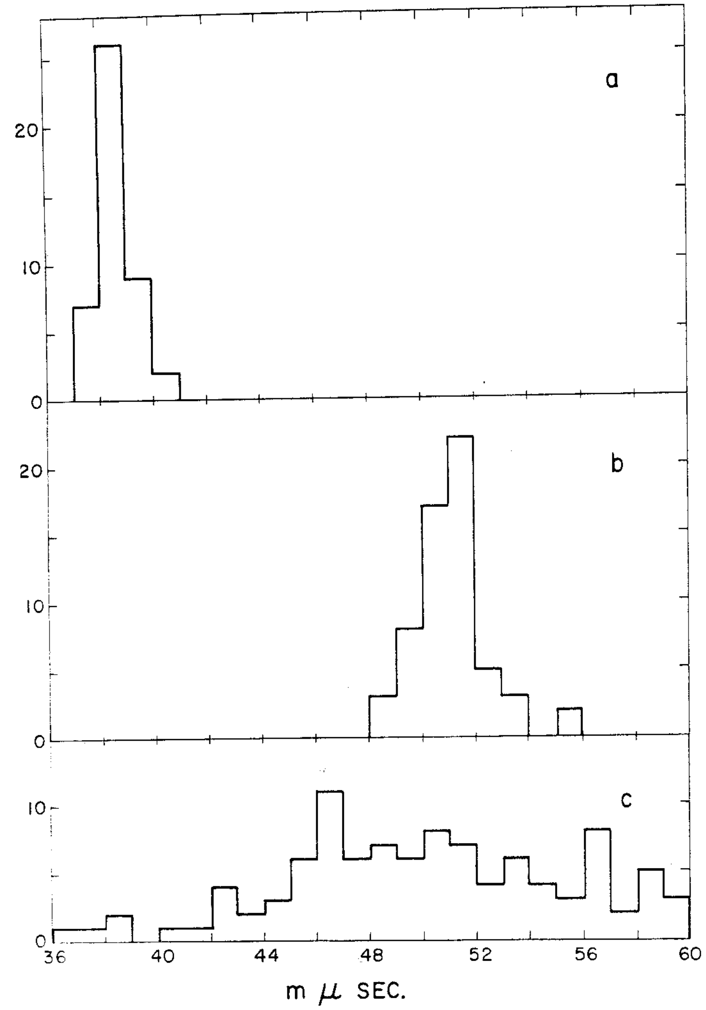


Fig. 3