Cosmic Ray Primary Electron Flux Measure-
ment with Rigidity above 5 BV

Lawrence H. Smith
1965

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COSMIC RAY PRIMARY ELECTRON FLUX MEASUREMENT
WITH RIGIDITY ABOVE 5 BV

A Thesis Submitted to
Case Institute of Technology
In Partial Fulfillment of the Requirements
for the Degree of
Doctor of Philosophy

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

by

Lawrence H. Smith

1965

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ABSTRACT

A measurement of the cosmic ray flux of electrons and protons is made, using a spark chamber to detect their interactions. The fraction of interactions due to electrons was determined by utilizing the difference between the electron cascade length and the nuclear particle interaction length. The number of nuclear particle interactions per plate was determined by interactions in the lower four lead plates. This information was extrapolated to the upper three plates and subtracted from the number of interactions in them.

Two flights were made at different altitudes, 2.16 gm/cm^2 and 4.35 gm/cm^2 . The lower flight, 69P, was made on Sept. 17, 1964, from Palestine, Texas, magnetic rigidity 4.7 BV, (1), (2), (22). The second flight, 78P, was made on Oct. 10, 1964, from the same location.

Triggering of the spark chamber is affected by a pair of scintillation detectors in coincidence, the area, solid angle factor being 5.7 sr/cm^2 , maximum. This detector system was monitored throughout the flight by observing the non-interacting nuclear particles. These also provided a measurement of the nuclear particle flux, $550 \pm 50/\text{sr/m}^2/\text{sec}$.

The electron flux was determined at 2.16 gm/cm^2 to be

$6.5 \pm 3.2/\text{sr}/\text{m}^2/\text{sec}$. giving a ratio of $1.3 \pm 0.62\%$ for the electron/proton ratio. The lower flight, 69P, accumulated more events and provides a better determination of the electron flux, $10.3 \pm 2.8/\text{sr}/\text{m}^2/\text{sec}$. This gives a ratio of $2.04 \pm 0.8\%$ electrons/protons. Using these two flights, the primary flux of electrons was determined to be less than $6.0/\text{sr}/\text{m}^2/\text{sec}$, and the primary electron/proton ratio is less than 1.3%.

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INTRODUCTION

The Earth's atmosphere and magnetic field make difficult the accumulation of information about primary cosmic rays on the surface of our planet. This difficulty is compounded in the case of primary electrons, because their flux is smaller and they are more readily produced in our atmosphere than nuclear particles. More has been done, consequently, to increase our knowledge about primary protons and the heavier nuclei than about electrons. These obstacles now can be reduced by using more modern experimental techniques and recently developed balloons.

Electrons detected at balloon altitudes will not all be primary in origin. Some will be produced by other particles interacting with the atmosphere. For this reason, higher altitudes must be obtained when primary electrons are to be detected. In addition to this, great care must be used in extrapolating the information acquired in the atmosphere to a conclusion about electrons outside the atmosphere.

Interest in the electronic component of cosmic rays has increased due to evidence accumulated from radio astronomy. Information about cosmic electrons can be indirectly obtained by observing their synchrotron radiation.

In general, cosmic radio emission can be separated into two types according to its origin, (3) emission from discrete sources and a general component varying only slightly with galactic coordinates. The general component can be further divided into two subclasses according to the mechanism of production, thermal and nonthermal. The thermal radiation is produced by the highly ionized gas within our galaxy, having a temperature roughly $10,000^\circ$. The nonthermal radiation is caused by "magnetic bremsstrahlung", "synchrotron radiation". A temperature of 10^8 degrees would be necessary for a thermal source producing radiation with an equivalent frequency.

If some assumptions are made as to the intragalactic dust density along with the intragalactic magnetic field strength, a calculation of an expected frequency spectrum can be made. The measured flux and spectrum indicates that the nonthermal radiation is produced by electrons between 10^8 - 10^{12} eV. Thermal radio emission, on the other hand, is caused by very less energetic particles.

The radio emission from discrete sources, often has a polarized component suggesting, therefore, "magnetic bremsstrahlung". Because we are immersed in the radiation from our own galaxy, it is more difficult to detect a polarization, but we can probe into the question by determining whether the conditions are suitable for this phenomenon. The radio emission spectrum

from our galaxy suggests that all the cosmic radiation is in a spherical envelope of radius $R = 3 - 5 \times 10^{22}$ cm and whose walls are nearly perfect reflectors(4). This sets an upper limit of 10^{18} eV for the energy of an electron which can be contained by our galaxy. Electrons with higher energy would certainly be rare unless these were from an extragalactic source.

A lower limit can be given to the energy of primary electrons by assuming an intragalactic magnetic field strength. This assumed value, 10^{-5} gauss, coupled with radio astronomical observations, gives a lower limit of 10^8 eV for injected energy of electrons. The energy can be expected to decrease due to intragalactic modulation by dust (18). Nevertheless, the detection of electrons with energy between these limits would prove significant. The flux of electrons and their energy spectrum, furthermore, would prove valuable in determining the sources of cosmic rays.

Criteria for a critical electron experiment have been set down(5). A detector which fulfills most of these has only recently been developed, the spark chamber. Other detectors have been used to measure the electron flux in cosmic radiation, however, (see table #1).

Several cloud chamber experiments have been performed to verify the existence of primary electrons with energy greater than 10^8 eV. (6),(7). The cloud chamber was randomly expanded and the electrons which interacted with the lead plates were detected by

TABLE #1

Investigator	Geomagnetic Cut-Off	Pressure Altitude (gm/cm ²)	Electron Flux (ele/sr/m ² /sec)	Electron-Proton Ratio
C. Critchfield, et al.	1.1 BV	15	less than 12.7	less than 2%
P. Meyer	1.3 BV	3-5	less than 80	less than 13%
J. Earl	.3 to 3 BV	4-6.5	32 ± 10	3 ± 1%
B. Agrinar, et al.	4.5 BV	4.6	6.6 + 2.8 - 1.7	1.5 ± 0.4%

their soft shower. These experiments set an upper limit of 28 ± 10 primary electrons $\text{m}^{-2} \text{sec}^{-1} \text{sr}^{-1}$ with energy greater than 5 BeV. This limit, however, is based on only 11 electron showers at 4.5 gm/cm^2 altitude.

A counter telescope was flown to $3 - 5 \text{ gm/cm}^2$ in 1960 (8). An upper limit of 8×10^{-3} incident electrons $\text{cm}^{-2} \text{sec}^{-1} \text{sr}^{-1}$ was obtained for electrons above 1.3 BeV. This figure is not corrected for possible contribution from protons, mesons and secondary electrons. A serious impediment to this experiment was the possible subtraction of shower events by an anticoincidence shield around the counter telescope. Shower particles at wide angles could prevent a shower event from being detected.

Both the cloud chamber and the counter telescope lack in providing complete information. The cloud chamber suffers because of its long dead time. The counter telescope lacks in the information that it provides about an individual event. A detector which compromises between the handicaps of these detectors might better accumulate data for this experiment. The spark chamber has a small dead time, but does not give as complete a picture of an individual event as the cloud chamber. The detection of higher energy events may be possible with this detector, however.

An experiment using a spark chamber was performed by B. Agrinier, et al. on Nov. 1963(9). Though difficulties in

the apparatus prevented complete success, an upper limit of 6.6 ± 2.8
 -1.7×10^{-4} primary electrons incident, ($\text{sr}^{-1} \text{ cm}^{-2} \text{ sec}^{-1}$)
was determined. The data was accumulated at an altitude between
4.3 to 4.9 gm/cm^2 . The geomagnetic cut-off was 4.6 BeV.

This spark chamber experiment was unknown to us when we
first attempted to fly our spark chamber in June, 1964. This
first attempt was unsuccessful, but in September and October,
1964, two successful flights were made. The first attained an
altitude of 4.35 gm/cm^2 and the second an altitude of 2.16
 gm/cm^2 residual atmosphere. The data accumulated and its
analysis are the topics of this thesis.

DESIGN CRITERIA

Previous experiments indicate that the electron flux is less than 32 ± 10 electrons/sr/m²/sec, (7). The primary proton flux, on the other hand, is roughly 620 protons/sr/m²/sec. It is necessary, therefore, to eliminate as many spurious events as possible. The problem is an old one, a small signal in a large background. To insure that the results are not confused by instrumental effects, the proton flux will also be monitored and compared with the relatively good figure given by other experimenters.

To reduce background of secondary electrons, the atmosphere above the gondola must be reduced as much as possible. The higher of the two flights, 78P, reached an altitude of 1.7 mm Hg as recorded on the Wallace and Tiernan Gauge, (see MAIN INSTRUMENT PANEL). This corresponds to roughly 140 thousand feet. This is a practical limit for a gondola of this weight. A record of 150 thousand feet has been recorded with lighter payloads. An altitude of 127 thousand feet was reached by the other flight, 69P. This is about 3.17 mm Hg.

To accumulate sufficient statistics, the equipment must operate at altitude for greater than a minimum length of time. To utilize all the film, on the other hand, 40,000 events must be recorded. These parameters place loose maximum and minimum limits on the flight duration.

If all events recorded are electrons, data will be accumulated at the rate, $(32 \text{ electron/sr/m}^2/\text{sec}) \times (\text{Axsolid angle})$. The second brackets contain the area solid angle factor which is 48 sr cm^2 . The expected signal rate, therefore, is 0.15 events per sec or roughly nine counts per minute. The area solid angle factor, as will be mentioned later, is larger for these events, (see SPARK CHAMBER PROPERTIES), but this is a reasonable design number. The rate of proton events can also be estimated at twenty counts per minute. Assuming, optimistically, that spurious counts will be roughly equal to proton plus signal, electron events, the flight will require 20 hours duration to use the 40,000 event capacity of the camera. Film storage doesn't seem to be a problem.

The flight might be shortened by increasing the detector area solid angle factor, but difficulties encountered with the wide angle events prevents this, (see SPARK CHAMBER PROPERTIES). Extra film in the camera permits ground testing and provides a safety factor in the event instrumental failure would waste film. Reasonable statistics can be accumulated in only two hours of flight. This would permit the accumulation of 120 electron events.

A battery pack with enough energy to run the equipment for 16 hours was used. To reserve this energy for running at altitude only, the gondola was turned on just before it had reached altitude. The instruments were monitored with a second camera during

ascent, however, (see MAIN INSTRUMENT PANEL).

As mentioned, the area solid angle factor is limited by the spark chamber. The spark chamber size, in turn, is limited by mechanical problems. It must be constructed from lucite or some other clear material so photographs of the tracks can be taken. The gas inside, therefore, is maintained with a lucite pressure box at one atmosphere. The wall thickness is one inch. This thickness grows rapidly as the size of the chamber is increased. Machining of the assembly also becomes increasingly more difficult. The pressure box is milled from a solid block of lucite. For these reasons, a conservative size of 6" x 7" x 7" was adopted. The useful volume, therefore, after accounting for the plate frames, (see SPARK CHAMBER DESIGN) is 5 1/2" x 5" x 7".

Within this volume a total number of twelve gaps in the main module and four gaps in the upper module was adopted. Every pair of gaps requires a large capacitor to store energy. These, consequently, add much weight and volume to the spark chamber system. The number of these is kept at a minimum. If it were not for this restriction, a more compact spark chamber could be constructed with many more gaps and thinner plates.

The upper module is designed to show the path of the incoming particle before it interacts. The plates of this chamber, consequently, are thin. Stainless steel is used for the plate material because of its good mechanical properties, (see SPARK

CHAMBER DESIGN). The five, ten mil plates have a total mass of $.9 \text{ gm/cm}^2$, (.065 radiation length)(10). Electrons entering these will occasionally interact, therefore.

Some plates in the main module are made of lead. The soft electron showers develop in this part of the chamber. These seven 250 mil lead plates in the top of the main module present 8 radiation lengths to electrons, (see DATA ANALYSIS). A primary electron of energy .5 BeV. will produce a cascade having a maximum number of particles in only three lead plates. Therefore, the shower for this energy electron will be fully developed. A primary electron with 1000 BeV. initiating a cascade in the first plate will produce a fully developed shower in the seven lead plates, (i.e. age parameter $s = 1$ at 9 radiation lengths) (10). The majority of the electrons will have energies between 4.7 BeV. and this maximum, 1000 BeV. Six magnesium plates are added below the lead plates to further examine the developed shower. These plates will prove useful in determining the energy of the electron. This procedure is outside the scope of this thesis.

To fully exhibit the shower developed in the lead plates, sufficient energy must be "dumped" into the discharge. It was found that a .0005 microfarad capacitor on each high voltage plate provided a thick spark for single tracks. Complete investigation about the properties of this chamber for multiple events wasn't possible. A high energy source for electrons isn't readily

available. Large capacitors were used to provide energy for many sparks. Using larger capacitors on the high voltage plates presents spurious sparking problems. That is, sparks appear where there aren't tracks. To increase the efficiency for multiple sparks, however, a separate power switch was provided for the top and bottom of the spark chamber, (see HIGH VOLTAGE PULSE AMPLIFIER). This permits the energy to be delivered more rapidly, hence providing higher efficiency for multiple tracks.

The discharge in the chamber is photographed with a camera mounted below the spark chamber. An eight foot optical path is provided by seven mirrors, (see MIRROR SYSTEM). The optical path determines the length of the gondola. A more compact package could be made if the optical path could be shortened. A spherical lens could be used on each chamber face which would then enable a shorter optical path.

The spark chamber, camera and magazine and the batteries comprise the main portion of the equipment. In addition to these is of course the electronic system which is housed in the electronics bell, (see ELECTRONICS PRESSURE BELL). This assembly was positioned near the chamber itself to keep the pulse cables short. Construction of these systems will be treated in separate sections. A block diagram with these sub-systems shown is pictured in figure #1.

Figure #1

GONDOLA CONSTRUCTION

Spark Chamber Design

The spark chamber phenomenon depends on a gas being electrically broken down along a path of ions left by the passage of a charged particle. To make use of this phenomenon to detect charged particles, the breakdown is controlled to occur only at the path of ions and only at the time when a path is present. A noble gas is used to fill the gaps between an array of parallel plates. A separate detector system must be used to signal the passage of a charged particle. When a particle is detected, alternate plates are given a high potential with a delay of less than 500 n.s. This potential is much greater than the static breakdown potential of the gas and a discharge occurs in the gaps. The path of least resistance for the breakdown is along the ion trail left by the charged particle. If the delay is excessive, the ion pairs recombine and the breakdown becomes random (11).

For reasons which aren't completely understood, only noble gases can be used. Limited success, however, is possible with hydrogen. The rarity and cost of the heavier noble gases further reduces the choice to helium, neon or argon. The presence of other gases "poisons" the spark chamber gas. As little as 1/2% of oxygen present in the spark chamber gas will completely

destroy the phenomenon (12). In this experiment, soft showers are detected and thus many particles are present in a single gap when the spark chamber discharges. For this reason the gas was selected for the greatest multiple sparking efficiency. Of neon, helium and argon, neon appears best (13). Neon, in the pure state, is expensive, but a mixture of 90% neon and 10% helium can be obtained at reasonable cost. This natural mixture of the two gases is separated directly from air*.

Construction of the Chamber

The neon-helium mixture is kept at one atmosphere between the plates. Spacing is maintained between the parallel plates with 1/4 inch lucite frames. The edges of the frames are polished to permit viewing of the sparks. These frames also serve to insulate the corners of the plates. Because of the small radius of curvature, a high field intensity results on the corners which would cause breakdown.

The stack of frames and plates is placed in a lucite box serving as the gas container. Gas is admitted to the gaps from the side of the container through holes in the edge of the frames. The frames are positioned by the container on three sides. Electrical connections from the plates are brought through the fourth

*Air Products Inc., Speciality Gas Department, Allentown, Pa. (oxygen content less than 4 p.p.m.).

side. An extension also in this side of the container houses the electrical connections from the plates to the lead-throughs. The container, or pressure box, can withstand a two atmosphere pressure differential.

The spark chamber is divided into two modules, (see figures #2 and #3). The upper module is a one inch high pressure box containing a thin plate spark chamber with 1/4 inch gaps. The plates are ten mil stainless steel. This material was chosen primarily because of its stiffness and resistance to tarnish. Thin plates of copper and aluminium were tried, but discarded because of bowing. Although definite standards can't be set, a bowing of 10 mils will change the efficiency in a 1/4 inch gap.

The second and main module has a 6 3/8 inch tall pressure box, (see figure #2 and #3). Twelve lucite frames separate the thirteen 1/4 inch plates. This module consists of twelve gaps, seven with lead plates above them and five with magnesium above. Unlike the thin stainless steel plates, these lead and magnesium plates oxydize. Oxydizing by air doesn't harm the plates, but grease from hands and other organic sources effects the sparking. Once grease gets on a plate it is difficult to remove, hence, handling was minimized to prevent it. To prevent excessive scratching of the lead plates, an alloy of lead and antimony was used. Antimony content was less than 8%.

EXPLODED VIEW OF SPARK CHAMBER

PHOTOGRAPH I

SPARK CHAMBER PLATE & DETECTOR ARRANGEMENT

Figure #3

No noticeable effect on sparking efficiency has resulted from using different plate materials in the same chamber. Because of the difference in resistivity and permeability of magnesium and lead, sparking may be thought heavier in gaps using one kind of plate than in gaps using the other. The lead antimony and magnesium plates behave alike.

Thin plates, however, give poorer efficiency than thick ones. Thick plates electrically isolate neighboring gaps. Because neighboring gaps share either a high voltage plate or ground plate, one gap may rob the other of its voltage and energy. When breakdown occurs in a gap, the current through the leads to its plates causes a potential drop in neighboring gaps. Unless breakdown occurs simultaneously in all gaps, the energy will be distributed on a first come first serve basis. This effect may be magnified by some other factor inherent to the spark chamber. More investigation would be necessary to isolate the effect of plate thickness.

The two modules are filled with gas from the same nipple located on the rear of the main pressure box. Holes in the aluminium plate separating the two modules admit gas to the upper chamber. The separating plate is made of 1/8 inch aluminium sheet. Two ears on the separating sheet are used to help support the spark chamber in the gondola. "O" rings in the top and bottom of each pressure box seal the modules. Top

and bottom plates are made of magnesium and are capable of withstanding two atmospheres. Pressures higher than this bow the plates and destroy the "O" ring seals.

The bottom plate is $3/4$ inch thick around the edges to provide a flat surface for the "O" ring. The center, however, is milled underneath, leaving a $1/8$ inch shelf. This reduces weight and provides a minimum amount of useless absorber between the detectors. The top plate is 1 inch around its boarder and milled in the center, from above, down to $1/8$ inch (see figure #5). A ridge is left in the milled cavity to provide a mount for the scintillation fluor. The cavity is covered and made light tight. The photomultiplier tube butts against the fluor through a hole in the boarder (see figure #2).

Six button head screws through the side of the main module, provide electrical lead-throughs for the high voltage plates. Teflon washers under the head of each screw makes a gas seal. The threads are removed on these screws except on the ends. Threads on the screws would make the connection inductive. Seven similar screws are provided for the ground plates. Silver braid* is used to electrically tie the plates to these screws. Odd numbered plates are connected to ground lead-throughs.

*Outer conductor subminax coaxial cable RG 188/U; Amphenol-Borg Electrical Corp. 421-105.

Connections through the walls of the small module are made using silver braid and button head screws also.

An effort is made to reduce all inductance in the connections between the spark gaps and the plates. The spark gap pulse has a sharp spike appearance. This indicates a large high frequency content. Since the energy is delivered to the plates with this sharp pulse, even small inductances greatly effect there performance.

To reduce the inductance in the lead-throughs, all sharp edges were removed. To this end, button head screws were specially machined for lead-throughs. The thread was deleted from them except on their ends. The braid soldered to these screws was smashed to a ribbon to reduce its inductance. All the bending of this braid was done in a way to reduce length but yet keep the radius large.

On the side of the spark chamber modules, resistors are mounted which connect the ground screws and the high voltage screws. These resistors provide a path for current while the radio frequency capacitors are being recharged.* Pressure is maintained around these high voltage resistors with a lucite cover sealed to the chamber with an "O" ring (see figure #4

*FBRW 2.5k 20%; Resistor Products Inc.; 914 S. 13th Street, Harrisburg, Pa.

SPARK CHAMBER (TOP VIEW)

Figure #5

and #5). On this boss, two cylinders are mounted to house the radio frequency capacitors. These capacitors store energy for the spark chamber. Each high voltage plate is connected to a capacitor. The capacitors have a banana plug on their chamber end which plugs into a receptacle mounted on the chamber. The other end of the capacitors are common. The three capacitors in each lucite cylinder are screwed into a brass disc at the common end.

Electrical connection is made to these capacitors from the electronics pressure bell with RG 8/U cable. A banana plug on the end of each cable plugs into a hole in the brass discs holding the capacitors. A cable from each lucite cylinder on the main module and one from the cylinders on the small module go through the base plate of the electronics bell. Each cable is fed through tygon tubing which is connected to a nylon fitting on the base plate and one on the end of the lucite cylinders. Hose clamps around the tubing at the fittings seal it. The boss housing the high voltage resistors, the capacitor cylinders and the electronics bell are all pressurized from a gas fitting on the base plate.

The electronics bell is mounted near the spark chamber to keep the coaxial cables connecting them short, (see photograph #2). Because the entire gondola isn't pressurized, the high voltage

components are put in the electronics bell. A pressure of one atmosphere is maintained inside the bell, capacitor cylinders and resistor bosses, with dry nitrogen gas. The small volume requiring pressurization, reduces the wall thickness necessary to withstand the pressure. The overall weight of the gondola and the useless material is minimized by keeping pressure vessels small. Showers from cosmic rays, not initiated in the spark chamber, may trigger the detector system, but aren't useful events. For this reason, reducing the amount of useless material increases the experimental value of the gondola.

The large number of gas seals in the gondola requires extra care to insure their tightness. To test these seals and the performance of all the equipment, the gondola was placed in an altitude simulation chamber. Air in the altitude chamber was pumped out while the gondola was observed through four portals. When pressure inside reached 2 to 6 mm of mercury, a blue glow appeared around the coaxial pulse cables connecting the spark chamber and capacitor cylinders when the chamber discharged. The pulse induces charge on the surface of the tygon tubing and lucite cylinders which in turn causes corona. This corona doesn't effect the performance of the spark chamber.

The gondola was run in the altitude chamber for several hours at 1 to 2 mm. to see if excessive heating would occur. At this pressure, convection cooling is very limited. Unless a good

PHOTOGRAPH 2

thermal conducting path is provided for all the electronic components, localized heating will occur.

Electronics Pressure Bell

All high voltage stages of the preamplifier system are inside a pressure container, the electronics bell, to prevent corona. In addition, the preamplifier and coincidence circuits are put inside to prevent localized heating. The gas tends to distribute the heat uniformly to all components by convection. Placing all components inside also permits all elements of the electronic system to be grounded at the same point, the base plate of the bell. Long ground leads can pick-up radio frequency noise from the spark chamber discharge, which could destroy semiconductor elements.

The preamplifiers are built on fiberglass-resin cards which plug into receptacles mounted on the base plate, (see photograph #1, p. 17). The signal is brought from the photomultiplier tubes with RG 188/U coaxial cable. The two signal cables plug into a header* sealed in the base plate below the card receptacles. Outputs from the preamplifiers go to another card on which the coincidence circuit and avalanche transistor circuit are built. In the event of component failure on any of the three cards, a new card can be substituted.

The secondary emission tube is mounted on an aluminium bracket beside the card containing the avalanche transistor and

*IPC #45975 receptacle, MB series Amphenol-Borg Electronics.

coincidence transistor, (see PREAMPLIFIER and COINCIDENCE CIRCUIT section). The components that make up this circuit are mounted on the bracket also. This bracket serves as a shield for the components and acts as a thermal ground for the secondary emission hexode. A second shield around the thyatron and spark gaps prevents radio frequency noise from getting directly to the low voltage components on the fiberglass cards.

The thyatron, beside the secondary emission tube, is mounted on four 1" stand-offs screwed into the base plate and thus to the gondola. Half the energy dissipated by the gondola is used by the thyatron filament. This amounts to about 20 watts.

An RG 188/U cable brings the pulse from the secondary emission tube, through the shield, to the thyatron. A .0002 mf capacitor carries the thyatron output pulse to the spark gaps. The spark gaps are surrounded with 100 mil teflon sheet lining the inside of an aluminium shield. Each spark gap is mounted by its cathode on a brass post on the base plate. All joints on the spark gaps and the resistors leading to them are painted with silicone grease to eliminate corona.

The 10 kilovolt supply for the thyatron and spark gaps is build on a 1/4 inch lucite shelf on the top of the bell assembly. The lucite disc insulates the supply from all other elements in the bell. The bell dome is coated on the inside top with rubber tape for insulation from the high voltage supply. The Cockroft-

Walton multiplier chain is potted in silicone rubber* to prevent corona. The high voltage is carried through the lucite disc in a heavily insulated wire to resistors having one end mounted underneath the disc. The other end of the resistors are soldered to the spark gaps.

The power supplies for the photomultiplier tubes and secondary emission tube are mounted on a 1/8 inch aluminium plate above the three resin-fiberglass cards. This plate serves as a heat sink and is thermally connected to the base plate with three aluminium supporting rods. The zener diode regulators for the preamplifiers and avalanche transistor circuit are mounted on this plate also. The ten watt zener diode used in the power supply regulator is mounted in a hole in this plate. An added function is served by this plate because it electrically shields the semiconductor elements of the preamplifiers from direct radiation from the spark gaps.

All power for the electronics bell assembly is brought through the base plate with an eight pin ceramic header. That is, the nominally six volt line for the filaments and the nominally 28 volt line for the semiconductor circuits are brought through this header. The trigger pulse for the camera flipflop and panel light flipflop circuits is brought through this also.

*Dow Corning RTV 501.

PHOTOGRAPH 3

Two cables on the outside of this header plug into receptacles in the main junction box of the gondola (see photograph #3).

The high voltage for the photomultipliers is brought through the base plate with another lead-through with only a single pin. Cables on the outside of this lead-through are potted with a hard compound which insulates the connection.* The high voltage for the spark chamber capacitors is brought through the base plate with three coaxial cables. This voltage is too high to expect potting to contain it. Since the inner conductor of the coaxial cable is designed to be insulated from the shield conductor, the coaxial cable forms a natural low leakage line. There are, however, no connectors which can be used with this cable that can withstand this high a voltage. Consequently the cable connection must remain unbroken from the spark gap to the capacitors. A lucite fitting bolted on the outside of the base plate and sealed with an "O" ring, feeds these three cables into three tygon tubes, (see CONSTRUCTION OF THE CHAMBER).

Spark Chamber Camera

The sparks of an event in the spark chamber, are photographed with an open shutter, 16 mm camera†, (see photograph #4).

*Hysol Corporation; PC 12-007A and PC 12-007B.

†Model III-B Flight Research Inc.; Subsidiary of Giannini Scientific Corp.; Box 1-F, Richmond, Virginia.

The motor in the camera runs continuously and is engaged to the advance mechanism upon command. When the camera advance flip-flop circuit is triggered, it generates a pulse of 20 milliseconds duration. This 28 volt pulse activates the clutch with a solenoid. Thus the motor is coupled to the advance mechanism in the camera. It stays engaged after the solenoid is released until its full operation is completed, approximately 40 ms from solenoid initiation to advance completion.

When the clutch is activated, the camera motor draws a "claw" down beside the film. This "claw" engages a perforation and drags the film past the aperture. Another stationary "claw" accepts a perforation at the end of this stroke and positions the frame.

While this operation is being performed, two sprockets, also driven by the camera motor, advance the reserve film in preparation for the next advance. This reserve relieves the "claw" of some of the strain.

Prior to the "claw" moving the film, a shutter is pulled over the aperture to prevent illumination while the film is in motion. Without this feature the image would be smeared because illumination actually occurs before the film is advanced. The instrument panel is illuminated immediately upon advance command. The image is therefore recorded after the sparks are photographed and on the next frame. In attaining the exact time at which an event

CAMERA AND REGISTER PULSER

C	TIME
1	21 MS.
.22	40
.47	80
.68	120

occured, therefore, the clock on the frame following the event must be read.

The avalanche transistor generates the pulse which activates the film advance flip-flop and light flip-flop. These flip-flop circuits are built on fiberglass-resin cards which plug into receptacles in the main junction box. They are, therefore, exposed to severe environment. The basic circuit is similar to the dead time flip-flop, but with two additional transistors added to amplify the out-put power, (see figure #6).

Unlike the camera, whose motor runs continuously, the magazine motor is activated only intermittently. A continuous 200milliamperere current is drawn from the 28 volt battery pack to idle the camera motor. Film is fed by the magazine to the camera using the camera motor. A ratchet clutch in the feed reel of the magazine gives a mechanical advantage to the camera motor to aid it in performing this operation.

The take-up reel, however, is driven with the magazine motor. After film has been used by the camera, it waits on a system of pulleys to be reeled onto the take-up reel. These pulleys maintain tension on the film with a spring attached to one and pulling it away from the others. When the pulley system is fully loaded, a micro switch is activated by the moveable pulley and the magazine motor reels the film tight again.

This model magazine nominally holds 800 feet of film. To increase its capacity, however, a mylar based film called "cronar" was used.* This is a film manufactured by Dupont which has a speed comparable to Plus X. A film comparable to this is also manufactured by Kodak and is called "Astar". Both of these films use 4 mil mylar for a base. There is a film soon to be tested which uses 2.5 mil mylar for a base. While the 4 mil mylar increases the capacity from 800 feet to 1000 feet, this new film would further increase the capacity to 1400 feet.

Mirror System

The camera with its magazine is mounted below the spark chamber, (see photograph #4). A system of front silvered mirrors brings the images of the two views to the camera†. (see figure #7). The mirrors present the front view above the side view to the camera. The lengths of the optical paths of both views are identical and equal to 8 1/2 feet.

A field of view must be large enough to contain the two views above one another. The frame reducing aperture was removed from the camera so the film between the perforations can be utilized. The standard tables for the field of view for a lens will give,

*Cronar 141-A 16 mm doubly perforated.

†Flight Research Model III-B; Post Office Box 1-F, Richmond, Virginia.

therefore, a conservative estimate for the field in this camera. Each projection of the spark chamber is $8 \frac{1}{4}$ inches high. At least $16 \frac{1}{2}$ inches are required for the field height. Since this is the larger dimension the camera was laid on its side to take best advantage of the film's dimensions. A two inch Wollensak lens* provides a $13'' \times 18''$ field, according to the tables, for an optical path of $8 \frac{1}{2}$ feet. This leaves a margin of safety in case the mirrors get jarred slightly.

It would be desirable to reduce this optical path. Unfortunately this isn't readily accomplished. For every gap in the spark chamber to be completely seen each would have to be viewed parallel to its plane. The camera, therefore, should be virtually at infinity. This could be affected with converging lenses placed on the spark chamber. A more simple solution, however, is to merely place the camera sufficiently far to be able to see the rear of the uppermost and lowermost gaps. An optical path of $8 \frac{1}{2}$ feet is required to satisfy this condition.

Sparks in the rear of the uppermost and lowermost gaps are somewhat obscured. A portion of the spark is nevertheless visible. The reflection of the spark on the plates of the spark chamber adds to the direct image and presents a normally appearing spark. The distortion created by this is small because the tracks

*Wollensak f/1.5 Raptar 2" (50 mm).

PHOTOGRAPH 4

MIRROR ARRANGEMENT

make a small angle with the verticle.

The arrangement of mirrors is shown in figure #6. Mirrors F-1, F-2, F-3 and F-4 fold the optical path for the front view and drop the image to the camera level. The camera lens is positioned directly below the side view optical path. Mirrors F-3 and F-4 are required to shift the front view's image over to the side view's position.

Mirrors S-1, S-2 and S-3 bring the image of the side projection down to the camera level and underneath that of the front view. Optical paths of both projections are of the same length. It is this constraint that necessitates so many mirrors.

Front silvered mirrors were used to eliminate "ghosts". These, however, are difficult to clean and repeated cleaning mars their surface. New mirrors, therefore, were installed before each flight.

A small thin mirror, mounted on the front of the spark chamber, brings the instrument panel's image along side the front projection's image. On this panel is mounted a twenty-four hour clock, Accutron.* This provides a correspondence between the main panel which has a similar clock and this panel's register which is photographed with each event. The time of occurrence and the event number are recorded on the frame following the event.

*Accutron, trade name, BuLova Watch Company.

Main Instrument Panel (Wollensak Panel)

A second camera is used to photograph slowly varying instruments. These instruments give information which doesn't require event by event correlation. The instrument panel is continuously illuminated with bulbs mounted on the face of each instrument. An exposure is taken every two minutes with a 35 mm Wollensak data camera. Twenty hours of data can be recorded with this camera on its fifty foot of film. Tri-X film was used to reduce the amount of illumination required.

A twenty-four hour clock on this panel along with the one on the spark chamber's panel permits correlation between the event and any information on the main panel. In addition this clock gives the exact duration of flight and time at altitude. The altitude, or more specifically the pressure is shown by a six inch Wallace and Tiernan gauge, (see photograph #5). This gauge reads from 0.1 mm to 20 mm. This range is sufficient to accurately give the floating altitude and offer a safety factor in case the balloon doesn't reach designed altitude.

The first and lower of the two flights had a ceiling of 3.01 mm. This was flight 69P, launched on September 17, 1964. The second flight, 78P, was launched on October 10, 1964 and reached a ceiling of 1.49 mm. Although the gauges have a repeatable accuracy of .02 mm, their zero setting can change. A correction is given, therefore, to all the readings. This

correction remains almost constant over the range of the gauge. The above numbers are the corrected pressures for the flights. The average floating altitude for the flights were 3.15 mm for 69P and 1.57 mm for 78P.

To determine the correction for the gauges, the instrument to be flown was compared with another denoted as the standard. This procedure was performed before and after each flight. The standard gauge was later calibrated absolutely with a Stokes McLeod gauge back in the laboratory. This indirect method of calibration was necessary because absolute calibration requires several days of pumping. This isn't feasible in the field. During this pumping, liquid nitrogen is kept in a cold trap to condense the water vapor from the system. The McLeod gauge is very sensitive to any water vapor.

Two small pressure gauges to the right of the Wallace and Tiernan gauge, indicate the pressure in the spark chamber and the electronics bell. Sparking efficiency in the spark chamber depends on the neon gas pressure. Because the volume of the chamber is small, even a small leak would be significant. The electronics bell pressure also is important because corona occurs around the high voltage components when the pressure drops below 12 psi.

PHOTOGRAPH 5

Two edgewise meters* monitor the voltage on the nominally 28 volt battery pack and the nominally 6 volt pack. These meters serve the added purpose of indicating the exact time at which the gondola is turned on. To save film and battery energy, the gondola was turned on after reaching altitude during a flight.

Turn-on was accomplished with a radio command system furnished by the National Center for Atmospheric Research. The radio command was linked to a relay system housed in the battery junction box. As a safety device a timer was used in parallel with this radio command system. In the event of the radio failing, the timer would turn the gondola on three hours after launch. A change in frequency of the radio beacon indicates to the ground control that the system is on. This information can prove important in determining the cut-down time. Partial failure of any piece of equipment in the radio command system could confuse the experiment. Information attained from the main instrument panel will eliminate this confusion.

Lastly, a mercury thermometer on the main panel records the temperature of the framework. Excessive heating could result from either of two sources. The energy released from the electronic equipment accumulates in the gondola, and the sun's

*Model 1522C, Simpson Electric Company, 5200 W. Kinzie Street, Chicago 44, Illinois.

radiation is very intense because of the lack of protective atmosphere. Heating by the sun is controlled by painting the outside of the gondola with a titanium dioxide pigmented paint. Convective cooling is negligible. On night flights, on the other hand, the temperature can get very low. The gondola loses heat by radiation and can get very cold despite the two inches of polyurathane foam and the heat released inside.

The first flight, 69P, was a night flight. The temperature ranged from 30 degrees centigrade to a recorded -5 degrees, but a much lower temperature is probable. The shutter of the Wollensak camera became sticky and obscured temperature readings below this point. The spark chamber was operating at the time of the last readable temperature.

The second flight, 78P, was launched in the morning. The temperature during this flight reached 25 degrees centigrade. A higher temperature was recorded on an unsuccessful flight made with this equipment. The reason in this case was attributed to not painting the polyurathane box with a Titanium dioxide pigmented paint. Also, however, the thermometer was coupled directly to the base plate and recorded a high of 60 degrees centigrade. On the two successful flights the thermometer was coupled to the framework with copper wool.

TABLE #2

Main Instrument Panel Flight 69P

Time C.S.T.	Pressure Altitude mm Hg	Temperature degrees Centigrade	Nominal 28v. supply volts	Nominally 6v supply amperes	Spark Chamber Pressure psi	Electronics Bell Press. psi.
17:24	launch	30	36	0.0	5.5	5.7
17:34		30	36	0.0	9.2	9.9
17:44		30	36	0.0	11.5	12.1
17:54		29	36	0.0	14.1	15.0
18:04		28	36	0.0	16.5	17.0
18:14		27.5	36	0.0	17.6	18.2
18:24	45	26.0	36	0.0	18.4	18.9
18:34	30	24.0	36	0.0	18.9	19.1
18:44	20	23	36	0.0	18.9	19.1
18:54	14.14	21.5	36	0.0	19.0	19.1
19:04	10.02	20	36	0.0	19.0	19.1
19:14	7.60	19	36	0.0	19.0	19.1
19:24	5.71	17.5	36	0.0	19.0	19.1
19:34	4.41	16.5	36	0.0	19.1	18.9

Time C.S.T.	Pressure Altitude mm Hg	Temperature degrees Centigrade	Nominal 28v supply volts	Nominally 6v supply amperes	Spark Chamber Pressure psi	Electronics Bell Press. psi
19:44	3.60	15.5	36	0.0	19.1	18.6
19:54	3.00	14.0	35.5	3.7	19.0	18.4 <u>turn-on</u>
20:04	2.99	13.0	34.0	3.7	19.0	18.7
20:14	3.00	12.0	34.0	3.7	18.9	18.6
20:24	3.00	11.0	34.0	3.0	18.9	18.6
20:34	2.96	10.5	33.0	3.6	18.9	18.6
20:44	3.10	10.0	33.0	3.6	18.8	18.6
20:54	3.00	9.0	33.0	3.6	18.8	18.6
21:04	3.10	8.0	33.0	3.6	18.8	18.6
21:14	3.09	8.0	32.5	3.56	18.8	18.6
21:24	3.10	7.0	32.5	3.49	18.5	18.5
21:34	3.19	7.0	32.0	35.0	18.5	18.5
21:44	3.13	6.5	32.0	3.48	18.5	18.5
21:54	3.12	6.5	31.5	3.48	18.4	18.2

Time C.S.T.	Pressure Altitude mm Hg	Temperature degrees Centigrade	Nominal 28v supply volts	Nominally 6v supply amperes	Spark Chamber Pressure psi	Electronics Bell Press. psi
22:04	3.09	5.0	31.5	3.45	18.4	18.2
22:14	3.09	4.5	31.5	3.5	18.3	18.0
22:24	3.12	4.0	31.5	3.5	18.3	18.0
22:34	3.09	3.0	31.0	3.5	18.3	18.0
22:44	3.05	2.0	31.0	3.5	18.3	17.9
22:54	2.94	2.0	31.0	3.5	18.3	17.9
23:04	2.99	1.5	30.5	3.45	18.1	17.8
23:14	3.04	1.0	30.5	3.45	18.1	17.8
23:24	3.07	0.5	30.5	3.45	18.1	17.5
23:34	3.10	0.0	30.5	3.45	18.1	17.4
23:44	3.12	0.0	30.0	3.45	17.9	17.3
23:54	3.12	0.0	30.0	3.5	17.9	17.2
24:04	3.10	-1.0	30	3.5	17.9	17.2
24:14	3.14	?	30	3.5	17.9	17.0

Time C.S.T.	Pressure Altitude mm Hg	Temperature degrees Centigrade	Nominal 28v supply volts	Nominally 6v supply amperes	Spark Chamber Pressure psi	Electronics Bell Press. psi
24:24	3.15	?	30.0	3.5	17.9	17.0
24:34	3.15	?	30.0	3.5	17.8	18.0
24:44	3.20	?	30.0	3.5	17.8	17.0
24:54	3.25	?	30.0	3.5	17.8	17.0
01:04	3.22	?	30.0	3.5	17.7	16.9
01:14	3.20	?	30.0	3.5	17.7	16.9
01:24	3.28	?	30.0	3.5	17.7	16.9
01:34	3.30	?	30.0	3.5	17.7	16.9
01:44	3.30	?	30.0	3.5	17.7	16.9
01:54	3.25	?	30.0	3.5	17.7	16.5
02:04	3.30	?	30.0	3.5	17.7	16.9
02:14	3.30	?	30.0	3.5	17.7	17.7
02:24	3.20	?	30.0	3.5	17.7	17.7
02:34	3.20	?	30.0	3.5	17.7	17.7

10

<u>Time</u> <u>C.S.T.</u>	<u>Pressure</u> <u>Altitude</u> <u>mm Hg</u>	<u>Temperature</u> <u>degrees</u> <u>Centigrade</u>	<u>Nominal 28v</u> <u>supply</u> <u>volts</u>	<u>Nominally 6v</u> <u>supply</u> <u>amperes</u>	<u>Spark Chamber</u> <u>Pressure</u> <u>psi</u>	<u>Electronics</u> <u>Bell Press.</u> <u>psi</u>
02:44	3.20	?	30.0	3.5	17.7	16.0
02:54	3.17	?	30.0	3.5	17.7	16.0
03:04	3.10	?	30.0	3.5	17.7	11.0
03:14	Spark Chamber no Longer Functioning.					
03:24						

07:00 Termination of Flight.

TABLE #3

Main Instrument Panel Flight 78P

Time C.S.T.	Pressure Altitude mm Hg	Temperature degrees Centigrade	Nominally 28v supply volts	Nominally 6v supply amperes	Spark Chamber Pressure psi	Electronics Bell Press. psi
06:15	launch	11.0	36.0	0.0	5.0	5.0
06:25		12.0	36.0	0.0	7.5	8.0
06:35		10.0	36.0	0.0	10.5	11.0
06:45		10.0	36.0	0.0	13.0	13.2
06:55		10.0	36.0	0.0	14.8	15.2
07:05		10.0	36.0	0.0	16.3	16.8
07:15		10.0	36.0	0.0	17.3	17.9
07:25		9.5	36.0	0.0	17.9	18.3
07:35		8.5	36.0	0.0	18.2	18.6
07:45		8.0	36.0	0.0	18.4	18.8
07:55	14.1	8.0	36.0	0.0	18.4	18.8
08:05	9.10	7.5	36.0	0.0	18.6	18.9
08:15	5.98	7.5	36.0	0.0	18.7	18.9
08:25	4.10	7.5	36.0	0.0	18.8	18.8

Time C.S.T.	Pressure Altitude mm Hg	Temperature degrees Centigrade	Nominally 28v supply volts	Nominally 6v supply amperes	Spark Chamber Pressure psi	Electronics Bell Press. psi
08:35	2.82	7.5	36.0	0.0	18.8	18.9
08:45	1.98	7.5	36.0	3.8	18.8	18.9 turn-on
08:55	1.66	8.0	32.0	3.8	18.8	19.0
09:05	1.73	8.5	32.0	3.8	18.8	19.3
09:15	1.73	9.5	31.2	3.8	18.8	18.9
09:25	1.74	10.0	31.0	3.8	18.8	19.5
09:35	1.75	10.0	31.0	3.8	18.8	19.5
09:45	1.80	11.0	31.0	3.7	18.8	19.7
09:55	1.77	12.0	31.0	3.7	18.8	19.7
10:05	1.76	12.5	31.0	3.7	18.8	19.7
10:15	1.71	13.0	31.0	3.7	18.8	20.0
10:25	1.68	14.0	31.0	3.7	18.8	20.0
10:35	1.68	15.0	31.0	3.7	18.8	20.0
10:45	1.70	15.5	31.0	3.7	18.8	20.2

Time C.S.T.	Pressure Altitude mm Hg	Temperature degrees Centigrade	Nominally 28v supply volts	Nominally 6v supply amperes	Spark Chamber Pressure psi	Electronics Bell Press. psi
10:55	1.70	16.5	31.0	3.7	18.8	20.2
11:05	1.66	17.0	31.0	3.7	18.8	20.2
11:15	1.65	17.5	31.0	3.7	18.8	20.2
11:25	1.66	17.5	31.0	3.7	18.8	20.3
11:35	1.66	18.0	31.0	3.7	18.8	20.3
11:45	1.69	18.0	31.0	3.7	18.8	20.3
11:55	1.76	18.5	31.0	3.7	18.8	20.3
12:05	1.81	19.0	31.0	3.7	18.8	20.3
12:15	1.87	20.0	31.0	3.7	18.8	20.3
12:25	1.87	20.0	31.0	3.7	18.8	20.3
12:35	1.89	20.5	31.0	3.7	18.8	20.4
12:45	1.89	21.0	31.0	3.7	18.8	20.4
12:55	1.82	22.0	31.0	3.65	19.0	20.4
12:05	1.75	22.05	31.0	3.65	19.0	20.4

Time C.S.T.	Pressure Altitude mm Hg	Temperature degrees Centigrade	Nominally 28v supply volts	Nominally 6v supply amperes	Spark Chamber Pressure psi	Electronics Bell Press. psi
13:15	1.73	23.0	31.0	3.60	19.0	20.4
13:25	1.71	23.0	31.0	3.60	19.0	20.4
13:35	1.69	24.5	31.0	3.50	19.0	20.4
13:45	1.69	24.5	31.0	3.50	19.0	20.4
13:55	1.65	25.0	31.0	3.50	19.0	20.4
14:05	1.64	25.5	31.0	3.50	19.0	20.4
14:15	1.62	26.0	30.0	3.45	20.2	20.4
14:25	1.63	26.5	30.0	3.45	20.2	20.4
14:35	1.62	27.0	30.0	3.45	20.2	20.4
14:45	1.63	27.0	30.0	3.45	20.2	20.4
14:55	1.65	27.0	30.0	3.45	20.2	20.4
15:05	1.68	27.0	30.0	3.45	20.2	20.4
15:15	1.72	27.0	30.0	3.45	20.2	20.4
15:25	1.75	27.5	30.0	3.45	20.2	20.4

Time C.S.T.	Pressure Altitude mm Hg	Temperature degrees Centigrade	Nominally 28v supply volts	Nominally 6v supply amperes	Spark Chamber Pressure psi	Electronics Bell Press. psi
15:35	1.75	27.5	30.0	3.45	20.2	20.4
15:45	1.77	27.5	30.0	3.45	19.4	20.1
15:55	1.77	28.0	30.0	3.45	19.4	20.1
16:05	1.79	28.0	30.0	3.45	19.4	20.1
16:15	1.8	28.0	30.0	3.45	19.5	20.2
16:25	1.79	28.0	30.0	3.45	19.5	20.2
16:35	1.79	28.0	30.0	3.45	19.4	20.2
16:45	1.80	28.5	30.0	3.45	19.5	19.9
16:55	1.85	28.5	30.0	3.45	19.5	19.8
17:05	1.89	28.5	30.0	3.45	19.5	19.8
17:15	1.88	28.0	30.0	3.45	19.6	19.8
17:25	1.88	28.0	30.0	3.45	19.6	19.8
17:35	Termination of flight (17:28 C.S.T.)					

Systems Layout

The major items of equipment in the gondola are concentrated at the same end. The camera is positioned below the spark chamber, the electronics bell is beside the chamber and the main junction box is behind the bell. This was necessary because the electronic connections must be kept short. Only the mirrors are required to be at the opposite end of the gondola.

To balance the gondola and take best advantage of the available space, the batteries are put at the far end beside the mirrors. They weigh roughly twenty-five pounds while the entire gondola weighs 200 pounds with rigging. The Wollensak camera is positioned below the battery pack and looks back at the panel below the electronics bell. A junction box is built into the battery supporting framework. This box, designated the battery junction box, contains the relays which control the turn-on operations.

Upon a command from the ground, the six volt battery pack is turned on. After two minutes the 28 volt battery pack is switched on and the high voltage is then generated. Turning the two on simultaneously may damage the tubes. A thermal delay tube provides the two minute delay, but a second radio command parallels this.

Flight instruments to terminate the flight and provide radio contact with the balloon from the ground are hung from below the

gondola in another box. These are furnished by the National Center for Atmospheric Research. A beacon in this box transmits the altitude in code to the ground station. At the desired altitude, a signal is transmitted to the receiver in this box which in turn activates a relay in the battery junction box to turn the gondola on. A failure of this receiver would abort the flight. A timer is included, therefore, to parallel the turn-on function. When the six volt battery pack is turned on in the gondola, a relay is activated which changes the frequency of the radio beacon. When the 28 volt battery pack is turned on by either the thermal delay tube or by radio command, the beacon frequency is changed back to its original value. In this way an indication is given to the ground station that the functions have been performed. Another attempt can be made at turning the equipment on if this indication is not received.

The gondola is hung from the balloon with a parachute stretched from the balloon's bottom fitting to the ring on top of the gondola's rigging. At the end of the flight, a radio command cuts the parachute from the balloon by detonating squibs on the nylon tie line. The chute, gondola and radio command box plummet from the balloon. At roughly 100,000 feet the parachute deploys and lowers the gondola to the ground. An airplane maintains radio contact with the falling gondola until

visual contact is made and the gondola is on the ground.

ELECTRONIC TRIGGERING SYSTEM

Detectors

A pair of scintillation detectors in coincidence trigger the spark chamber, (see block diagram). The upper detector is a piece of pilot "B"* plastic fluor, 4 x 4 x 1/2 inches, viewed on the side by an Amperex 152 AVP.† This is a ten stage photomultiplier tube having a photocathode diameter of 14 mm. When operated at 1800 volts the tube has an overall gain of 5×10^8 . The anode sensitivity is 30 A/lumen.

The lower detector is a block of Pilot "B", 2 x 2 x 1 inches, viewed from below by another Amperex 152 AVP. A pyramidal light pipe 1 1/2 inches tall is used to join the photomultiplier to the plastic fluor, (see figure #8). The upper fluor and lower fluor with its light pipe are wrapped in aluminium foil and covered with black photographic tape. The two detectors are spaced 8 1/4 inches apart, giving a maximum area, solid angle factor of $5.7 \text{ cm}^2 \text{ sr}$.

Silicone grease is used to make optical contact between all optical joints. A slight pressure is maintained on the

*Trade name, Pilot Chemical Company.

†Amperex Electronics Corp., 230 Duffy Avenue, Hicksville, Long Island, New York.

DETECTOR ARRANGEMENT

lower detector and its photomultiplier tube by pressing the tube up against the bottom of the chamber and clamping the tube in its bracket. A rubber band on the back of the upper detector's tube applies a slight pressure.

Preamplifiers and Coincidence Circuits

The output from these detectors is about .07 volts in amplitude for minimum ionizing particles. Preamplifiers bring the pulse voltages to 3.3 volts and clip larger pulses at this level. The preamplifiers are five stage amplifiers with feedback for temperature stability, (see figure #9). The delay in the preamplifiers is about 12 nanoseconds, but as short as 8 ns for large pulses. The preamplifiers are supplied by a 10 volt reference diode which makes them independent of battery voltage and isolates them from rotating equipment. That is, equipment requiring large current surges and which reduces the line voltage.

The outputs from the preamplifiers are fed into a diode coincidence circuit having a time resolution of 50 nanoseconds. The bias of the "coincidence transistor" is supplied by two 220 ohm resistors and two diodes tied to its base. While current is flowing in these diodes, the "coincidence transistor" is held off. A pulse from one preamplifier cuts only one diode off and this is not sufficient to turn the "coincidence transistor" on. When current from both diodes is shut off by pulses from

PREAMPLIFIER AND COINCIDENCE CIRCUIT

the preamplifiers, the transistor conducts.

Since the preamplifiers can deliver a maximum of 3.3 volts, the bias level must be set on the "coincidence transistor" so that this voltage from one preamplifier isn't sufficient to turn it on. This is adjusted with the 1000 ohm potentiometer on the emitter of the "coincidence transistor". For the detector system to work with the discrimination level set such that this requirement is met, a minimum ionizing particle in the detectors must produce at least a 3.3 volt output from the preamplifiers.

This sets a minimum photomultiplier voltage below which coincidences by single relativistic particles are not possible. A test was made on the detector system to determine what this minimum photomultiplier voltage level was, (see 1500 v Photomultiplier Supply, p.75). The voltage on the photomultiplier tubes must be greater than 1400 volts as determined by this test. The voltage during the flights was set at 1500 volts. This can be monitored throughout the flight by observing the straight-through non-interacting protons, "straight-throughs".

The maximum output pulse voltage from the preamplifiers is a key factor in operation of the logic circuit. The maximum output can vary with temperature and supply voltage. It must be noted here that this maximum is not determined by the zener diodes on the base of the "coincidence transistor". These diodes are to limit the amount of radio noise fed back by the

spark chamber when it "fires". This noise sometimes destroys the output transistor of the preamplifiers.

The saturation current of the last transistor in the preamplifier is one element determining the maximum output pulse voltage from the preamplifiers. This can vary with temperature. When the temperature increases, the saturation current increases and the output pulse voltage also increases. For this reason a safety factor must be used. Therefore, a 3.5 volt pulse from one preamplifier must not be able to turn the "coincidence transistor" on.

In principle, the diode coincidence circuit shouldn't be effected by input pulse height. Once the output transistor is saturated, the pulse height is as large as it can get. Also, once the current through the diode is stopped, no further effect can be produced by that preamplifier. A combination of effects makes the logic non-ideal, however. The negative feedback is only transient, consequently, a long pulse will have less negative feed-back toward its end than near its leading edge. Long, large pulses will produce a larger output. This alone would be tolerable, but the inherent capacitance in the diodes permits the narrow pulses to pass and the current through the diode is not only stopped, but a reverse current occurs.

When both preamplifiers deliver a 3.3 volt pulse to the "coincidence transistor" it turns on, producing a 5 volt output

pulse. A number of functions must be performed upon coincidence and this one transistor wouldn't be able to deliver the energy to do everything. For this reason, an avalanche transistor is used to "fan out" the signal. Its output pulse serves the primary purpose of triggering the high voltage amplifier for the spark chamber. The secondary functions are triggering of the camera advancing mechanism, dead time system and panel light pulsing system. The output pulse from the avalanche transistor is 10 volts, but can be made as high as 110 volts with a 50 ohm output impedance.

Since the output impedance is so low, it shunts the radio frequency noise to ground hence isolating the preamplifiers and coincidence circuit from the high voltage amplifier. Only a nanosecond delay is incurred by adding this fan-out stage to the logic circuit.

Dead Time System

The dead time system allows the camera to advance and the high voltage supplies to recover before another event is accepted. The camera advance and the panel light pulsing systems will be discussed later. In general, the camera is the limiting factor determining the maximum rate at which events can be accepted. The dead time must be longer than the time necessary for the camera to present a new frame. The other elements in the gondola

can be made to recover much more rapidly than the camera can advance a frame. To save power, however, it was possible in this experiment to introduce a longer dead time and allow the high voltage supplies to recover slowly. The dead time was small compared to the average time separation between events despite the increase. For this reason an accurate counting rate measurement was possible.

If particles going through only one detector, "singles", trigger the system, the repetition rate will be high. This renders the spark chamber less efficient in defining events. "Singles" counting occurred during the first hour of flight 69P and first several hours of 78P, (see, DATA ANALYSIS section). The dead time wasn't long enough to permit the spark chamber to operate with 100% efficiency during a continuously high repetition rate. The rates taken during these periods were inaccurate because the dead time was comparable to the live time.

A pulse which occurs less than 120 milliseconds behind another will not trigger the spark chamber. When the avalanche transistor fires, a flipflop circuit is triggered. This circuit, designated the dead time system, applies a negative pulse to the secondary emission tube which is 120 ms long. This pulse starts several microseconds after the secondary emission hexode has conducted and hence doesn't hinder its

DEAD TIME FLIP FLOP

operation. This pulse aids the tube in its recovery (see figure #10).

High Voltage Pulse Amplifier

The high voltage pulse amplifier consists of three elements, a secondary emission hexode, hydrogen thyatron and a spark gap. The first stage of the amplifier is the secondary emission tube, originally manufactured by C.B.S., but now made by the York Company.* This tube, the 7548, was chosen for its high voltage gain and non-inverted output. A 10 volt positive input yields a positive 700 volt output with a rise time of 20 nanoseconds and delay of 30 nanoseconds. The output is taken from the dynode and fed to the thyatron grid.

The hexode is operated in a boot-strap cathode follower mode. The plate signal which is normally the output of a tube is fed back to the cathode. This increases the output pulse rise time of the device. The electrons pulled from the cathode are accelerated toward the dynode. At the dynode, each electron knocks three more electrons free, which are then accelerated toward the plate. The effect of the electrons being knocked from the dynode is to leave it positive. Once the grid is pulsed the tube will continue its cycle until the capacitor

*The York Research Corporation, Stamford, Connecticut

HIGH VOLTAGE PULSE AMPLIFIER

between the cathode and plate is discharged. When this capacitor is discharged, current will flow in the 1000 ohm resistor between the cathode and ground and made the grid negative with respect to the cathode. The output pulse voltage will be roughly the amplitude of the potential difference between the dynode and plate in their quiescent state. When this is made excessive the rise-time of the output pulse becomes slow. With 1000 volts on the plate the dynode can be made between 300 and 500 volts. This gives 700 to 500 volts output with a 50 to 30 nanosecond rise-time.

The thyatron conducts when its grid reaches 300 volts. Although as much as 100 volts bias can be used, no bias was used during the flights. The power for this class C amplifier is excessive. The delay was reduced, to compensate for this omission, by triggering the thyatron with a high voltage pulse. The output pulse reaches 7 kilovolts about 100 nanoseconds after receiving the trigger pulse.

This thyatron, HY-2, 7621, was selected because of its relatively low filament power and its rugged construction. E. G. & G.* developed this small, compact, ceramic tube specifically for airborne applications. It consumes 20 watts in its filament, roughly half the power used in the gondola.

*Edgerton, Germeshausen and Grier, Inc.; Boston, Massachusetts.

Finally, the energy is switched to the spark chamber itself by two GP-17A spark gaps developed by E. G. & G. This spark gap fires when its trigger electrode reaches 3 kilovolts. The spark gaps release energy stored in six high frequency capacitors* .0005 microfarad capacitors connected to the thick plate chamber's high voltage plates and two .0002 microfarad capacitors on the thin plate chamber. One spark gap is the switch for the thin plate chamber and the upper three capacitors on the thick plate chamber. The other spark gap is the switch for the lower three capacitors on the thick plate chamber. These lower three capacitors store energy for the lower six gaps of the spark chamber. For showers and interactions, these will have more particles and require more energy. By devoting one spark gap to these lower gaps, their efficiency for showing the many particles was increased.

The delay between thyatron pulse and spark chamber breakdown is less than 50 nanoseconds and probably less than 20 ns. The total delay between particle passage and the spark chamber break-down is 220 nanoseconds. This assumes a 30 nanosecond delay in the photomultiplier tubes. This total delay is shorter than necessary to achieve 100% efficiency with single particle

*.0005 microfarads, 25 KWVDC capacitors made by Plastic Capacitors Inc.; Chicago 14, Illinois.

events (11).

The rise-time and shape of the pulse from the spark gap to the spark chamber are unknown due to the difficulty in eliminating the associated radio frequency noise from the spark gaps and spark chamber. This noise by-passes the oscilloscope's attenuator and obscures the trace. The delay measurement is accurate despite this difficulty since the radio noise occurs after the delay to be measured.

POWER SUPPLIES AND FILTERING SYSTEMS

1500 Volt Photomultiplier Supply

The simplicity of the detector system allows the gain in the photomultiplier tubes to vary without perturbing the experiment. It is necessary, however, for the gain to remain greater than a minimum value. As mentioned previously, a minimum ionizing particle passing through a detector must produce a three volt pulse from the preamplifier. Without measuring the actual gain of the photomultiplier tube, the minimum voltage can be determined by using "sea level mu-mesons".

The detectors were arranged similar to the flight assembly, except all absorber was removed from between and above them. To determine the threshold, the detectors were put in coincidence, and the rate was measured over a thirty minute period. The supply voltage to the photomultipliers was varied in steps and the rate at each step recorded. The results are plotted in figure #12.

The relativistic muons all give the same pulse height regardless of energy. The ionization is a very weak function of energy once the particle is relativistic. As the gain of the photomultiplier system is increased, a point is reached when these minimum ionizing particles produce a three volt pulse .

from the preamplifier. At this point the coincidence rate will suddenly increase. The rate will stay constant despite a further increase in photomultiplier gain. The voltage at which this sudden increase occurs is the minimum voltage allowable during the flight.

Several factors could enter here to complicate the calibration above. The flux of sea level muons follows a cosine squared law, that is the flux falls off as the cosine² of the angle from the vertical. The solid angle of the detectors is small enough, however, that the flux can be considered to be constant.

Another complicating feature results due to the finite thickness of the detectors. The upper detector is a half inch thick. The lower one is one inch thick. The fringe effect for these detectors can be as much as fifty per cent. It is this feature that causes the continuous rise in coincidence rate even after the minimum ionizing particle threshold has been exceeded.

When the gain is raised too far above the point of diminishing returns for coincidences, the tube noise becomes excessive. The noise can get frequent enough as to give chance coincidences. This voltage is a characteristic of the photomultiplier tube and for the 152 AVP is at 1650 volts. A particularly noisy pair of tubes will not have a clearly defined threshold at which all true coincidences are counted. The coincidence rate from such a pair

of tubes will just increase as the voltage increases and have a smooth curve. The pair of tubes used has a combination of the two extremes as, of course, all tubes are non-ideal.

The threshold voltage is seen on the plot to be 1400 volts. These photomultiplier tubes can be operated with up to 1800 volts, but the noise becomes excessive at 1650 volts. The bounds on the photomultiplier supply are 1400 to 1600 volts. A d.c. to d.c. inverter, model 320 m, was purchased from Universal Transistor Corporation* as the photomultiplier supply. This supply operates from 28 volts and draws about 35 ma under load. The variable output was adjusted to 1450 volts during the flight. One meg ohm resistors were used in the dividing chains of the photomultiplier tubes, producing a 5 meg ohm load with both tubes operating. The inverter has an efficiency of 50%.

One Kilovolt Plate Supply

The secondary emission hexode and the avalanche transistor require voltages higher than reasonably can be supplied with batteries. For these two elements a separate d.c. to d.c. inverter is used. A one kilovolt inverter similar to the one used for the photomultiplier supply was obtained from the

*The Universal Transistor Corp.; 380 Oak Street, Copiague, Long Island, New York.

Universal Transistor Corporation also. This supply is capable of delivering 1.2 milliamperes at one kilovolt. The supply draws 155 ma from the 28 volt batteries while under load, thereby having 28% efficiency.

The output of the supply is regulated by a corona discharge tube, GVS-1000*. The avalanche transistor, requiring only 150 volts, is supplied from this one kilovolt inverter by reducing the voltage with a 10 meg ohm resistor and regulating this by a coratron. The coratron is a Victoreen Instrument device, VX 64.

Regulating and Filtering System

The camera clutch, register solenoid and the magazine motor are activated simultaneously by the avalanche transistor. These inductive devices produce noise which continues throughout the dead time interval. This noise would prevent normal recovery by the supplies and in some places produce failure of an element. To isolate the electronic elements from these inductive devices a filter is put on the 28 volt line to the semiconductor elements.†

A "T" filter is made with two 2500 microfarad capacitors and two hash filter chokes, Miller 7825. This filter is used

*Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.

†J. W. Miller Company, 5917 S. Main Street, Los Angeles, California (0.6 millimeter).

on the 28 volt line going to all elements of the gondola using semiconductor elements. The nominally 28 volt battery pack varies from 28 volts to 36 volts so zener diodes are used for the individual semiconductor circuits.

The preamplifiers require 10 volts. A single reference diode 1N2624 is used to provide the ten volts for both preamplifiers, (see figure #13 A). The coincidence circuit, avalanche transistor bias and secondary emission hexode bias are all supplied by another reference diode, 1N2624, (see figure #13 B).

The two d.c. to d.c. inverters, photomultiplier supply and the one kilovolt plate supply, are regulated at their input by a single 10 watt zener diode, 1N2988, (see figure #13 C). The multivibrators in the inverters draw large current surges when in the "on" mode. For this reason they could interfere with each other. To prevent interference, a 33 ohm resistor is put in series with the one kilovolt supply and then a capacitor filters the surge on the inverter itself. The photomultiplier, 1500 volt supply, needs a greater regulation, hence the resistor could not be put on it even though it is the less powerful of the two. In addition to the capacitor on the inverter in the 1 kilovolt supply, there is also two on the zener diode. A 10 microfarad electrolytic type and .05 microfarad

ZENER REGULATORS

disc capacitor in parallel.

10 Kilovolt Cockroft Walton Generator

The 1/4 inch gap between the plates of the spark chamber can be broken down with as little as 5 kilovolts. The spark chamber principle, however, requires a fast rise pulse of larger than static breakdown amplitude. The energy stored in the radio frequency capacitors on the spark chamber is switched to the high voltage plates by two spark gaps. The spark gaps can hold off a maximum potential of 12 kilovolts. The nearer to this maximum one operates the spark gap, the more rapidly it will switch the stored energy.

On the other hand, after repeated pulsing the spark gap's maximum hold off potential decreases. To prevent spontaneous breakdown from the aged spark gap, a compromise of 10 kilovolts was used. At this voltage the spark gap is capable of at least 400,000 pulses before the static breakdown potential becomes too low. The delay in breakdown is less than 50 nanoseconds with 10 kilovolts.

A 10 kilovolt supply capable of recharging all the radio frequency capacitors in the dead time interval of 120 milliseconds is necessary. In addition this power supply must regulate its output. The output must stay below the static breakdown potential of the gap and yet high enough to prevent unnecessary

delay. G.A.W.*, under contract, developed a multivibrator-Cockroft Walton multiplier which is adjustable from 8 to 12 kilovolts, (see figure #14).

Two kinds of feedback are possible with the regulator. The recovery time for recharging the capacitors is shorter when feedback is obtained from the output. The adjusted output is regulated to $\pm 1\%$ with a variation of input from 24 to 36 volts and in a temperature range from 0 degrees to 40 degrees centigrade. If less regulation can be tolerated, the feedback can be obtained from the positive terminal of the multivibrator. This feedback connection has the advantage of making the inverter more efficient.

For maximum efficiency, germanium transistors are used in the multivibrator. Normally only silicon transistors are used in applications where extreme temperatures are encountered, but they aren't as efficient at high frequencies. The square shaped wave produced by the multivibrator has a fundamental frequency of 5000 cycles/sec., yet has a high frequency content also.

The ideal multivibrator would have a wave shape perfectly square. That is, its transistors would be either completely on or off and make the transition between the two states in no

*August Hruschka, William Voelker, Cleveland, Ohio.

HIGH VOLTAGE INVERTER

time. In this way, minimum transistor losses occur. This wave shape, however, is non-ideal for the transformer. The core material has a low permeability at high frequencies. Consequently, transformer losses would become significant. A compromise is made between transistor losses and transformer losses.

The existence of two germanium transistors in the multi-vibrator reduces the maximum ambient operating temperature. This restriction is lessened, somewhat, because of the relatively little power drawn by the inverter compared to that which the 2N1905 transistors are capable of dissipating. These 2N1905 transistors are rated at 50 watts while only 5 watts is used by the inverter. The transistors' junction temperatures will remain nearly the same as ambient, thus increasing the maximum allowable ambient temperature.

The square shaped wave of the multivibrator is transformed with a Spellman T-7A transformer to roughly 2.5 kilovolts half peak potential. The secondary of the transformer produces a wave shape which is the differential of the primary and has a saw tooth shape. The multivibrator has been used with a ten stage Cockroft Walton multiplier chain to produce 25 kilovolts.

The multiplier stages of the Cockroft Walton are constructed from .005 microfarad capacitors* and 1N2381 diodes† having a

*D6-75-5; Plastic Capacitors Inc., Chicago 14, Illinois.

†1N2381; General Instruments, 600 W. John Street, Hicksville,

10 kilovolt peak inverse voltage. The multiplier string is encapsuled in silicon rubber compound* to prevent corona. This enables the entire assembly to be placed inside a metal container.

The output from the multiplier section is fed through a 1000 meg ohm resistor to the 50 K ohm trimpot in the regulator. This is compared with the potential of the 1N429 reference diode. The difference is sensed with the differential amplifier consisting of two TI 429 and two 2N929 transistors. The output from the differential amplifier is amplified by another TI 429 and used to bias a series regulator with another TI429. The series regulator utilizes two transistors to regulate the amount of current to the multivibrator. The 2N1579 provides the necessary power amplification to control the 2N1483 which transmits the current to the multivibrator. All regulator transistors are silicon material.

Long Island, New York.

*Dow Corning, RTV 501.

SPARK CHAMBER PROPERTIES

The spark chamber more nearly satisfies all the requirements of this experiment than any other detector. I've had an opportunity to learn, during this experiment, however, some limitations of this detector which can possibly be eliminated in the future.

A detector was required for this experiment that can segregate a large number of unwanted particles from a relatively small number of electrons. Since all the electrons will interact in the spark chamber, the detector system was arranged to enhance the number of interactions compared to the number of "straight throughs". Only a small portion of the protons will interact in the chamber. The lower detector was made small to produce a small area solid angle factor for "straight through" particles. Particles which interact, however, will still be accepted over a large solid angle. The scattering and multiplying of particles in an interaction produces a higher probability that one may get into the lower detector.

This same feature, however, also produces many unwanted events. Interactions due to particles at extremely wide angles will occasionally trigger the detector system. These events can't be used because the chamber has too low an efficiency for

exhibiting them.

Furthermore, the detectors' solid angle-area factor cannot be used when calculating the flux of interacting particles. This must be determined after the events have been scanned. An area-solid angle factor was finally determined for the shower-type events which was approximately 40% larger than that for the "straight throughs". It must be noted here that this system inherently produces an uncertainty in determining the flux, due to the possible errors in choosing events which are in the solid angle.

To determine whether a specific event is in the solid angle or not, its initiating particle must be seen. When this wasn't possible, the center of the shower particles was used to obtain a center line. In either case the trajectory of the incoming particle or the center line of the shower was required to intersect specified dimensions at the top and bottom of the chamber. These events not satisfying this requirement were not used.

Larger solid angles could be used with this spark chamber if the efficiency for wide angle tracks wasn't low. The spark chamber is capable of displaying a single track left by a particle making an angle of 40 degrees with the perpendicular. This same track, however, might not be displayed if it is in the midst of other tracks left by particles traveling nearly perpendicular

to the plates of the spark chamber. For this reason a narrow coincidence cone is used. Experiments using the spark chamber to detect events with few particles can use larger solid angles.

Another problem encountered with interacting particles is that they have a greater probability of being detected when the interaction is initiated in the top of the chamber. Interactions initiated high in the chamber scatter and multiply more than those initiated below. Electron soft showers will be developed by $8 \frac{1}{2}$ radiation lengths when they are initiated in the top of the chamber. Nearly all the electrons, 97%, will interact in the first three plates.

Back scattered particles from interactions in the top plates can trigger the event. This phenomenon produces wide angle events which can't be used. Only the upper few plates are involved with this phenomenon because the back scattered particles are of relatively low energy. Inclusion of these would enhance the detection efficiency of the upper plates and greatly effect the electron flux measurement. Wide angle interactions are the most numerous spurious types of events.

Particles on the periphery of the shower may not be displayed by the spark chamber. The energy of the discharge will concentrate at the core of the shower and therefore, peripheral tracks will be dim or not seen. The edge particles in general

make a larger angle with the perpendicular to the plates and thereby suffer in efficiency of display. Although there is a correspondence between shower width and energy, the relationship is not a simple one.

In general, the shower structure as viewed with the spark chamber, cannot be studied in detail. For example, a soft shower cannot be differentiated from a nuclear interaction, when many particles are present. No use can be made of the hard core in a nuclear interaction. Further study of this problem may prove worthwhile, however.

Individual electron events cannot be identified so another means must be used to select the electron flux from the proton background. To do this, use is made of the difference in interaction length. All the electrons interact in the first few plates. The nuclear particles, on the other hand, have such a long interaction length that almost the same number will interact in each plate.

This method depends heavily on the spark chamber's ability to determine the exact plate of interaction for a specific event. Several characteristics of the spark chamber inhibit this judgment. Gaps two, four and six are less efficient than gaps one, three and five. Also, for interactions which broaden slowly, it is difficult to know whether there are two particles close

together or just one particle.

The second difficulty, interactions which broaden slowly, cannot be surmounted. Careful scanning is required to minimize its effects. The first difficulty can, however, be circumvented by treating the even numbered gaps added to a neighboring odd gap, (see DATA ANALYSIS section).

This even-odd distribution of energy can be explained electronically. Gap number one is more efficient than number two. This is because number one gap doesn't share a ground plate with another gap as all others do. The energy stored in the capacitor connected to plate number two is divided between the first two gaps. Since gap number one has a better ground than number two the energy is split unevenly in favor of the first gap. This unbalance is transmitted to gap number three by the capacitance between plates number three and four. Plate number three is ground for gaps number two and three. To gap three, therefore, a better ground is presented than to gap four. Again the energy is divided unevenly. This transmission dies out by the fourth high voltage plate and is almost unnoticeable to gap six. No trace of this unbalance is seen when looking at "straight through" type events.

An attempt to minimize this effect was made, but with only limited success. By making all grounds as good as possible and

reducing lead length and inductive connections, the effect was minimized. The capacitors and spark gaps themselves must be modified to eliminate this problem completely. The basic problem seems to be that the energy is delivered to the chamber plates with a spiked shape pulse. A more ideal shaped pulse would be a square shape or at least one with a more gentle decline than that of a spike. The effect of going to a square shape would be to distribute the energy over a longer time and yet still provide a fast rise time. One method of doing this might be to store energy in a coaxial cable instead of a capacitor.

DATA ANALYSIS

Noninteracting protons and heavier nuclear particles trigger the detectors. As mentioned previously, however, they have a smaller coincidence cone than the interacting particles, (see SPARK CHAMBER PROPERTIES). The flux of these particles is relatively well known and their rate can be calculated. Their rate should be constant throughout the flight and be the same for both flights. The difference in the residual atmosphere will not affect the rate because the nuclear interaction length is large compared to it.

The flux of cosmic ray penetrating particles has been measured by other investigators and is given as $600 \pm 50/\text{sr}/\text{m}^2/\text{sec}$. (2), (14), (19), (20). Therefore, for a pair of detectors defining an area solid angle of 5.73 sr-cm^2 the rate will be 20.6/min. The fraction of these particles that will interact in the spark chamber can readily be calculated assuming the proton interaction length is 120 gm/cm^2 and the alpha particle interaction length is 68.9 gm/cm^2 (21). The portion of the penetrating particles which are alphas is obtained from other experiments and determined as 12%, (19). Using these values and the total material for interaction in the spark chamber, 52 gm/cm^2 , it is found that 61% of the penetrating particles will not interact, 12.6/min.

The area solid angle factor used above is the largest one possible for the detectors. This is the cone calculated assuming the particles need just touch the edge of the scintillation fluor. Because the detectors have a finite thickness, an exact coincidence cone is not defined. The cone calculated by assuming the particles must completely traverse the fluors to be detected, is 3.78 sr-cm^2 . This would produce a rate for non-interacting particles of 8.3/min. Consequently, a variation of 42% can be explained by the detector's thickness effect.

The most reasonable rate for non-interacting particles is that calculated assuming they need traverse $1/4$ inch of fluor in each detector. This rate would be 11.3/min. The remainder of the particles will interact, 7.2/min, (see Appendix A). Not all of these interactions will be identified as nuclear interactions. Many will not produce other particles energetic enough to get out of the lead plates and hence will be identified as non-interacting. For this reason an accurate interaction rate cannot be measured.

In addition to this problem, there is the atomic interaction, knock-on electrons, which is not included in the nuclear interaction length. The high energy nuclear particle will occasionally transfer enough energy to an atomic electron from the plate material, to knock the electron into the gap. There

will appear a double spark in that gap. The proton will continue in a straight path perhaps with no other interaction, (see photograph #6).

Knock-on electrons have been observed by other investigators with other detectors, (15). The number obtained from this cloud chamber experiment, compares with that for the spark chamber; 0.015 knock-ons per penetrating particle per plate in the cloud chamber and 0.02 knock-ons per penetrating particle per plate for the spark chamber. This number for the spark chamber remains the same when the plate thickness is changed. The same number was obtained with 1/4 inch lead plates, 10 mil stainless steel plates and 20 mil stainless steel plates.

The mild nuclear interactions and knock-on type events cannot be differentiated with the spark chamber. At sea level, however, the knock-on events can be isolated since very few high energy nuclear particles are present. In comparing these results with the knock-on events at altitude, it must be assumed that the relativistic mu-meson and proton produce the same number knock-ons. This has been studied by others and proven to be a good assumption, (16), (17). At altitude, where nuclear interacting particles are present, there does not appear to be any way of measuring the knock-on rate.

The "straight through" rate calculated for the detector system at altitude is really the rate of "straight through" plus

KNOCK-ON EVENT

knock-on rate. To determine this from the data, only the "straight through" events were used. To this number was then added the number of knock-on events calculated from the percentage determined from sea-level mu-meson observations. The rate of "straight through" events was determined in an area solid angle of 5.73 sr-cm^2 . Using these events and the above considerations, the flux of penetrating particles for the lower flight, 69P, was found to be $550 \pm 50/\text{sr/m}^2/\text{sec}$. The higher flight had a measured flux of $567 \pm 50/\text{sr/m}^2/\text{sec}$. These rates stayed within statistical standard deviations throughout the time data was accumulated for this thesis.

During part of the higher flight, 78P, the logic circuit triggered the spark chamber on "singles". That is, a particle traversing only one detector triggered the spark chamber. The system, however, still counted on useful events. Live time and film were expended because of this malfunction.

A second useful function was served by the "straight through" events, that of determining the sparking efficiency of the spark chamber throughout the flight. This was determined for the period of time over which data was collected for this thesis and the efficiency remained 100%. The multiple sparking efficiency, however, cannot be measured. More stringent requirements are necessary for 100% multiple sparking efficiency, hence the

straight through efficiency sets only a lower limit. It can be said that the multiple sparking efficiency remained above a minimum acceptable level, but not that it remained 100% or constant.

As mentioned previously, the penetrating particles not identified as "straight through" events are interactions. This rate should be 7.0/min, or 39% of the total flux. The portion of these interacting in each section of the spark chamber can be calculated, knowing the breakdown of the material in the chamber:

top module + plate #1	8.0 gm/cm ²
each lead plate	6.28 gm/cm ²
each magnesium plate	1.11 gm/cm ²
total material	52.0 gm/cm ²

The proton interactions are calculated using an interaction length of 120 gm/cm². The fraction of penetrating particles which are alphas is obtained from other experiments and given as 12%, (19). Taking this into consideration, the number of nuclear interactions per plate can be calculated:

top + plate #1	1.21 c/min.
plate #2	0.93 c/min.
plate #3	0.90 c/min.
plate #4	0.87 c/min.

plate #5	0.84 c/min.
plate #6	0.80 c/min.
plate #7	0.76 c/min.
plate #8 thru #12	0.75 c/min.
total interactions	7.06 c/min.

The correction due to heavier particles than alphas is small. Several nuclear interactions are pictured in photographs #7 and #8. All of the above interactions will not be identified because some will be too weak. Coulomb scattering type interactions are included in the interaction lengths given. Only interactions that produce secondary particles that can traverse several lead plates will be detected. The above calculation will, however, indicate the slope a line will take, drawn through the interaction per plate curve. That is, the number of missing interactions per plate should be the same, assuming they are few.

The electron flux was obtained from the data by subtracting the proton events from the total interactions. This cannot be performed for individual events because the spark chamber is not capable of showing the necessary detail for labeling a specific event, (see SPARK CHAMBER PROPERTIES). Instead, advantage is taken of the difference between the interaction lengths of the electron and nuclear particles to segregate the two types of interactions.

-100-

NUCLEAR INTERACTION EVENT

-101-

NUCLEAR INTERACTION EVENT

All electrons will interact in the first three plates of the chamber. Nuclear particles will interact almost equally in every plate, see the distribution on the previous page. By examining the interactions in plates 4 and lower, the nuclear interactions in plates 1, 2 and 3 can be determined. Figures 15 and 16 show this for the two flights. The straight line representing the nuclear interactions was determined using interactions in plates #4 + #5 and #6 + #7.

In general, a more accurate line could be determined for the nuclear interactions by using a least squares fit to all four plates. This was not possible, however, because of the even-odd gap sparking, (see SPARK CHAMBER PROPERTIES). The error limits are statistical standard deviations and do not contain the possible instrumental effects. The effects of the dead time are small as determined from the "straight through" rate.

The interactions were obtained from the film in three steps. The events were catalogued into five categories: "straight throughs", "interactions", "no sparks", "questionables" and "others". The first two categories contain the pertinent events for this experiment. Further analysis was subsequently performed on these.

The "straight through" column contained all the events

FLIGHT 69P

Events in 9.64 sr cm^2
Reel #4 44.05 min
116 Total Events

Reel #5 33.9 min
52 Total Events

$10.3 \pm 2.8 \text{ ele/sr/m}^2/\text{sec.}$
 4.35 g/cm^2 Residual Atmosphere

FLIGHT 78P

Reels #3 and #4 to Sheet #26

78 Total Events

71.65 min

9.64 sr cm²

6.5 ± 3.2 ele/sr/m²/sec.

2.16 g/cm² Residual Atmosphere

Figure #16

-105-

STRAIGHT THROUGH EVENT

with no double sparks, (see photograph #6). The heavier multiply-charged particles are also in this section. These, however, have many multiple sparks as well as a straight track. The effect is not too dissimilar from the "shaggy dog" effect of the nuclear emulsion. Mu-mesons are also in this column and characterized by a scattering particle penetrating the entire chamber and not interacting.

The interactions of both electron and nuclear character were placed in the "interactions" column. Knock-ons were also put in this column even though they aren't strictly the same class of interaction. Interactions due to particles entering the chamber at wide angles weren't included, but placed in the "questionables" or "other" columns. The "interactions" column of events was rescanned and then each event was measured if, more than two particles were seen to leave the bottom, the center line intersected the first and last gap, and the width of the shower cone was defined and less than half a spark chamber wide. Four measurements were made on each event and for each projection, the position of its top, its far left side, its center line at the bottom, and its far right side.

The events surviving this set of criteria were then separated according to their angle and position in the chamber.

Those not having their center line in a specified cone were discounted. The remainder were tabulated according to their plate of interaction. These are the ones used in the flux calculations shown in figures #15 and #16.

The "no-spark" column contains the events which have given coincidence, but not gone through the spark chamber. An example of this type are the interactions of particles with the material in the gondola. These may give low energy radiation sufficient to produce a pulse in each of the detectors, but not sufficient or numerous enough to enter the spark chamber and leave an ion path. As a result, no discharge appears. Also in this category is included the events due to an electronic malfunction. Two types of malfunction can give rise to events of this nature. The camera occasionally will advance two frames instead of one, and it is possible for the logic circuit to pick up noise from rotating equipment still operating after the dead time period from the previous event. This is called re-triggering, (see SPARK CHAMBER CAMERA). This column of events is entirely useless.

The column of "questionable" events are also not useful. These are the very wide angle interactions and the interactions initiated outside the spark chamber, (see photographs #10 and #11). A malfunction of the dead time could produce this effect.

-108-

WIDE ANGLE EVENT

-109-

WIDE ANGLE INTERACTION

If an event occurs too rapidly after another the spark chamber won't show the second with a good efficiency. The "straight through" rate and character would indicate if this were occurring. This was discussed in the paragraph on "straight through's".

The last category was for events which could be completely understood, but not pertinent to the experiment. Of these perhaps the most interesting is the albedo, (see photograph #12).

-111-

ALBEDO EVENT

CONCLUSION

The flux of electrons at two altitudes was obtained with the statistical standard deviations determined from the number of events used, see table #4. Two instrumental effects have hampered the measurements; even-odd gap sparking and determination of the plate of initiation for an interaction, (see SPARK CHAMBER PROPERTIES). The instrumental effects on the results cannot be determined now. These can be studied after the spark chamber characteristics for multiple particle events have been better determined. The spark chamber could be operated with an accelerator to study this problem. Consistency checks on the data indicate that these effects are small.

The data used for these measurements was 50% of the data from 78P and 40% of that from 69P. Portions of the flight must be carefully checked before they can be used because of inconsistent results shown by their data. More scanning is necessary to completely analyze all the flights.

The flux of penetrating particles has also been measured with the data accumulated and is $550 \pm 50/\text{sr}/\text{m}^2/\text{sec}$. which corresponds very closely with other experiments, (2), (14), (18), (19). The error shown here is the combined error due to solid angle uncertainty and statistical standard deviations.

By the use of these two flights, an upper limit for the primary electron flux can be determined and is $6.0/\text{sr}/\text{m}^2/\text{sec}$. see table #4. The flux measurements obtained at the two altitudes are somewhat higher than those given by B. Agrinier, et al. (9), see table #1. That experiment utilized two scintillation detectors also, but a double minimum ionizing pulse was required by the lower detector.

The electron, proton flux ratio for primary particles above 5 BV. is determined as less than 1.2%. This result is entirely consistent with theoretical calculations based on a model developed by F. Hoyle which gives an expected electron to proton ratio of 0.9%, for a rigidity of 5 BV, (18).

TABLE #4

pressure altitude gm/cm ²	flux ele/sr/m ² /sec	electron/proton
4.35	10.3 ± 2.8	2.0 ± 0.8%
2.16	6.5 ± 3.2	1.3 ± 0.6%
0.0	2.7 ± 4.2	0.6 ± 1.0%

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APPENDIX A

Calculated Rates

"Straight through" and "Knock-on" rate assuming a penetrating particle rate, $I = 550/\text{sr}/\text{m}^2/\text{sec}$ and nuclear interaction length of:

Protons 88% I ----- $120 \text{ g}/\text{cm}^2$

Alpha Particles 12% I ----- $69 \text{ g}/\text{cm}^2$

	Area		Rate
	Solid Angle	Solid Angle	
A) If particles just nick detectors	.222 Sr	5.77	11.6 c/m
B) Go through 1/8" of each	.210 Sr	5.46	11.0 c/m
C) Go through 1/4" of each	.198 Sr	5.15	10.4 c/m
D) 1/4" of top detector and 1/2" of bottom	.188 Sr	4.90	9.9 c/m
E) Completely through both detectors	.145 Sr	3.78	7.6 c/m