

**THE EAST-WEST
COSMIC RAY EFFECT
AT CORVALLIS, OREGON**

by

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**THE EAST-WEST
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INTRODUCTION

An asymmetry of the cosmic ray intensity with respect to the meridian plane is to be expected from Stormer's theory (12) of charged particles in the magnetic field of the earth if the primary radiation contains an electrically charged component with more rays of one sign than of the other.

The asymmetry can be detected by arranging two or more Geiger tubes in a plane with the axes of the counters parallel to each other.

Electronic circuits are used so that a cosmic ray must pass through all the counters to register a count on the recorder. In this way the direction of motion of the particle can be determined.

The first experimental evidence of an east-west asymmetry was observed by Johnson and Street on the summit of Mount Washington, New Hampshire, at a geomagnetic latitude of 56° . (6, p. 381) In the years following several investigators measured the asymmetry, but most of these investigations had been conducted below the knee of the latitude affect.

The results of these investigations showed that the asymmetry increases at higher elevations at a particular latitude and decreases with an

increase of geomagnetic latitude at a constant elevation. This evidence agrees with the theories presented by Stormer, Lemaitre and Vallarta.

The present investigation was undertaken to verify the asymmetry at a high latitude where at least a part of the asymmetry is due to the earth's field on the meson component of the radiation.

THEORY

It is well known that magnetic fields affect the trajectories of charged particles. The result of such a magnetic field is a force perpendicular to the plane defined by the direction of motion of the particles and the direction of the magnetic field. If the primary rays are charged particles the effect of the magnetic field of the earth on their motion will be a function of their mass, their charge, their velocity, the intensity of the field, the relative direction of the field, and the trajectory. Of course, the field will exert no effect on them if the primary radiation is made up of uncharged particles.

The presence of matter between the surface of the earth and the source of the radiation renders the problem of a direct measurement of the east-west asymmetry difficult. The confusion of secondaries begins at the top of the atmosphere, only a few miles above the surface of the earth. The presence of the earth's magnetic field begins to curve the primary rays at distances of several thousands of miles from the surface even though the strength of the field is only a fraction of a gauss at the earth's surface. Therefore, by observing the variation of intensity with changes of direction and position on the earth's surface it is still possible to observe an imbalance of charge in the primary radiation.

The relations between the magnetic rigidity, which depends on the product of mass and velocity of the ray divided by the amount of its

charge, and the measured intensities are very complex due to the form of the earth's field; but if a uniform field is used a fairly simple theory can be presented.

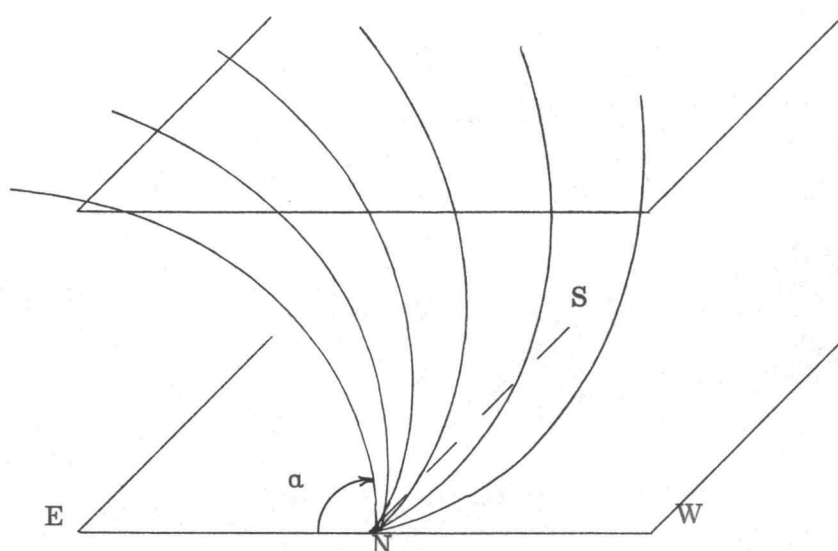


Figure 1.

Referring to the above figure, assume measurements of intensity can be made from any point in the lower plane which is the plane of the earth's surface. The direction of the magnetic field is from S to N, and it is uniform between the two planes. A positive ray of a particular rigidity and incident on the top plane from the left horizon will arrive at the point N at some angle α . The angular region to the left of α can be

illuminated only by rays of a higher rigidity but the region to the right should be uniformly illuminated by rays of this particular rigidity. If no rays existed except those represented in the figure there would be a sharp cut-off in the intensity at the angle α . By knowing this cut-off angle and the strength of the magnetic field, the sign of the charge and the rigidity can be determined. If rays were bent in the opposite direction, indicating a negative charge, the region of low intensity would be on the opposite side of the vertical.

If the radiation has some distribution over all values of rigidity the sharp cut-off would be replaced by a gradually changing intensity. The difference between the intensities at two angles would be due to rays whose rigidity lie within the range between the two cut-off values. Unless absolute equality exists between the number of particles of the same nature and the same energy, charged positively and negatively, there should be a variation in intensity with direction. If all the primary radiation is made up of positive charged particles there should be a difference between the number of particles reaching the earth from the east and west.

Because of the stronger magnetic field at the magnetic equator this east-west asymmetry should and does show a maximum effect at the equator as verified by Johnson and by Auger and Leprince-Ringuet. (8, p. 88) The east-west asymmetry decreases in going either north or south of the equator until the poles are reached. Here the primary rays are moving parallel to the field lines so there is no effect.

The above theory does not explain the asymmetry observed at high latitude nor the large asymmetries at angles near the horizon within the equatorial belt. This asymmetry is due to the effect of the magnetic field on the secondary component of the radiation. As the mesons lose energy in the atmosphere, they are deflected through some angle β from their initial primary orbit. If there is an imbalance of charged particles, these deflections will result in an asymmetry in the angular distribution.

An experiment conducted at sea level by Hughes (3, p. 592-597) has shown about twenty per cent more positive than negative mesons so that greater intensities should be observed coming from the west.

TELESCOPE CONSTRUCTION

The Geiger tubes were constructed with a Pyrex glass envelope. The cathodes were made out of copper foil 0.10 centimeters thick. The foil was rolled into cylinders 9.6 centimeters in diameter and 100 centimeters long. The cathodes were held tightly against the glass envelope by two ring shaped pieces of spring copper placed near each end of the cathodes. The central wire was 4 mil tungsten and the cylinder connection was 20 mil tungsten. Pyrex to Uranium to Nonex glass seals were used for the leads entering the tubes.

After the tubes were completed the interior was cleaned with six normal nitric acid. The tubes were rinsed with water several times until all of the nitric acid was removed. The NO_2 generated by the action of nitric acid on the copper cathode turned it a dark velvety color. This tends to increase the work function of the copper.

The tubes were gently warmed and pumped down to about 25 microns of pressure with a Cenco-Hyvac pump. The filler gas was from a commercial tank of Argon (96%) and CO_2 (4%). The tubes were filled to a pressure of 6 centimeters of Hg.

The Geiger tubes were mounted in a wooden frame so that the axis of each tube was in the same plane and parallel to the axis of the other two tubes. The distance between the top and bottom tubes in the

telescope was 89 centimeters with the middle tube midway between. This gives a resolving angle of 12.2° . The wood frame was mounted on an axle parallel to the axis of the Geiger tubes and could be rotated through a 180° arc. The angle of inclination from the vertical could be read from a protractor to the nearest one-half degree. (See Figure 4)



Figure 4. Experimental Apparatus

ELECTRONICS

In 1947, Stuart Forbes, an Oregon State College graduate student built a triple coincidence circuit for laboratory and demonstration purposes (1, pp. 1-55). The circuit included a Neher-Harper quenching circuit and a Rossi coincidence circuit which would allow single counts, double or triple coincidences to be recorded and also provides for anti-coincidence counting. A stabilized high voltage supply for the Geiger tubes and a low voltage supply for the amplifier are all included on the same chassis.

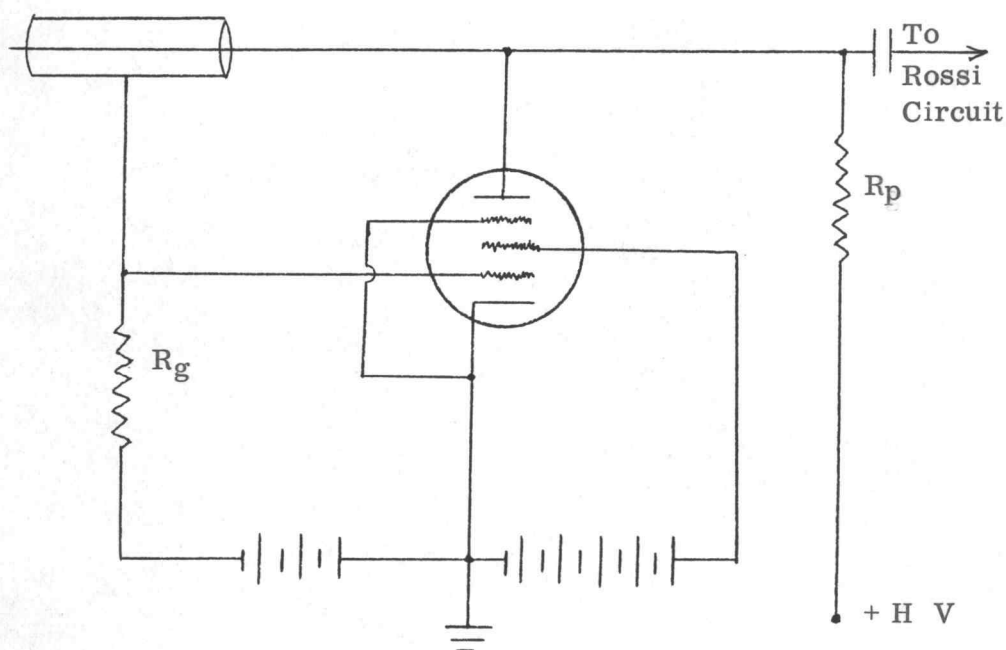


Figure 2. Neher-Harper Quenching Circuit

The Neher-Harper quenching circuit is an electronic circuit which holds the potential across the Geiger Muller tube below the starting

potential long enough so that all charged particles in the tube can be collected, thus insuring that the counter will only record one event for each ionizing particle that passes through the Geiger Muller tube. In this circuit the grid of the quenching tube is biased so that the tube is normally nonconducting. When an ionizing particle passes through the Geiger Muller tube, the current flowing through the Geiger tube causes the grid bias to become less negative and the quenching tube will conduct. The current passing through the plate resistor produces a potential drop which is subtracted from the high voltage. If the potential drop is great enough to decrease the counter voltage below the threshold potential, then the counter is effectively quenched. The voltage on the Geiger Muller tube is reduced until the grid returns to its original value. The time for this is determined by the RC time of the grid circuit. (See Figure 2)

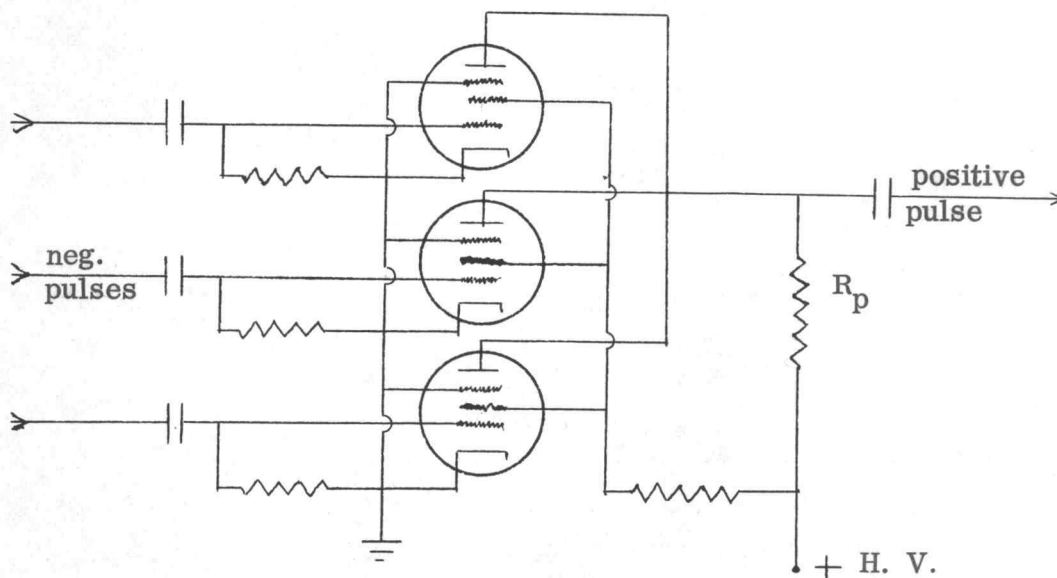


Figure 3. Rossi Connection for counting triple coincidences

The negative pulses from the quenching tubes are fed into the grids of the tubes making up the coincidence circuit. The tubes in the coincidence circuit have zero bias on the control grids and a current of several milliamperes will be flowing through R_p , so the plate potential is only about three or four volts. When a negative pulse arrives on the grid of any of the three tubes it ceases to conduct. However, because all the plates are in parallel, this will only change the plate potential a small amount. Similarly, if two tubes are biased to cut-off, there still will be only a small change in the plate potential. If all three tubes cease to conduct, the change in plate potential becomes considerable. This will produce a large positive pulse which may be further amplified by a subsequent circuit. If this circuit is made insensitive to all but large positive pulses, no count will be recorded unless a coincidence occurs in all the counters. (See Figure 3)

Each of the three tubes making up the Rossi circuit has a switch located between ground and the cathode. By opening one of these switches, that particular tube is removed from the Rossi circuit and the remaining two tubes continue allowing only double coincidences. If two of these switches are opened the third tube will be recording the counting rate from a single Geiger tube. Opening or closing the proper switches will allow single, double or triple coincidences to be recorded.

A more detailed description of this apparatus is presented in Forbes' thesis.

Only one minor change had to be made in Forbes' apparatus to make it useful for this experiment. Because of larger Geiger tubes and therefore larger counting rates it was necessary to make the RC time of the quenching circuit as small as possible. Several different grid resistors were tried ranging in size from 1 megohm up to 20 megohms, the latter being the size that Forbes used when he built the apparatus.

The bias for the quenching tubes is controlled by a potentiometer mounted in the rear of the chassis and for a particular grid resistor the grid potential must be within certain limits. If the grid potential is made too negative, the voltage pulse from the Geiger tube will not affect the plate current enough to extinguish the discharge. If the grid potential is made too low, the plate current will be so great that it will become impossible to get the counter voltage above the threshold voltage. (9, pp. 940-943)

The resistors that were less than 10 megohms made the grid potential adjustment so critical that it was impossible to duplicate any results. The 10 megohm resistor was finally used with the grid biased to -6.3 volts. This allowed for a drift of ± 0.2 volts before any change in counting rate was noticed.

GEIGER MULLER TUBE CHARACTERISTICS

One of the most important characteristic curves of a counter is the familiar plateau curve in which the counting rate is plotted as a function of voltage with a constant radiation flux. This curve is characterized by a rapid rise from the starting potential to the Geiger threshold potential. Beyond this point the curve levels off to form a plateau. At the upper end of the plateau the counting rate again starts rising with potential. The non-selfquenching counter generally has a very flat plateau, unless a gas is present that forms negative ions, or has metastable states.

Argon does not produce a noticeable amount of negative ions and the 4% carbon dioxide is enough to remove the energy in the metastable states of argon by collision.

A plot of counting rate versus voltage is shown on page 14 for each of the three Geiger tubes used. The mechanical Cenco counter is only capable of recording 60 pulses per second so a Nuclear Chicago Model 161A scaler was connected through a condenser to the plate of the quenching tube so that the data for these curves could be obtained. The power supply had a maximum voltage of 1600 volts so that it was impossible to reach the continuous discharge region at the upper end of the plateau.

Another important characteristic of a counter is its efficiency.

This is the probability that a cosmic ray will produce an electron

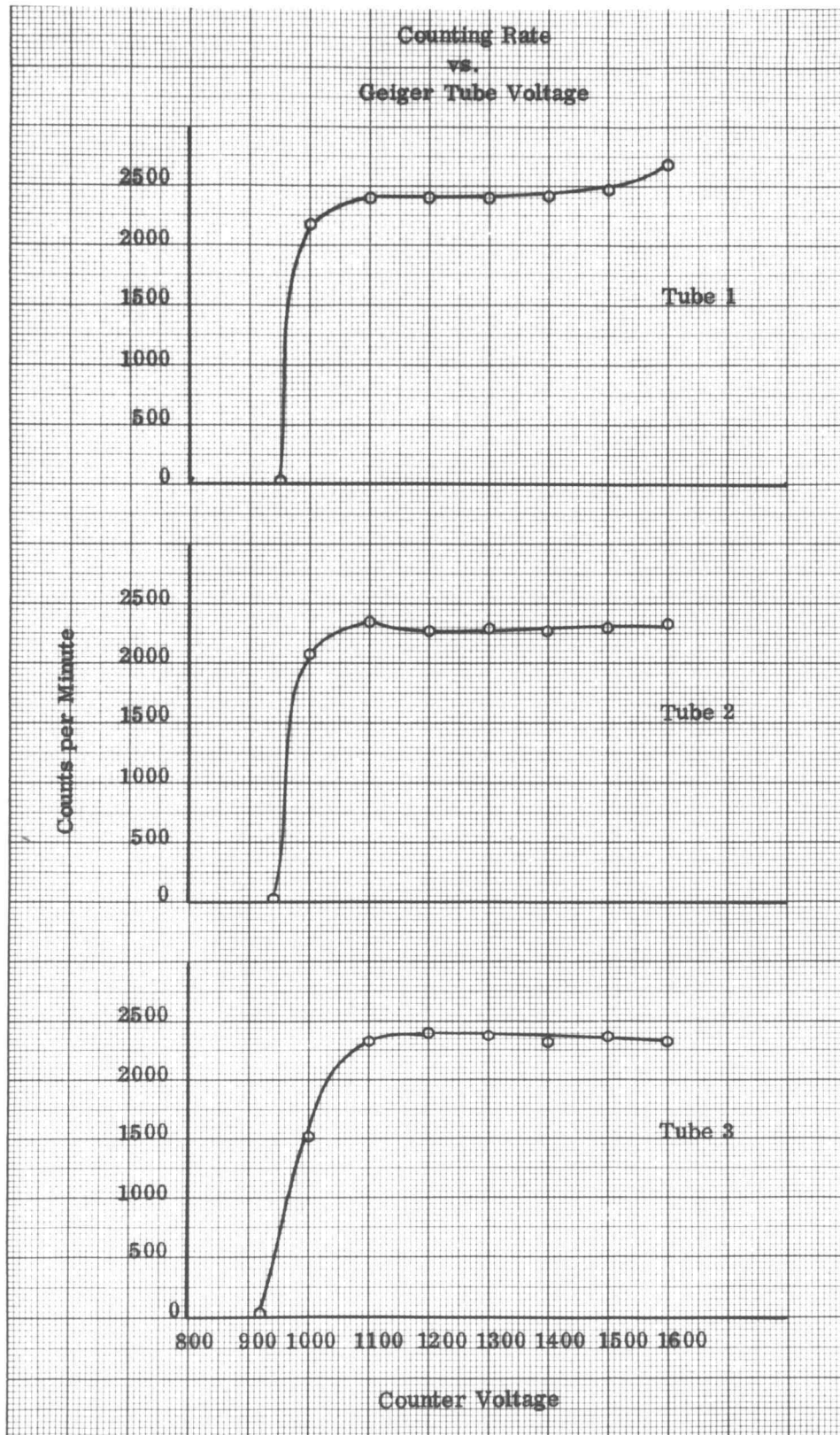


Figure 5.

in the counter and that this electron will produce an avalanche. The efficiency is related to the specific ionization of the particle being detected. The specific ionization, S , is the number of ion pairs, per centimeter of path, per atmosphere pressure, left in the gas when the particle passes through it. The probability that no electrons will be produced when a particle passes through the tube is e^{-slp} , where l is the length of path and p is the pressure of the gas in atmospheres. The efficiency of the counter, which is the probability that one electron will be produced, is therefore equal to $1 - e^{-slp}$. To find the specific ionization, S , by a high speed cosmic ray, the empirical formula $S = 1.1 N_e + 3$ can be used, (2, pp. 791-808) where N_e is the number of electrons per molecule. Argon has 18 electrons, therefore $S = 22.8$ ion pairs per centimeter per atmosphere. For a path length of only 2 centimeters the efficiency is then $E = 1 - e^{-3.6}$, or an efficiency of 97%.

EXPERIMENTAL PROBLEMS

The pulse was traced through the circuit with a Type 541 Tektronix Oscilloscope. The pulses were obtained from the natural cosmic ray background and therefore appeared at random positions on the screen. The pulse on the grids of the quenching tubes had a maximum pulse height of 2.25 volts. The pulse on the plate of the quenching tubes or the grids of the coincidence circuit had a pulse height ranging from 0 to 90 volts.

In order to determine the dead time of the counter it was necessary to determine the minimum pulse height that would trip the triple coincidence circuit. A pulse generator (11, pp. 1-27) which would produce 60 pulses per second was connected to the grids of the Rossi circuit. The generator had a pulse height that could be varied from 0 to 100 volts and three separate settings for the rise time. The minimum pulse height was found to be about 36 volts when pulse rise time was set at 0.3 microsecond. With this minimum pulse height established, the observable dead time was about 150 microseconds.

Shielding of the leads running to the Geiger Muller counters was somewhat of a problem. If the leads are not shielded there will be coupling between counting circuits due to the capacitance between the leads. Following Forbes' advice, the positive wire leading to the Geiger counter was shielded and the shield grounded to the chassis. However, the

counting rate still appeared to be a function of the length of the leads. This was due to the negative leads' sensitivity to changing fields in the room, and changing the grid potential of the quenching tube. The amount of change in grid potential varied directly as the length of the negative lead. Because of this the negative lead was also shielded and this shield was grounded to the chassis.

During the last few days of the experiment the coincident counting rate dropped over fifty per cent during the daylight hours but during the night, the counting rate appeared normal at all angles from the vertical. The singles counting rate for each tube was the same during the day or night which would eliminate some type of photo-effect due to visible light. The sensitivity to visible light was checked several times before the experiment was started and there appeared to be no variation in counting rate with the amount of daylight. A constant voltage Sola Transformer was used during all the experiment so that line voltage fluctuations were not a feasible explanation.

On July 24, the air temperature and relative humidity remained fairly constant from mid-afternoon until early evening but the counting rate changed as stated above. This would eliminate an explanation due to temperature or humidity. No other explanations could be presented, so the last five or ten per cent of the observations in Table II were taken during the early evening and night hours.

EXPERIMENTAL RESULTS

The apparatus was set up in the south-east corner of the Physics-Chemistry building. The room was on the fourth floor of a five story building. The telescope was positioned so that the axes of the Geiger tubes were parallel to a true north-south line. Alternate east-west readings were taken every hour. The results of this data appear in Table I. The difference between the east and west readings are much too large to be attributed to the east-west effect. Most of this difference in readings can be explained by an unsymmetrical shielding due to the walls and ceilings of the building.

After the data in Table I were taken the apparatus was moved to the roof of the building and all of the data in Table II was collected on the roof. Alternate east-west readings were taken every half hour so that the average reading at a particular angle should be independent of changes in temperature and barometric pressure.

The Geiger tube leads were insulated from the wood frame of the telescope by Bakelite insulators. Although this precaution was taken, the frame would absorb so much moisture during the night hours that the insulators would lose their insulating properties. This would cause a leakage which would drop the Geiger tube potential below the threshold voltage. This problem was eliminated by illuminating that portion of the frame near the terminals by an infra-red heat lamp during the night.

The exterior of the glass envelopes was cleaned with acetone at least once a day to remove dust and fingerprints which would cause a leakage across the Geiger tubes.

The Geiger tube potential was held at a constant 1160 volts for all the readings. This value of the potential was sufficient to operate all three of the Geiger tubes above their respective threshold potentials.

The circuit was tested for spurious coincidence by disconnecting the high voltage lead from one of the three Geiger tubes forming the telescope. In this condition not a single count was recorded over a twelve hour period. The number of accidental coincidences to be expected when three counters are used in coincidence can be calculated from the equation

$$A_3 = 3 n_1 n_2 n_3 t^2$$

where n_1 , n_2 , and n_3 are the average counting rate of the first, second and third tubes respectively and t is the resolving time. (7, p. 145) The accidental double coincidence rate can be calculated from the equation

$$A_2 = 2 n_1 n_2 t$$

where the notations are the same as above. Therefore the triple accidental rate should be

$$3 \times 40^3 \times (1.5 \times 10^{-4})^2 = 4.32 \times 10^{-3} \text{ coincidences per second}$$

or

$$A_3 = 15 \text{ coincidences per hour.}$$

The accidental triple coincidence rate was checked experimentally by putting the plane of the telescope 90° from the vertical. In this position the accidental rate was 8.3 coincidences per hour. The accidental double coincidence rate was experimentally determined in the same manner except that the middle tube of the telescope was removed from the Rossi circuit. This gave a double coincidence rate of 972 coincidences per hour compared to the calculated rate which is equal to 1728 accidental double coincidences per hour.

The vertical intensity was checked using the top and bottom tube in the telescope in double coincidence. The results of eight observations gave an average counting rate of 1281 counts per hour. The number of accidentals subtracted from 1281 should approximately equal the triple coincidence rate minus the accidentals for the vertical intensity.

$$1281 - 972 = 309 \text{ double coincidences per hour}$$

$$304 - 8.3 = 295.7 \text{ triple coincidences per hour}$$

The number of accidentals per hour has not been subtracted from the intensities listed in Table I and II, since the asymmetry is a relative measurement and any correction for accidentals or cosmic ray showers is unimportant. These effects are constant with azimuth.

Table II shows the value of the intensities for angles from 90 degrees west to 90 degrees east. R is the standard deviation of the mean and

is defined as the square root of the mean divided by the square root of the number of observations. R' is the experimental standard deviation of the mean and is defined by the equation

$$R' = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n(n-1)}}$$

where n is the number of observations and x_i is the number of counts per hour for the i th observation and \bar{x} is the mean value of n observations.

The symbols r and r' are defined as the probable error of the mean and are equal to $.6745 R$ and $.6745 R'$ respectively.

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TABLE I

Cosmic Ray Intensities, Standard Deviations and Probable Errors

Angle from Vertical	Number of Observations	Counts per Hour	R	R'	r	r'
0	32	241.0	2.74	2.64	1.85	1.78
10 W	24	239.5	3.16	2.62	2.13	1.77
10 E	24	235.8	3.13	2.95	2.11	1.99
20 W	24	229.9	3.09	2.74	2.08	1.85
20 E	24	220.2	3.03	3.07	2.04	2.07
30 W	20	208.2	3.23	3.38	2.18	2.28
30 E	24	186.5	2.79	2.42	1.79	1.63

TABLE II

Cosmic Ray Intensities, Standard Deviations and Probable Errors

Angle from Vertical	Number of Observations	Counts per Hour	R	R'	r	r'
0	28	304.0	3.30	2.94	2.23	1.98
10 W	18	298.3	4.07	3.59	2.75	2.42
10 E	18	291.6	4.03	3.15	2.72	2.12
20 W	18	272.7	3.89	3.84	2.62	2.59
20 E	17	266.9	3.97	4.21	2.68	2.84
30 W	17	241.0	3.77	3.53	2.54	2.38
30 E	17	233.5	3.71	3.88	2.50	2.62
40 W	60	178.7	1.73	1.70	1.17	1.15
40 E	60	172.2	1.70	1.68	1.15	1.13

TABLE II continued

Angle from Vertical	Number of Observations	Counts per Hour	R	R'	r	r'
50 W	18	125.6	2.64	2.67	1.78	1.80
50 E	18	120.8	2.59	2.16	1.75	1.46
60 W	17	78.5	2.15	1.70	1.45	1.15
60 E	17	74.8	2.10	2.24	1.42	1.51
70 W	17	35.4	1.44	1.30	0.97	0.88
70 E	17	35.0	1.44	1.32	0.97	0.89
80 W	15	15.0	1.00	0.54	0.67	0.36
80 E	15	14.1	0.97	0.73	0.65	0.49
90	10	8.3	0.91	0.53	0.61	0.36

CONCLUSION

The results of this experiment are shown on the graphs on pages 26 and 27. The graph on page 26 agrees fairly well with the results of other experimenters. The length of the lines through the points in Figure 7 are twice the probable error.

The asymmetry graph shows a definite asymmetry with a greater number of cosmic rays reaching the earth from the west than from the east. This graph supports the theory of a positive excess in the primary radiation.

The graph of the asymmetry shows large probable errors but the agreement with Johnson (4, pp. 11-15 and 5, p. 17) is fairly good. Seidl (10, pp. 7-11) determined a value of 0.0010 ± 0.0022 for the asymmetry at a geomagnetic latitude of 51° north and at an angle 20° from the vertical. The resolving angle of Seidl's double coincidence telescope was about 40° . This value of the asymmetry is much smaller than the $.022 \pm .011$ determined from the present experiment.

It would be necessary to collect data for many months to decrease the probable error in a determination of the magnitude of the asymmetry at this particular location.

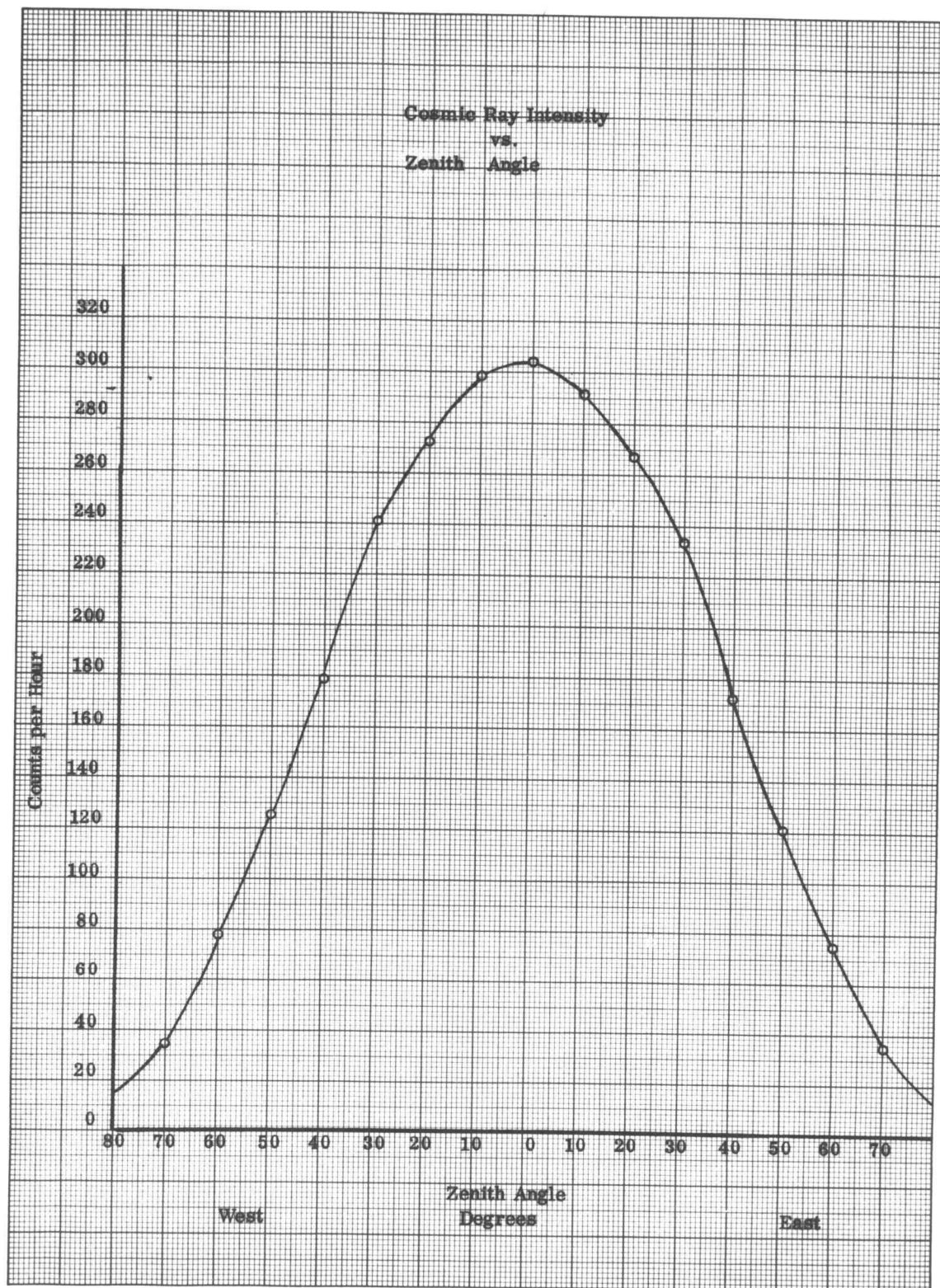


Figure 6

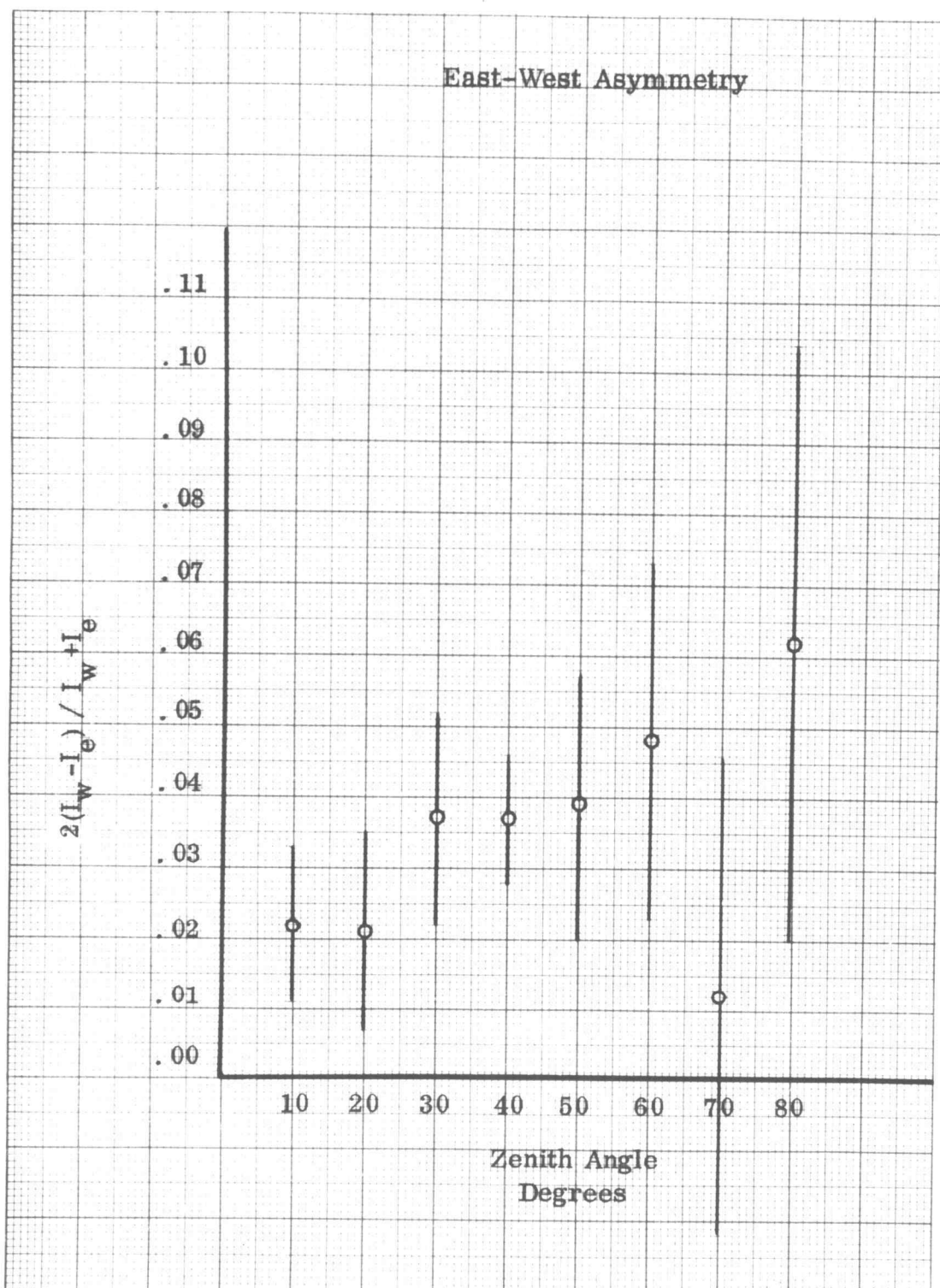


Figure 7.

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