DEVELOPMENT OF MUON TELESCOPES

FOR A STUDY OF COSMIC RAY ANISOTROPIES

A Thesis

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By

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ABSTRACT

The design, construction and development details of two almost identical muon telescopes are included in this thesis. The telescope orientations are such that one telescope scans the celestial equator two hours ahead of the other as the earth rotates about its axis.

Experimental techniques are fully described and preliminary results which have been obtained at the Allen Physics Laboratory, University of Manitoba, are presented.

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INTRODUCTION

Charged particles, now known as cosmic rays, are continually "raining" on the earth and its surrounding atmosphere from relatively unknown and distant sources in space. These particles are far from being mono-energetic, having energies ranging from the thermal energies of sun-emitted particles to energies of the order of 10^{15} to 10^{21} eV.

Research into cosmic radiation began essentially at the start of this century. Investigators such as C. T. R. Wilson, Geitel and Elster experimented on the residual conductivity of air, taking careful precautions to prevent ionisation of the sample by all then known radiations. The residual conductivity was in fact, as they correctly concluded, due to an external radiation. The first important step forward was made by Victor F. Hess who, after a balloon flight at an altitude of 16,000 ft., where he found electroscopes to discharge much more quickly than at ground level, concluded that "a radiation of very great penetrating power enters our atmosphere from above".

The field of cosmic rays soon attracted more workers - celebrated names such as W. Kohlhorster, R. A. Millikan, and Erich Regener. Until the late 1920's, it was widely held that the radiation, probably of solar or galactic origin, was composed of high energy gamma rays, an idea shortly to be drastically changed. The year 1929 saw the first measurement of a cosmic ray coincidence rate by Bothe and Kohlhorster, who used two Geiger-Muller counters, with and without absorber between them. If the cosmic flux consisted solely of photons, a coincidence count would have required the very improbable possibility that a Compton electron be formed in the matter of both counters by the traversing cosmic ray. The particle nature of cosmic rays received further support from two important discoveries. Firstly, the latitude effect (variation of cosmic ray intensity with geomagnetic latitude) observed by Clay (1927) and Compton (1933) and secondly, the east-west asymmetry (greater cosmic ray flux from the west than from the east) found by T. H. Johnson (1934, 1938). Each of these effects demonstrated that most, if not all, of the cosmic radiation was deflected by the earth's magnetic field, this radiation therefore being composed of charged particles. Furthermore, the east-west asymmetry revealed an excess of positively charged particles at sea level.

At this stage progress was relatively fast, being triggered into action once more by Anderson's (1933) discovery of the positron, previously theoretically predicted by Dirac. The idea of particle-photon cascades being part of the radiation detected at sea level was soon treated theoretically by both Bhabha and Heitler (1937) and Carlson and Oppenheimer (1937). This gave a satisfactory explanation of a maximum intensity in the radiation, found by Pfotzer at an atmospheric depth of 95 gm/cm^2, and heralded the discovery of extensive air showers by Schmeiser and Bothe (1938), Auger et al. (1938) and Kohlhorster et al. (1938). It is now known that such phenomena are due to primary particles with energies $\gtrsim 10^{15}$ eV. and consist of dense cascades of electrons and photons which "breed" via pair production and bremsstrahlung in the atmosphere. These showers spread over large areas with dimensions of the order of several hundred metres.

During this period Hess' observation of the great penetrating power of the cosmic flux was clarified by the all-important identification of the μ-meson or muon in cosmic radiation by Neddermayer and Anderson (1937) and by Street and Stevenson (1937). The muon is a positively or negatively charged non-stable particle of mass equal to 206.8 electron-masses with a lifetime of $(2.22 \pm 0.02) \times 10^{-6}$ seconds. However, its most important property which in fact determines the penetrating power of cosmic radiation is its reluctance to interact with nuclei. Just four years later, Schein, Jesse and Wollan (1941) were able to demonstrate that the muon intensity increased above the Pfotzer maximum. Theoretical treatments by Swann (1940) and Carlson and Schein (1941) predicted the primary cosmic ray particles were protons. It was then thought that the muons were produced by interaction of these protons with atmospheric nuclei, while the electron or "soft" component of the secondary radiation was believed

level, while the possibility of an alpha particle doing likewise is negligible.

with photographic plates, showed that the muon was in fact a decay product of another secondary cosmic ray - the π-meson or pion, a strongly interacting particle.

The Primary Radiation

Since World War II much has been added to the knowledge of the primary cosmic ray flux by investigations prior to its interaction with atmospheric nuclei, and also by study of the interplanetary intensity between and beyond the Van Allen radiation belts. Above a height of 50 km. the primary intensity is essentially constant, apart from variations with geomagnetic latitude. Such variations arise because shielding by the earth's magnetic field decreases with increasing latitude, i.e., maximum counting rate is found above the magnetic poles. Beyond the Van Allen radiation belts containing low energy protons and electrons trapped by the earth's magnetic field, the interplanetary intensity is also nearly constant above 95,000 km., and is greater than the primary intensity, as the shielding effect of the earth's field is no longer effective at such heights.

Freier et al. (1948, 1950), using balloons and photographic plates, demonstrated that the primary flux was essentially a proton flux, but did contain the nuclei of heavier particles. They found 9% of the flux to be alpha particles, while approximately 1% consisted of heavier nuclei with masses up to that of iron. The 1% mixture of heavier