the form

$$\alpha(h\nu) \sim [h\nu - \epsilon_g - \hbar\omega_{\vec{K}_0}]^{3/2}.$$

In the derivative technique the exponents of the arguments of α become $-\frac{1}{2}$ and $\frac{1}{2}$, respectively.

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[10]Measurements of the second derivative of the tunneling current in a Si diode gave $53.2 < E^{LO} < 55.4$ meV and $56.5 < E^{TO} < 58.7$ meV (Ref. 9). Neutron-scattering data (Ref. 8) give similar phonon energies, assuming that the conduction-band minima lie at $\vec{k}_0 = 0.85\,\vec{k}_{max}(100)$ (Ref. 11). Recent ENDOR measurements in Si (Ref. 12) indicate an uncertainty possibly as large as ±15% in this value of k_0. Thus the neutron-scattering data are consistent with a TO-LO energy difference as small as 1 meV.

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[13]We are indebted to J. J. Hopfield for pointing out the importance of the translational invariance of the free exciton Hamiltonian and the merging of the higher-lying exciton excited states.

INSENSITIVITY TO COSMIC RAYS OF THE GRAVITY RADIATION DETECTOR*

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A search for coincidences between cosmic-ray shower signals in a large scintillation counter and gravitational-radiation detector signals indicates that the gravitational radiation detector does not produce a signal when hit by showers of particle density of the order of 100 particles/m^2.

The inherent interest in and significance of the reported discovery of gravitational radiation[1] calls for establishing the certainty of these results. It has been suggested that some of the signals in the gravitational radiation detector could be due to the deposition of energy in the large aluminum cylinder used as a detector.[2] It might also be possible for cosmic radiation to excite the piezoelectric crystals used to couple the normal mode of cylinder oscillations to the electromagnetic degree of freedom of the detector. We monitored cosmic rays at a gravitational radiation detector, and the coincidence rate between cosmic ray events and excitations of the detector was found to be consistent with the rate for accidentals. The experiment showed no evidence for sensitivity of the gravitational radiation detector to cosmic-ray events corresponding to more than 100 particles/m^2 recorded by the scintillator telescope. Details of the experimental arrangement and the results obtained are presented below.

Two large ($27 \times 36 \times \frac{1}{2}$ in.) plastic scintillators[3] in a telescope arrangement were placed immediately over the 96-cm.-diam gravitational-radiation detector. The scintillators were centered over the piezoelectric crystals and covered approximately 0.45 of the length of the detector. The detector has been previously described in Ref. 1. Each scintillator was viewed by two 7746 photomultiplier tubes attached by a light piping arrangement which covered an entire 27-in. $\times \frac{1}{2}$-in. edge. For each scintillator the signals were fed into an "or" circuit and the outputs of the two circuits were put into coincidence. This coincidence pulse was used to gate a linear gate and stretcher which stretched the summed outputs of all four photomultipliers. A threshold detector in the form of an integral discriminator on the output of the linear gate and stretcher was used to produce a marker pulse which was stretched to about $\frac{1}{4}$ sec and recorded on a chart recorder. This chart could be read to about 0.1 min. The output of the gravitational-radiation detector was also recorded on a chart recorder. Figure 1 shows a block diagram of the electronics with pertinent pulse widths indicated.

The scintillation detectors were calibrated using a radioactive gamma-ray source to relate signal size to energy deposition. It was observed that a Co^{60} source (which deposited a maximum of 2.5 MeV in the two detectors when one decay gamma ray from each decay went into the detectors) gave a signal of a certain maximum amplitude at the output of the linear gate and stretcher. In the experimental run the photomultipliers were operated at lower voltage to avoid any saturation problem. Using the published gain versus applied voltage characteristics[4] of the photomultiplier, as well as the relative attenuator settings, we then evaluated the energy deposition from a shower, assuming that all the particles

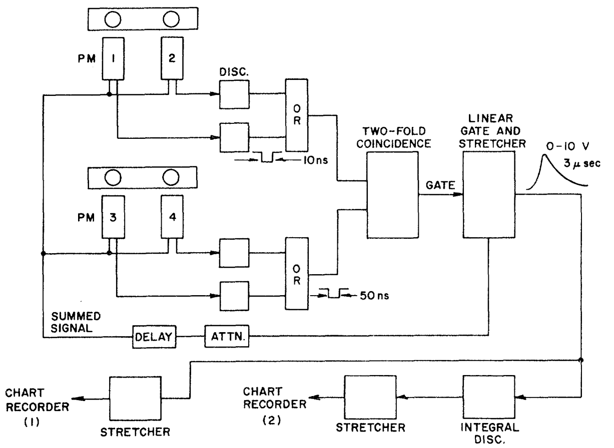

FIG. 1. A block diagram of the electronics used to record the cosmic ray events. The phototubes were RCA 7746 operated at 1600 V. The rest of the electronics were commercially available as follows: discriminator (DISC), EG & G quadratic discriminator T140/N; OR circuit, EG & G C-144/N; coincidence, EG & G C-104; linear gate and stretcher, Lecroy Dual Gated Pulse Stretcher, Model 124; integral discriminator, Canberra Instruments, Model 1435. The stretchers used to lengthen the pulses for the Esterline-Angus chart recorders were built in our laboratory. The phototube anode signals were summed on the input of the linear gate and stretcher. The last dynode signals were used to fire the discriminators at a level well below that of interest. The phototube discriminator timing was within 2 nsec for all four units.

are minimum ionizing, each depositing of order 2 MeV/(g/cm^2) in the plastic scintillators.[5]

To verify that we were detecting charged particles in extensive air showers, we calculated the rate for occurrence of showers. For showers at sea level with particle densities greater than or equal to Δ, the rate is given by Galbraith[6] as $N(>\Delta) = 562\Delta^{-1.4}$ h^{-1}. We get Δ from the number of particles required, according to our calibration, to give a signal above threshold, divided by the area of the scintillators. This gives $\Delta = 120 \pm 40$ particles/m^2, where the estimated error reflects the uncertainty of the pulse heights as well as the nonuniformity of light collection. This range of values of Δ gives an estimated counting rate of 0.46 to 1.22 counts/h. We observed 0.85 counts/h.

Thus our cosmic-ray detector is sensitive to showers of the order of 100 particles/m^2. About 0.85 times/h a shower of particle density greater than this hits the cosmic ray detector and proceeds to hit the gravity-radiation detector, after a small energy loss in the plastic scintillator and vacuum-tank walls of the gravitational-radiation detector.

In an experimental run of duration T hours we record C cosmic ray counts exceeding threshold. Then the count rate of cosmic ray events above threshold is $N_c = C/T$ h^{-1}. For each cosmic-ray event mark on the chart recorder the time of the event is read to within 0.1 min and then the gravity-detector chart is scanned to find if it has a pulse within the resolving time. If a gravity-detector pulse is found in coincidence with a cosmic-ray pulse, we then count how many times in an hour interval about the coincident pulse pulses with an amplitude equal to or greater than the coincident pulse occur in the gravitational radiation detector. This number is N_g.

In one run of 260 h, there were 220 cosmic-ray event marks, giving a rate $N_c = 0.85$ h^{-1}. 34 of these were in coincidence with gravitational-radiation detector pulses above a certain threshold, which was selected such that pulses greater than this amplitude occur less than 30 times/h. Such a level corresponds to signals smaller than any reported as gravity events in Ref. 1. Using an estimated resolving time of $\tau = 0.3$ min, the expected number of chance coincidences in a run of duration T hours is given by

$$\eta_{\rm ch} = \tau N_c N_g T$$

$$= \frac{0.3}{60} \times 0.85 \times 30 \times 260$$

$$= 33 \pm 6.$$

The uncertainty of ±6 counts in $\eta_{\rm ch}$ reflects only the statistical errors in the determination of N_c and N_g. The estimated resolving time of 0.3 min reflects systematic uncertainties in the time calibrations on the chart recorders and the uncertainties in the reading of the chart. We observed 34 ± 6 counts during this run, supporting a hypothesis of pure chance coincidences. Table I gives the results obtained for various levels of discrimination for the gravity-wave detector.

To investigate whether there was any correla-

Table I. Count rate versus discrimination level of the gravitational-radiation detector.

N_g (Counts/h)	No. of coincidences in 260 h Observed	Expected
30	34 ± 6	33
20	21 ± 5	23
10	13 ± 4	11
1	2 ± 1	1

tion between gravitational-radiation detector coincidences and cosmic-ray shower events, we looked for threefold coincidences between a pair of gravitational radiation detectors and the cosmic ray detector. During the 220-h interval in which the data summarized in Table I were accumulated, 14 coincidences were observed between the detector under the cosmic ray telescope and another detector in the same room. None of these coincidences was in coincidence (within ±0.5 min) with high particle-density, cosmic-ray shower events. On a chance basis only 0.15 count would have been expected. Using a local detector at Maryland and one at Argonne during this same interval some 29 gravitational-radiation detector coincidences were observed. (Of the order of 10 of these coincidences could have been accidentals.) On the basis of a ±0.5-min resolving time, 0.3 count was to be expected and d none was observed. Thus there is no evidence for a correlation between gravitational-radiation signals and cosmic ray showers.

A preliminary experiment was made with a 2 × 6 × 4-in. Pb-glass Cherenkov detector, underneath the same gravitational-radiation detector. The Cherenkov counter was biased such that it would register the signal from a single electron of energy ≃0.3 GeV entering the detector. The gravitational radiation detector subtends about $\frac{1}{4}$ of the solid angle available to the Cherenkov counter. In 89 hours of running with a Cherenkov-detector counting rate of 5.6 counts/h and the gravitational-radiation detector biased to give a rate of 2 counts/h, a total of 3.3 coincidence counts were expected and 3 were observed.

In air showers at sea level, particle lateral distributions are such that the hadronic density is about one percent of the electronic density in a region of particle densities of the order of 100/m^2. These hadrons carry an energy density exceeding that of the electronic component.[7] If the gravitational radiation detector were excited by these hadrons, the excitations would be in coincidence with the cosmic-ray events we detected.

In this experiment we have monitored air showers that have a density greater than 100 particles/m^2. The coincidences between these shower events and excitations of a gravitational radiation detector were at a rate that was consistent with accidentals computed using the singles events in each detector and the resolving time of the instrumentation.

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