Letters to the Editor

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Temperature Effect of Cosmic Radiation at 1000-M Water Equivalent Depth

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IN the course of experiments performed together with J. Barnóthy in a coal mine at 1000-m water-equivalent depth, I had occasion to note the intensities of the most penetrating component of cosmic radiation and the outer-air temperature for a period of three years. Temperature correlation was not the main purpose of the experiments; accordingly, a number of different arrangements were used.

The coal mine is situated at 35-km NW from Budapest. The apparatus was installed at 470-m depth below the surface in a side gallery of the mine, the latter having a diameter of 2 m, with a brick casing of 1-m thickness. The temperature at this location was constant within $\pm 1°C$ during the whole year.

The intensities were measured with a threefold coincidence-counter train of 8×100 cm^2 sensitive area. Each tray consisted of two parallel connected G-M counters. The coincidences were selected by means of a Barnóthy circuit, having a resolving time of 1.4×10^{-6} sec. (This circuit is essentially identical with that generally known as the Getting circuit; its description was published in Naturwissenschaften **21**, 835 (1933).) The distance between extreme trays was 101.3 cm, and provision was made for interposing 80 cm of lead between the counter trays. The adopted procedure was to put the same amount of lead simultaneously between top and center counter tray and center and bottom counter tray. With every thickness of lead the intensities were recorded without interruption in average for two weeks, and the whole absorption curve was surveyed several times. The temperature correlation was reckoned for every thickness of lead, i.e., for every arrangement separately.

A total of 2066 coincidences was recorded during 10,226 hours. Column 1 of Table I indicates the total thickness of the interposed lead; column 2, the date; column 3, the total time of the measurement; column 4, the total number of counts; column 5, the mean outer-air temperature for the same period; column 6, the correlation coefficient derived from the different runs with the same arrangement; column 7, the temperature effect and its probable error computed with its help. In order to compute the temperature effect, the different lengths of the periods were considered.[1] Some of the individual values have relatively large errors, but the mean of the nine individual results yields a temperature effect: $+0.74\pm 0.13$ percent per degree C, which value exceeds about six times its probable error and, therefore, the existence of a positive temperature effect is ascertained.

The temperature values indicated in the table were kindly supplied by the Hungarian Meteorologic Office; they refer to the records of the meteorologic station of Esztergom, situated about 8-km north from the mine. Unfortunately, no upper-air temperature data were available.

Performing a similar computation with barometric pressure, we obtain for the barometer effect:

$$BE = +0.42\pm 0.90 \text{ percent per mm Hg.}$$

This means that no correlation exists between cosmic-ray intensity at great depth and barometric pressure. The absence of a barometer effect rendered the application of multiple correlation superfluous, and the observed temperature effect can in no case be attributed to an overlooked influence of barometric pressure. The analysis revealed that factors other than temperature do not influence the intensity.

The temperature effect obtained has the sign which we would expect if in accordance with the view expressed previously;[2] the most penetrating component of cosmic radiation consists of neutrini created by the disintegration of the mesons in the atmosphere. In this case the intensity of the neutrini, i.e., the number of neutrini with energies greater than E

$$I_\nu = \text{const.}\int_{2E}^{\infty}\frac{1-\exp(-L/l)}{E^{\gamma+1}},$$

where

$$l=\tau_0 E/\mu c$$

increases with increasing temperature, since if the place where the mesons are formed is shifted upwards, a larger number of mesons disintegrate before reaching sea level, and, consequently, a greater number of neutrini with great energies are created. I should like to emphasize that the conception that at great depth only meson-decay products are observable is supported by other observations. J. Barnóthy[3] has shown that according to this assumption the exponent γ, of the energy in the absorption law of the radiation, increases from 1.8 to 2.8 for depth below 300-m water equivalent, and, further, that at great depth—contrary to the results found by Auger at small depth—the intensity is relatively greater in inclined directions than would correspond to the thickness of the absorbing layer, in agreement with experimental findings. According to this interpretation we should have to expect for the radiation below 300-m water equivalent a positive temperature effect.

Let us assume that mesons are formed at a height of 80-mm Hg. According to aerologic observations 80-mm Hg corresponds in average to $L=15{,}935$ m, and it has a temperature variation with respect to the temperature at

TABLE I. Summary of results.

Lead in cm	Date	Total time in hours	Total number of counts	Mean temperature	Correl. coefficient	Temperature effect
0	1941 VI	662.7	165	20.7°	−0.702	−0.243±0.084
	1942 XII	477.1	125	0.1		
	1943 III	192.9	46	10.3		
10	1941 VII	466.5	94	20.2	+0.914	+1.015±0.077
	1941 IX	520.5	106	15.4		
	1943 II	343.8	59	4.6		
15	1941 IX	321.2	75	13.4	+0.939	+1.152±0.070
	1941 XII	383.4	74	−2.1		
	1943 II	356.4	78	2.9		
20	1941 X	230.0	55	5.6	+0.279	+0.861±1.35
	1941 XI	249.8	45	1.1		
	1943 I	478.0	106	−2.2		
25	1941 III	284.0	52	0.7	+0.950	+0.793±0.039
	1941 X	305.2	57	7.0		
	1943 I	359.2	61	−5.0		
35	1941 I	416.5	76	−2.7	+0.530	+0.400±0.26
	1941 V	366.4	68	18.3		
	1943 VI	398.0	85	16.5		
40	1940 XII	312.7	57	−8.0	+0.107	+0.082±0.36
	1941 X	344.7	57	12.0		
		327.0	65	15.2		
45	1941 II	333.9	60	2.0	+0.780	+1.06 ±0.25
	1941 IV	429.8	77	10.0		
	1943 V	439.5	91	14.8		
50	1941 III	406.5	59	4.4	+0.946	+1.562±0.082
	1941 IV	408.8	80	10.0		
	1943 IV	411.8	83	15.2		

sea level:

$$\frac{1}{L}\frac{dL}{dt}=0.16\pm0.03 \text{ percent per °C.}$$

The temperature effect of the meson intensity at sea level,

$$\frac{1}{I_\mu}\frac{dI_\mu}{dt}=\frac{L}{l}\times 0.16 \text{ percent per °C,}$$

can theoretically be as well greater or smaller than 0.16 percent in conformance to the mean free path of the mesons before decay, l being smaller or greater than L. For the temperature effect of the neutrini, created at the decay of the mesons, we obtain:

$$\frac{1}{I_\nu}\frac{dI_\nu}{dt}=\frac{L}{l}\frac{\exp[-L/l]}{1-\exp[-L/l]}\cdot 0.16\leqq 0.16 \text{ percent per °C;}$$

hence, theoretically, it can only have values smaller or equal to 0.16 percent per °C, whereas the experimental value is about five times greater.

[1] L. Jánossy and G. D. Rochester, Proc. Roy. Soc. London **A183**, 186 (1944).
[2] J. Barnóthy and M. Forró, Zeits. f. Physik **104**, 744 (1937); Phys. Rev. **53**, 848 (1938); Phys. Rev. **55**, 868 (1939); Phys. Rev. **58**, 844 (1940).
[3] J. Barnóthy, Zeits. f. Physik **115**, 140 (1940).

Atomic Absorption Coefficient for X-Rays

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IN a previous paper[1] it was shown that the mass absorption coefficient for any given element could be calculated from the empirically derived expression:

$$\frac{\mu}{\rho}=(C\lambda^3-D\lambda^4)+\sigma_e Z\frac{N_0}{A}.$$

Further work has led to an expression which may be of theoretical significance.

It has been found that the atomic absorption coefficient τ_a, for any element and between any two critical absorption wave-lengths, may be represented within the accuracy of observational error by the expression:

$$\tau_a=\left\{\frac{\nu_1\nu_2}{\nu^3}-\frac{\nu_1\nu_2\nu_3}{\nu^4}\right\}K,$$

where ν is the frequency of the incident radiation, and ν_1, ν_2, and ν_3 are apparently critical frequencies resulting from rational quantized transitions within an atom of atomic number Z. K is an invariable constant. A manuscript on the subject is now in preparation and will be published shortly.

[1] J. A. Victoreen, J. App. Phys. **14**, 95 (1943).

Electrostrictive Effect in Barium Titanate

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IN a recent paper[1] and in his thesis Shepard Roberts has demonstrated a new type of electrostrictive effect in a ceramic piece made up of polycrystalline barium bitanate. In this effect mechanical resonances can be excited by a small applied alternating voltage when either a high direct-current field, or a remanence polarization induced by a high direct-current field, are present. Roberts identified the lowest frequency modes as radial vibrations of the disk, but, although his data show it, he failed to identify the thickness mode with a very high electromechanical coupling. Further measurements have been made by the writer of the radial and thickness modes of barium titanate disks as a function of the applied field. Considering the device as an electromechanical vibrator,[2] the data on the resonance frequency, the separation of resonance and antiresonance frequencies, and the capacity of the crystal give enough data to determine the electromechanical coupling factor k, the elastic constant for radial vibrations (Young's modulus), the elastic constant for the longitudinal thickness mode ($c_{11}=\lambda+2\mu$), and the electrostrictive constants. The elastic constants are

$$Y_0=\frac{\mu(3\lambda+3\mu)}{\lambda+\mu}=9.1\times10^{11} \text{ dyne/cm}^2; \quad (1)$$
$$\lambda+2\mu=1.16\times10^{12} \text{ dyne/cm}^2.$$

From these we can determine

$$\lambda=4.4\times10^{11};\quad \mu=3.8\times10^{11};\quad \sigma=\text{Poisson's ratio}=0.27. \quad (2)$$

The electrostriction constants for the two modes are shown plotted in Fig. 1 for ascending and descending