Magnitude of Cosmic Ray Bursts

IN a paper which I had the privilege of presenting for them at the recent London Congress of Nuclear Physics, R. D. Bennett, G. S. Brown and H. A. Rahmel described some very large cosmic ray bursts, which they recorded using a large argon-filled ionisation chamber stationed on Mount Evans. In six of these bursts the number of ion pairs suddenly appearing within the chamber was greater than 3×10^8. The largest one threw the electrometer off scale, which meant more than $6{\cdot}25 \times 10^8$ ion pairs. It is of interest to estimate the total energy involved in such a process.

Using Gärtner's value[1] of 29·6 electron volts per ion pair in argon, the energy required to produce the ions caught within the chamber exceeds $1{\cdot}85 \times 10^{10}$ e.v. Experiments performed by E. O. Wollan using different pressures of argon in our recording chamber show, however, that the magnitude of the bursts is at least roughly proportional to the pressure. This means that up to the highest pressure employed (50 atmospheres) only a small fraction of the ionising radiation from the burst is absorbed in the argon. We may thus assign as a lower limit to the total energy about four times that which is actually measured.

If we suppose that a burst is merely a large shower, and if we use the interpretation of shower production presented by P. M. S. Blackett and others at the Congress, intense ionisation such as occurs in the bursts should extend throughout the whole region traversed by the shower-producing radiation (photons ?) excited by the impact of the cosmic ray particle upon an atomic nucleus. If the region within which this radiation is absorbed is homogeneous, the fraction of its energy spent within a region of small thickness δx is approximately

$$F = \mu e^{-\mu x}\,\delta x, \qquad (1)$$

where μ is the absorption coefficient of the radiation in the medium. If, however, the burst originates in a medium a (the steel walls of the chamber) and spreads through a cavity of thickness δx filled with medium b (argon gas) which absorbs only a small fraction of either the photon radiation or the secondary beta rays which they excite, the fraction of the energy spent within medium b is

$$F = \mu\frac{\mu_b}{\mu_a}e^{-\mu x}\delta x, \qquad (2)$$

where μ_a and μ_b are respectively the effective absorption coefficients of the secondary beta rays in the two media. Measurements on the transition effect indicate that μ for the shower-producing radiation in iron is about 0·13 cm.$^{-1}$. The absorption of the high-speed β-rays is found to be nearly proportional to the density, that is :

$$\mu_b/\mu_a = \rho_{\text{argon}}/\rho_{\text{iron}} = 0{\cdot}0106.$$

For the largest bursts we may take $e^{-\mu x} = 1$. Thus from equation (2) we get $F = 0{\cdot}033$ as the fraction of the total energy absorbed within the ionisation chamber. This corresponds to a total energy of about 6×10^{11} electron volts for the largest recorded burst.

Several considerations must increase somewhat this estimate of the energy : (1) The number of ions produced in the chamber was greater than $6{\cdot}25 \times 10^8$. (2) It is impossible that all of the secondary shower-producing rays can have passed through the chamber, though most of them may have done so. (3) A part of the shower-producing rays will probably have been absorbed before reaching the chamber. The total energy of the largest burst must thus have been between 10^{11} and 10^{12} electron volts, and probably nearer the latter value.

These energies correspond to the masses of atoms of atomic weight 100–1,000. They are thus too great to arise from any kind of nuclear process, unless it be the improbable one of a nuclear chain reaction within the instrument, and involving many atoms. The apparent absence of any possible mechanism whereby such a chain reaction might be effected seems sufficient to rule out this suggestion.

It is noteworthy, however, that in order to penetrate to 600 m. of water, where cosmic rays are still perceptible, according to recent calculations of Bethe a proton must have an energy of the order of 2×10^{11} electron volts, and an electron greater energy, while no photon should reach such a depth. It would thus appear probable that cosmic rays occur with sufficient energy to produce directly all the ionisation observed in these bursts.

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[1] O. Gärtner, *Ann. Phys.*, **2**, 94 ; 1929.

Heavy Water in the Animal Body

IN NATURE of December 8, p. 879, Hevesy and Hofer report an experiment in which they study the rate of elimination of a quantity of heavy water ingested (in man). They found that half the quantity was excreted in the urine 9 (± 1) days after the ingestion. From this they calculated that "the average time a water molecule spends in the body is 13 ± 1·5 days", and assume "that most of the water taken becomes completely mixed with the water content of the body".

Some time ago, we made an experiment on the absorption of heavy water from the small intestine of the rat. We had already made the following calculations, and now bring them forward in support of Hevesy and Hofer's view.

A 4·5 per cent xylose solution, that is, a solution isotonic with the blood, was made in a 1·66 per cent solution of heavy water in ordinary water. By the exchange of four OH groups, the heavy water had now a concentration of 1·64 per cent. 6 c.c. and 4 c.c. respectively of this solution were injected into 60 cm. jejunal loops of two anæsthetised rats, which had fasted for 20 hours. After one hour the animals were killed, and the contents of the loops taken for analysis. We know from previous experience that in such experiments the quantity of fluid remains about the same, while about one fifth of the xylose is absorbed, and sufficient sodium chloride diffuses in to keep the solution about isotonic with the blood.

The heavy water content of the intestinal fluid was then analysed, after thorough purification and repeated acid and alkaline distillation. It was found to be 0·07 per cent in the first case, and 0·05 per cent in the second. This shows that there is a very rapid exchange of water injected (with its indicator