which would not have been possible had a heavy door been used instead.

Stray radiation at various points was measured by a Victoreen radiation meter, both inside and outside the building, and the results are recorded in Table 1.

It will be seen that the building affords adequate protection to everyone having to do with the betatron. When it is realized that the betatron will seldom, if ever, be operated continually for an 8-hr day the actual radiation likely to be received by any person is considerably smaller that that indicated in Table 1. The background count of a counter inside a lead castle situation in the main physics building is not affected by the operation of the betatron, although the background inside the betatron building is affected.

The betatron was manufactured by Allis-Chalmers Company of Milwaukee, Wisconsin, under the direction of Dane Scag. The machine is very similar to the one being used by the betatron group under D. W. Kerst at the University of Illinois. The machine is provided with four elevator screws simultaneously operated by a single motor to raise the upper yoke of the magnet. This greatly facilitates the replacement of donuts. The poles of the magnet are made of oriented steel and the field is adjusted for azimuthal uniformity by package coils. The machine is provided with a monitor which records the instantaneous intensity of radiation with auxiliary circuits to integrate this intensity. After a prearranged dose in roentgens has been given the machine automatically shuts itself off. The condensers for the tuning of the betatron are all located in the control unit.

The betatron, as installed, could operate only at an energy of about 25 Mev but it is being altered to operate through a range of energy levels below this value. An integrator circuit is being constructed to maintain any energy setting of the betatron to an accuracy of 0.1 percent. This will be accomplished by causing expansion of the electronic orbit to occur when the magnetic flux reaches a predetermined value. The machine will then operate at this energy or flux regardless of line voltage fluctuations or frequency changes. For constant voltage input to the betatron building, the magnetic flux is constant to within ± 2 percent as the frequency varies from 59.7 to 60.3 cycles per second.

The group working with the betatron plans to do experimental work in the field of nuclear physics. Some of the problems which will be attacked first include the measurement of the threshold energy for photodisintegration for (γ, p) and (γ, n) reactions in which the product of the reaction is not radioactive. This means that it will be necessary to detect the protons or neutrons produced in the reaction. Other problems involve the measurement of the energy distribution in the betatron spectrum so that the actual cross sections for photodisintegration may be measured.

For the investigation of the therapeutic applications of the betatron a d-c amplifier in conjunction with a small probe ionization chamber has been constructed. This will be used to measure the distribution of radiation within a water phantom. This distribution will be measured for a series of sizes of fields and for different types of step filters in an effort to get a clinically useful distribution. After this has been accomplished the machine may be used for cancer therapy. Many interesting experiments using the electron beam have been tentatively planned. These, however, must await the successful development of pumping techniques for use with electron donuts which have been obtained from the University of Illinois.

The authors would like to take this opportunity to thank those who have helped them to obtain the betatron and its building and auxiliary equipment in such a short time. In particular they wish to express their appreciation to D. W. Kerst and his associates, of the University of Illinois, who made available to them the facilities of their laboratory and who gave generously much valuable information and advice.

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Note on the Origin of Cosmic Rays[1]

W. Baade and F. Zwicky (*Phys. Rev.*, 1934, **45**, 138 and 46, 76), F. Cernuschi (*Phys. Rev.*, 1939, **56**, 120), and F. Hoyle (*Monthly Notices R.A.S.*, 1946, **106**, 384) have suggested that supernovae might be responsible for cosmic rays. Hoyle has recently considered this idea more closely in connection with his ideas about the origin of the chemical elements (*ibid.*, p. 343). He suggests that the heavy nuclei, or, better, the nuclear lumps, which are expelled during the supernova outburst might lose their accompanying electrons and thus become surrounded by strong electric fields in which nuclei might be accelerated up to energies as high as the largest energies found in cosmic rays. As a point in favor of this theory, Hoyle points out that, assuming that the average supernova will produce 0.1 M_0c^2 (M_0: solar mass; c: the velocity of light) energy in the form of cosmic rays, the density of extragalactic nebulae and the frequency of supernova outbursts are such that one can just explain the observed density of cosmic rays observed on the earth.

However, H. Alfvén (*Z. Physik*, 1937, **107**, 579) has pointed out that a galactic magnetic field of only 10^{-13} gauss would be sufficient to keep all cosmic rays inside our galaxy, and L. Spitzer, Jr. (*Phys. Rev.*, 1946, **70**, 777) has given strong arguments for the existence of such a galactic field. This means that we have to consider only our own galaxy as far as the production of cosmic rays is concerned. If we again assume that supernova outbursts are responsible for cosmic rays, we now have to estimate how large a density of cosmic rays we can expect. Assuming the production of cosmic ray energy per supernova to be about 0.001 M_0c^2 (Hoyle's estimate seems to us to be rather high, and we shall see that even a ten times smaller estimate would have been sufficient in order to get agreement between the observed and estimated energy densities), and assuming one supernova out-

[1] This letter was written while the author was temporarily at Yerkes Observatory, Williams Bay, Wisconsin.

burst per 500 years per galaxy (Zwicky, F. *Astrophys. J.*, 1942, 96, 28), the energy produced per sec per galaxy is about 10^{11} erg. According to R. D. Richtmyer and E. Teller (*Phys. Rev.*, 1949, 75, 1729), the lifetime of a cosmic ray in our galaxy is about 50 million years. Assuming the volume of our galaxy to be about 10^{12} cubic parsec ($\approx 3.10^{67}$ cm^3), the total cosmic ray density in our galaxy should be about 10^{-11} erg cm^{-3}. This is of the same order of magnitude as the value of about 5.10^{-13} erg cm^{-3} obtained by Richtmyer and Teller from B. Rossi's data (*Rev. mod. Phys.*, 1948, 20, 537.).

As far as the production of the high energy particles in the supernova outburst is concerned, we favor a mechanism different from that suggested by Hoyle, but essentially the same as that proposed by Cernuschi. Cernuschi proposed the fission of the nuclear lumps as the mechanism and made some estimates of the available energy per fission fragment on the basis of a very crude model of the nucleus. At present, we have a better understanding and knowledge of the energy which can be released in a fission process of a nuclear lump. Also it seems to us that the primary cosmic rays should not be the fission fragments but the neutrons accompanying the fission. For an estimate of the energy which becomes available at a fission process, we shall use N. Bohr and J. A. Wheeler's expression (*Phys. Rev.*, 1939, 56, 426) for the packing constant (i.e., the energy content per unit mass)[2] of a nucleus of charge Z and atomic weight A in the form given by G. B. van Albada (*Astrophys. J.*, 1947, 105, 393):

$$f = \alpha y^2 + \beta y - \gamma + kZ^2A^{-4/3} + sA^{-1/3}, \tag{1}$$

where f is the packing constant and

$$\left.\begin{array}{l} y = (\tfrac{1}{2}A - Z)/A, k = 0.63\ mMU, s = 15\ mMU \\ \alpha = 83\ mMU,\ \beta = 0.81\ mMU,\ \gamma = 6.65\ mMU. \end{array}\right\} \tag{2}$$

From van Albada's considerations of equilibria at zero temperature and high densities, it follows that the specific charge of the nuclear lumps ejected by the supernova will be in the neighborhood of 1/4:

$$Z/A \sim 1/4. \tag{3}$$

Using equations (2) and (3), equation (1) takes the form:

$$f = -1.3 + 0.04\ A^{2/3} + 15\ A^{1/3}\ mMU \tag{4}$$

and the energy content of the nuclear lump is given by:

$$E = Af = -1.3\ A + 0.04\ A^{5/3} + 15\ A^{2/3}\ mMU \tag{5}$$

In Table 1 we have collected the values of f in mMU, and E in mMU and in ev for different values of A.

It is immediately seen from Table 1 that the fission of nuclear lumps with A equal to or larger than 10^5 will produce energies of the order of the highest observed cosmic ray energies.

The present note must not be taken too seriously, but there are a few points that might be well worth looking into. The first one is the fact that the primary cosmic rays contain about 30% nuclei with Z between 2 and 26 (see, e.g., Bradt, H. L., and Peters, B. *Phys. Rev.*, 1948, 74, 1828 and 1949, 76, 156). This can partly be due to the ejection of these nuclei with energies of the order of magnitude of their rest energy by the supernova during the outbrust (cf. Hoyle, *Monthly Notices R.A.S.*, 1946, 106, 384), or partly due to possible tripartitions. Experiments with uranium (Tsien, S. T. *et al.* *J. Phys. Rad*, 1947, 8, 165 and 200; see also Titterton, E. W., and Goward, F. K. *Phys. Rev.*, 1949, 76, 142, and Lark-Horovitz, K., and Schreiber, R. E. *Phys. Rev.*, 1941, 60, No. 2, 156) indicate that one tripartition occurs against about 200 to 400 ordinary fission processes. It might be interesting to investigate theoretically whether the highly unstable nuclear lumps would favor a larger percentage of tripartitions, and how the distribution of the fission products (especially the light one) over the various Z values would be.

TABLE 1

A	f in mMU	E in mMU	E in ev
100	2.9	300	$3 \cdot 10^8$
200	2.7	500	$5 \cdot 10^8$
300	2.8	800	$8 \cdot 10^8$
500	3.2	1,600	$2 \cdot 10^9$
1,000	4.2	4,000	$4 \cdot 10^9$
5,000	12	$6 \cdot 10^4$	$5 \cdot 10^{10}$
10,000	18	$2 \cdot 10^5$	$2 \cdot 10^{11}$
100,000	85	10^7	10^{13}
1,000,000	400	$4 \cdot 10^8$	$4 \cdot 10^{14}$
10,000,000	2,000	$2 \cdot 10^{10}$	$2 \cdot 10^{16}$

A second point is whether it is possible to understand from the supernova picture of production of cosmic rays that the cosmic ray spectrum behaves like E^{-3}. In order to investigate this it would be necessary (a) to have a quantitative picture of the supernova outburst, which also would give a test for the validity of the equilibrium theory of the chemical elements (see, e.g., ter Haar, D. *Amer. J. Phys.*, 1949, 17, 282 and *Cosmogonical problems and stellar energy*, to be published); and (b) to have a quantitative statistical picture of the fission of nuclear lumps. The aging process discussed by E. Fermi (*Phys. Rev.*, 1949, 75, 1169) in his paper on the origin of the cosmic rays has certainly also to be taken into account. Indeed, it may well be that, as in so many other instances, a more acceptable theory will only be formed when ideas from all the different papers will have been melded togethed into one large compromise.

I should like to express my thanks to Dr. K. Lark-Horovitz for a discussion on the subject of this paper.

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[2] Reference in the text as mMU (milli mass units).