of instability since it would have no mass defect. It is of interest, therefore, to see if its much greater velocity in cosmic rays would increase its time of dissociation sufficiently to enable it to be observed.

If t_0 is the time of disintegration of the particle at rest and t the time when it is moving with velocity $v = \beta c$ we have

$$t = t_0/(1-\beta^2)^{\frac{1}{2}}.$$

From the relativistic energy equation

$$eV = 300\, mc^2[(1-\beta^2)^{-\frac{1}{2}} - 1],$$

it follows that the relative times of disintegration of two particles having energies V_1 and V_2 e-volts is given by

$$t_2 = t_1 \frac{V_2 + 300\, mc^2/e}{V_1 + 300\, mc^2/e},$$

where m is the mass of the particle, here equal to 137 times the mass of an electron, and $300\, mc^2/e = 7 \times 10^7$. The relative distances traveled before disintegration is then given by $d_2 = d_1 v_2 t_2 / v_1 t_1$.

Taking the mean energy of the end-points of β-decay spectra to be 10^6 e-volts I find that the ratio of the distance traveled by a cosmic heavy electron of 10^{12} e-volts energy to that traveled by a β-decay heavy electron before spontaneously disintegrating is 10^5. To account for the continuous energy distribution of β-rays the heavy electron would have to dissociate while still close enough to the nucleus to interact with it, so that this figure of 10^5 is hardly great enough to allow the heavy electron to be observed in cosmic rays, unless the interaction with the nucleus caused the slower β-ray heavy electron to be dissociated in a time much shorter than its time of spontaneous disintegration. Crane[4] has reported that in the course of some cloud chamber experiments a few β-particles appeared to behave in an anomalous way for which no satisfactory interpretation could be found. Zwicky[5] also has drawn attention to some peculiar cloud chamber tracks which, in his view, may be due to the electron suddenly changing its rest mass. This is just what would be observed if a β-decay heavy electron disintegrated spontaneously outside the atom, the probability of dissociation of the particle by interaction while it is still close to the nucleus is not quite unity.

Corben[6] has suggested that the heavy electron may be formed by the combination of an electron with one of Eddington's neutral particle ($\frac{1}{4}$ of a scalar particle) which has a mass 135.9. He considers this occurs with the emission of a neutrino. In Eddington's theory,[7] however, the neutral particles have no objective existence: they form a background consisting of the unspecified particles of the universe. The highest energy level of this background represents the ground level of the "object system" to which the vector wave functions of quantum theory apply: the scalars apply to the background which forms the reference frame. The neutral particles of the background, which are all below the ground level of the object system, are therefore in negative energy states. It is a *vacancy or hole* in the background that manifests itself as a particle in the object system.

If the neutron→proton transition in the nucleus interacts with the background as I have suggested,[8] and causes an electron to be created, the hole left in the background will represent the creation of a neutral particle with spin $\frac{1}{2}$, which could then combine with the electron to form a heavy electron which obeys Bose statistics, as is suggested above. The hole must represent an uncharged particle of spin $\frac{1}{2}$ for charge and spin to be conserved among the particles of the object system. On this view the heavy electron is created by the neutron→proton transition in the atom.

The University,
St. Andrews, Scotland,
May 14, 1938.
F. L. Arnot

[1] Yukawa, Proc. Phys.-Math. Soc. Jap. **17**, 48 (1935).
[2] Neddermeyer and Anderson, Phys. Rev. **51**, 884 (1937) and others.
[3] Bhabha, Nature **141**, 117 (1938).
[4] Crane, Phys. Rev. **53**, 317 (1938).
[5] Zwicky, Phys. Rev. **53**, 611 (1938).
[6] Corben, Nature **141**, 747 (1938).
[7] Eddington, *Relativity Theory of Protons and Electrons*.
[8] Arnot, Nature **139**, 1065 (1937).

Some Results of the Search for Super-Novae

Some time ago Baade and I discussed the existence of a new class of novae which surpass the common novae in luminosity by a factor of one thousand.[1, 2] We proposed to call these new stars *super-novae*, a designation which is now in general use. It should be emphasized, however, that super-novae in some respects differ fundamentally from ordinary novae.

In our original communications[1, 2] we made a first tentative attempt to estimate how often super-novae appear in an average nebula. From a considerable, though very heterogeneous set of records from various sources extending over the past fifty years we concluded that the frequency of occurrence of super-novae in an average nebula is of the order of one per several centuries. We also suggested that the study of super-novae promises to throw new light on the problem of the generation of energy in stars and perhaps on the origin of the cosmic rays. In conjunction with considerations concerning the tremendous liberation of energy in super-novae we suggested the formation of *collapsed neutron stars*[1, 2] as the most powerful source of energy.

These suggestions clearly reveal the great potentialities of a study of super-novae. We decided that no effort should be spared to track down and to study in detail as many as possible of these rare objects. Several seasons of unsuccessful work with unsatisfactory telescopic equipment preceded a period in which the greatest advance was made with the aid of the 18-inch $f:2$ Schmidt telescope which had been built in the meantime with the authorization of the observatory council of the California Institute of Technology.

In the period from September 5, 1936 until January 31, 1938, about six hundred excellent photographs covering seventy square degrees each were obtained with the Schmidt telescope. The resulting search is equivalent to the continuous control during one year of about 1800 nebulae whose apparent brightness is greater than $m = 15$. Since three super-novae were discovered in the period mentioned, the resulting frequency is one *super-nova per average nebula* of our collection *in a period of six hundred* *years*, a result which confirms the correctness of our original estimate.

The two brightest of these super-novae, which appeared in N.G.C. 1003 and I.C. 4182, have now yielded a vast amount of information which will be presented in a series of papers to the *Astrophysical Journal*. Summarizing some of these results we may state:

1. For the first time excellent photographic light curves have been obtained for super-novae, including the maxima. A large number of photographs taken with yellow filters is also available from which red magnitudes may be derived.
2. Intensive spectroscopic studies by M. L. Humason, R. Minkowski and others have shown that super-nova spectra are totally different from the spectra of any other known stellar objects.
3. The most luminous super-novae may be brighter than the nebulae in which they appear by as many as five magnitudes, as the case of the super-nova in I.C. 4182 has shown. This brightest of all super-novae which is consequently the *brightest stellar object ever observed*, has, according to Baade, an absolute *photographic* magnitude close to $M=-16.6$, corresponding to about four hundred million times the luminosity of the sun. The total radiation of energy from a bright super-nova between the wavelengths $\lambda=6800$A and $\lambda=3600$A over a period of one year after its appearance amounts to about 10^{49} ergs.
4. The frequency of occurrence of super-novae has been determined as already mentioned.

The most important conclusion which we may draw from these new observational results is, that the existence of *two classes of temporary stars*, super-novae and common novae, has been established beyond doubt. The new data have also furnished for the first time the necessary basis for a consistent statistical evaluation of the data available for previously observed super-novae. This evaluation has been carried out in detail by Dr. Baade and has resulted in significant results regarding the average absolute magnitudes of super-novae as well as the dispersion in magnitudes.

California Institute of Technology,
Pasadena, California,
May 18, 1938.
F. ZWICKY

[1] W. Baade and F. Zwicky, Phys. Rev. **45**, 138 (1934) and **46**, 67 (1934); Proc. Nat. Acad. Sci. **20**, 254 (1934) and **20**, 259 (1934). See also F. J. M. Stratton, *Handbuch der Astrophysik*, Vol. 7 (1936), p. 671.

[2] F. Zwicky, The Scientific Monthly **40**, 461 (1935); Proc. Nat. Acad. **22**, 457 (1936) and **22**, 557 (1936); Publ. Astro. Soc. Pac. **48**, 191 (1936) and **49**, 204 (1937).

Angular Distribution of Slow Neutrons from a Paraffin Surface

In experiments on the properties of slow neutrons and the induced radioactivities produced by slow neutrons it has been a common practice to use a Rn-Be neutron source embedded beneath the surface of a paraffin block and plane parallel layers of absorbers and detectors. The analysis of such experiments requires a knowledge of the angular distribution of neutrons coming from the surface. The expected distribution has been derived theoretically by Fermi[1] and found to be $f(\theta)\sim\cos\theta+\sqrt{3}\cos^2\theta$. The distribution has been studied experimentally and found to follow the Fermi distribution to within experimental errors.

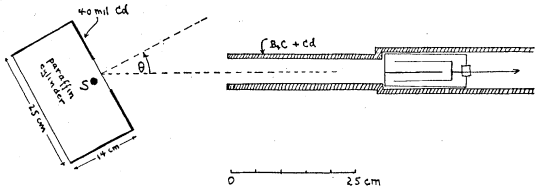

FIG. 1. Experimental arrangement for observing the angular distribution of slow neutrons emerging from a paraffin surface.

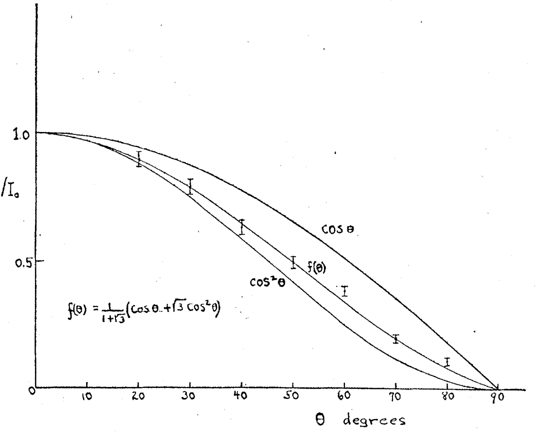

FIG. 2. Observed angular distribution of slow neutrons from a paraffin surface. The observations are shown with their standard errors and fit the Fermi distribution, $f(\theta)$, to within the accuracy of the experiments.

Figure 1 shows the experimental arrangement. A Rn-Be source of neutrons, S, was placed 3 cm beneath the surface of the end of a paraffin cylinder of the kind described by Amaldi and Fermi.[2] The neutrons emerging from the surface were detected in a BF_3 ionization chamber which was placed within cylindrical shields of B_4C and Cd forming a collimator for slow neutrons. The ionization pulses due to the slow neutron disintegration of B^{10} were observed with a pulse amplifier and counter. The variation of slow neutron intensity with angle was measured by rotating the BF_3 ionization chamber about a vertical axis in the plane of the paraffin surface.

The cylinder was covered entirely with Cd (0.88 g Cd/cm^2) with a hole 7 cm in diameter in the center of the end cover. This hole defined the area of the emitting surface, and was at the center of, and smaller than, the area "seen" by the detecting chamber. This insured having the same emitting surface effective at all angles. The BF_3 chamber subtended an angle of 6° 30′ from a point at the center of the emitting surface. The collimator tube absorbed possible stray slow neutrons from the walls and floor.

Counts were taken without and with Cd over the end of the collimator tube, the difference between these runs being taken as the slow neutron count. Fig. 2 shows I/I_0 plotted as a function of angle, θ. The observed points are shown with the fluctuations based on the standard errors of I and I_0. The solid lines give for purposes of comparison the functions $\cos\theta$, $\cos^2\theta$, and $f(\theta)$. The observed points tend to