

(probably satellite chromosomes) remain so connected, in many cases, until the equatorial-plate stage. In a lateral view of the equatorial plate, the nucleolus appears as a pyriform structure. In some cases it seems to be attached to the chromosomes at one side of the plate, but looped over so that the greater part of it lies on the opposite side. In lateral views of certain anaphases there appears at one end of the cell a chromatic body, evidently the nucleolus, surrounded by a hyaline region.

A few apparently binucleate cells were observed in the periblem and dermatogen both in longitudinal and in cross sections. The origin of polysomaty is held by some workers to be due to the fusion of nuclei in binucleate cells; others contend that these binucleate cells are too rare to account for polysomaty, and that the fusion of resting nuclei cannot account for the closely paired arrangement of the chromosomes.

Summary.—Polysomaty is a regular occurrence in the periblem of primary and secondary roots in four varieties of *Cucumis Melo*. It is rare in the plerome. Disomaty is the more frequent condition, but some tetrasomatic cells appear.

There is an increase in frequency of polysomatic nuclei from the younger toward the older portion of the meristematic region.

In some polysomatic nuclei all the chromosomes are paired; in some, pairing is incomplete; in others there is no pairing.

Polysomaty occurs in the stem tip and in leaf primordia.

¹ A. Lorz, *Cytologia*, **8**, 241–276 (1937).

² H. D. Wulff, *Planta*, **26**, 275–290 (1937).

³ Z. A. Kozhukhow, *Bull. Appl. Bot. Pl. Breeding*, **14**, 89–96 (1925).

⁴ T. W. Whitaker, *Amer. Jour. Bot.*, **17**, 1033–1040 (1930).

⁵ Z. A. Kozhukhow, *Angew. Bot.*, **10**, 140–148 (1928).

PRODUCTION OF ATOMIC RAYS AND OF COSMIC RAYS IN SUPERNOVAE

BY F. ZWICKY

NORMAN BRIDGE LABORATORY OF PHYSICS, CALIFORNIA INSTITUTE OF TECHNOLOGY

Communicated June 10, 1939

A. Supernovae.—Several years ago, Baade and I made the following suggestions:¹

(1) A class of very rare temporary stars exists, some of whose major physical properties are similar to those of common novae, but in a superlative degree. We proposed that the new stars might appropriately be called supernovae.

(2) Supernovae are an origin of the cosmic rays.

Our first problem obviously was to locate as many *active* supernovae as possible in order to prove the correctness of assertion (1). Through the discovery of nine supernovae² with the Schmidt Telescope on Palomar Mountain, the solution of this problem has now reached a stage of completeness which is sufficient to allow us to turn our attention to assertion (2). We therefore proceed to outline some of the general processes which presumably take place in supernovae and which are capable of producing *cosmic rays* as well as *atomic rays* of high energy.

B. Atomic Rays Ejected in a Supernova Outburst.—We may assume that, similar to the well-known phenomena which take place in common novae, gaseous clouds of considerable mass are ejected from supernovae. An atom of the mass m will have the kinetic energy

$$\epsilon_k = m\bar{v}^2/2 = kmc^2 \quad (1)$$

where \bar{v} is the average velocity of the ejected gas clouds, and c is the velocity of light.

Since it has not yet been possible to interpret the spectra of supernovae, we do not know the exact numerical values which the constant k assumes for individual supernovae. A number of reasons may be advanced, however, which indicate that k for a supernova is at least a hundred times larger than for a common nova. For instance, it was found by Minkowski³ that the permanent features in the spectra of four recent bright supernovae were subject to a general progressive red-shift, a shift which over the period of one year corresponds to a relative change in wave-length λ of about

$$\Delta\lambda/\lambda \cong 0.05. \quad (2)$$

This red-shift, so far, leaves us with the choice of two interpretations. If real, it may indicate

(a) A progressive change in Doppler displacement, corresponding to a change of the actual velocities of the ejected atoms.

(b) A progressive gravitational red-shift caused by the continuous contraction of the stellar remnant of a supernova into a highly collapsed star.⁴

In case (a) we conclude from (2) that, in the early stages of a supernova, the velocity of ejection \bar{v} must be

$$\bar{v} \geq 0.05c = 15000 \text{ km/sec.} \quad (3)$$

with a resulting value k_1 of k ,

$$k_1 \geq 1.3 \times 10^{-3}. \quad (4)$$

In case (b) we conclude from (2) that the gravitational potential on the

surface of the stellar remnant of a supernova, about one year after maximum, is

$$\varphi = -c^2\Delta\lambda/\lambda = -0.05c^2. \quad (5)$$

The average potential energy ϵ_p of a particle of mass m in the stellar remnant therefore is

$$\epsilon_p < -0.05mc^2. \quad (6)$$

Consequently, during the contraction of the stellar remnant, whose mass is M , the total gravitational energy

$$\mathfrak{E}_t > 0.05Mc^2 \quad (7)$$

has been liberated in form of radiation, kinetic energy of the ejected gas clouds, etc. I have recently shown⁴ that the total energy $\mathfrak{E}_{\text{vis}}$ liberated in form of visible light (in case (b)) constitutes but a small fraction of \mathfrak{E}_t . A major part of \mathfrak{E}_t is available to endow every ejected particle of mass m with a kinetic energy of the order

$$\epsilon_k \cong 0.05mc^2 \quad (8)$$

which corresponds to a value k_2 of k , where

$$k_2 \cong 5 \times 10^{-2}. \quad (9)$$

Finally, from simple considerations⁵ regarding the light pressure on the ejected gas clouds, an approximate relation may be derived connecting the luminosity of a nova at maximum brightness with the average velocity of expansion \bar{v} of the ejected gas clouds. If we denote with $\mathfrak{M}_{\text{max}}$ the absolute magnitude of the nova at maximum, this relation is

$$\mathfrak{M}_{\text{max}} = -5 \log_{10} \bar{v} + \mathfrak{M}_1. \quad (10)$$

The constant \mathfrak{M}_1 may assume somewhat different values for different novae inasmuch as it contains a term $\log R_0$, where R_0 is the radius of the original star. I have shown⁵ that the relation (10) satisfactorily represents the data which are available at the present for ordinary novae. Extrapolating (10) to supernovae, it follows that for these stars

$$10^4 \text{ km/sec} < \bar{v} < 10^5 \text{ km/sec}. \quad (11)$$

From all of these considerations it becomes therefore highly probable that for an average supernova

$$\epsilon_k \geq 1.5 \times 10^{-3}mc^2. \quad (12)$$

This means, for instance, that the kinetic energy of an iron atom ejected from a supernova presumably lies in the range

$$10^8 \text{ el. volts} < \epsilon_k(\text{Fe}) < 10^9 \text{ el. v} \quad (13)$$

Intergalactic and interstellar space are hence, through supernovae, continually supplied with *atomic rays* which are made up of high speed atoms and ions, the kinetic energy of which is proportional to their atomic weight. Some of the phenomena which atomic rays may cause on their journey through various stellar systems I have discussed previously.⁶

In the search for an interpretation of the spectra of supernovae, it will be well to keep in mind that velocities of the order contemplated in the preceding considerations will tend to displace and to widen absorption lines and emission lines to a degree not so far encountered in the spectra of any of the familiar celestial objects.

C. *Cosmic Rays Generated during the Breakdown of the Electric Fields Which Are Built up through the Violent Fission of a Star.*—Several processes which presumably take place in a supernova outburst would seem to be capable of producing cosmic rays. Some of these processes depend strongly on the radiation density and the relative concentrations of various stages of ionization of the ejected gas atoms. Since we do not have at our disposal sufficient data on the required physical characteristics of a supernova to discuss these modes of generation of cosmic rays in detail, we shall describe them in the second part of this paper in a general fashion only.

There is, however, imaginable one process capable of generating cosmic rays, the existence of which in supernovae appears extremely probable on the basis of available data on supernovae. This process is related to the creation of large differences in electric potential because of *random* separation of elementary particles of positive and negative charge.⁸ If we disregard the systematic segregation of positive and negative ions, which is to be discussed in the second part of this paper, electric potential differences of the order⁸

$$\Phi \geq 10^9 \text{ volts} \quad (14)$$

can be built up through the violent random segregation of positive and negative charges during the fission in a supernova. Since I have discussed this process in another place⁸ we proceed to consider briefly those processes which tend to systematically segregate electric charges of different signs.

D. *Generation of Large Differences in Electric Potential Because of the Selective Action of the Light Pressure on Various Particles.*—The kinetic energies, which atoms and ions, electrons and protons acquire in a directed flow of radiation depend on the character of the particle considered, as well as on the spectral distribution of this radiation. The ultimate value of the kinetic energy is essentially determined by the following processes.

(1) As long as the density of the ejected gas clouds is large enough to suppress any selective acquisition of energy, the final velocity \bar{v} of all

particles will be the same. This case of the atomic rays was discussed in Section B.

(2) When the density, because of the expansion of the gas clouds, becomes so low that collisions do not any more seriously interfere with the accelerating action of the radiation, selective acceleration will take place. For instance, electrons will be accelerated more than protons; and atoms and ions, through the photoelectric effect and particularly through the efficient action of light pressure in strong resonance absorption lines, may acquire considerable kinetic energies. The problems involved here are of great interest, but cannot as yet be treated in detail in the case of supernovae because of lack of knowledge regarding the determining physical conditions in the neighborhood of a supernova.

(3) In both of the stages (1) and (2) of the expanding gas clouds, the selective action of the light pressure tends to segregate positive and negative charges. This segregation will result in the systematic building up of differences in electric potentials. We have no detailed knowledge regarding the total amount of the charges carried away, nor do we know what the ultimate distances of separation of these charges are. We know, however, that the light pressure in supernovae is sufficient to produce charges and separations such that the total potential energy \mathfrak{E}_p due to these charges is of the order of the total energy \mathfrak{E}_r emitted in the form of radiation, where \mathfrak{E}_r is equal or greater than the energy $\mathfrak{E}_{\text{vis}} \cong 10^{48}$ ergs⁷ carried away by the radiation in the visible spectrum. This permits us to estimate the possible limits of the differences in electric potential which may be built up temporarily because of the selective action of the radiation in a supernova outburst.

Suppose that the segregating action of the light pressure has created a space charge σ e. s. u./cm.³ in a volume $V = L^3$ surrounding the stellar remnant of a supernova. The total electric potential energy then is

$$\mathfrak{E}_p = \overline{E^2}L^3/8\pi = \alpha Mc^2 \quad (15)$$

where $\overline{E^2}$ is the averaged square of the field strength and α may be of the order $\alpha = 10^{-4}$. Therefore,

$$(\overline{E^2})^{1/2} = (8\pi\alpha Mc^2/L^3)^{1/2}. \quad (16)$$

We obtain the maximum potential difference Φ_{max} if the space charge is essentially of one sign, say negative on the stellar remnant and positive on the ejected gas clouds. We may then have

$$\Phi_{\text{max}} \cong L(\overline{E^2})^{1/2} = (8\pi\alpha Mc^2/L)^{1/2}. \quad (17)$$

If we put $M = \mu M_{\odot}$ and $L = Dr_{\odot}$ we obtain

$$\Phi_{\text{max}} \cong 8 \times 10^{19}(\mu/D)^{1/2} \text{ e. s. u.}, \quad (18)$$

with a radial field component of the average order

$$\bar{E} \cong \Phi_{\max}/Dr_{\odot} \quad (19)$$

and a total space charge Σ of the order

$$\Sigma = \bar{E}L^2 \cong (8\pi\alpha Mc^2L)^{1/2}. \quad (20)$$

The value of D , about one hundred days after maximum, according to the considerations of section *B* may be of the order $D = 10^6$ which, with $\mu = 1$ would result in

$$\Phi_{\max} \cong 8 \times 10^{16} \text{ e. s. u.} \quad (21)$$

and

$$\bar{E} \cong 300 \text{ volts/cm.} \quad (22)$$

$$\Sigma \cong 5 \times 10^{33} \text{ e. s. u.}$$

E. Breakdown of the Electric Fields Surrounding the Stellar Remnant.—

The space charges and the electric fields in the ejected gaseous masses will break down when the radiation from the stellar remnant decreases to a point where it is not any more able to support these space charges. At that stage the mean free paths of the individual corpuscles will also have become very large because of the exceedingly rapidly decreasing density of the expanding gas clouds. Breakdown of the enormous electric potentials will cause the production of elementary corpuscles whose kinetic energies are well *within* and *above* the range of those observed in cosmic rays. Supernovae thus may well be regarded as a powerful source of cosmic rays.

Baade and I have shown previously¹ that on the picture just discussed, combined with results, now available, of the frequency of supernovae, it is also possible to account for the total intensity of the cosmic radiation observed on the earth.

Finally, attention should be drawn to the fact that particles of different charge and mass will emerge with different kinetic energies from the collapse of the electric fields. In the first place, the energy of particles of equal sign will be the largest for the lightest particles. In the second place the kinetic energy will be larger for the particles which are located in initially large electric fields. The operation of these two effects may lead to a satisfactory understanding of the asymmetry in cosmic rays which causes the east-west effect.

The considerations sketched in this paper will be discussed in more detail in another place.

¹ W. Baade and F. Zwicky, these PROCEEDINGS, 20, 254 (1934); and 20, 259 (1934).

² F. Zwicky, *Publ. Astr. Soc. Pacific*, 50, 215 (1938); and 51, 36 (1939).

- ³ R. Minkowski, *Astrophys. Jour.*, **89**, 156 (1939).
⁴ F. Zwicky, *Phys. Rev.*, **55**, 726 (1939).
⁵ F. Zwicky, these PROCEEDINGS, **22**, 457 (1936).
⁶ F. Zwicky, *Ibid.*, **22**, 266 (1936).
⁷ W. Baade and F. Zwicky, *Astrophys. Jour.*, **88**, 411 (1938).
⁸ F. Zwicky, *Phys. Rev.*, **55**, 986 (1939).
-

AN EXPERIMENT IN HUMAN VITAMIN A-DEFICIENCY

BY GEORGE WALD AND DAVID STEVEN¹

BIOLOGICAL LABORATORIES, HARVARD UNIVERSITY

Communicated June 14, 1939

The first observable symptom of vitamin A-deficiency in man and other mammals is a rise of visual threshold known as night-blindness. This response is based at least in part on the direct participation of vitamin A in a retinal cycle with the photosensitive pigment of the rods, rhodopsin.² With other conditions held constant, the sensitivity of the rods to light depends upon their rhodopsin content. As the level of vitamin A falls on a deficient diet, the concentrations of all components of the retinal cycle, including rhodopsin, decrease and the visual threshold reciprocally rises. Measurements of the rise and reversal of night-blindness therefore yield important information concerning the utilization of vitamin A *in vivo*. One set of such measurements upon a human subject has already been reported from this laboratory.³ The present paper describes the results of a second experiment in which identical observational methods were employed.

The subject D. S. is 22 years of age, 5 feet and 10¹/₂ inches in height and weighs 155 pounds. Throughout the course of the research he remained in excellent physical condition, ate very well and exercised regularly.

A standardized procedure was employed in all the measurements. Following 4 minutes' exposure to an intense light-adapting screen (4200 millilamberts), the absolute threshold of vision was measured periodically on alternate eyes during about 40 minutes in darkness. The test field for the threshold determinations is circular and subtends a visual angle of 2.1°. It is fixated 11.7° above the fovea, and is exposed by the subject for flashes of approximately ¹/₆₀ second.

The experiment was begun with a period of vitamin A saturation, lasting 18 days, during which the normal diet was supplemented with 51,000 International Units of vitamin A daily, or from 10 to 25 times the accepted maintenance level.⁴ Dark adaptation measurements during this period are shown as closed circles in figure 1. They are of characteristic form. The threshold falls rapidly to a first plateau, maintained until about the 11th