EXTRATERRESTRIAL EFFECTS OF COSMIC RAYS

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A. Introduction.—So far only interactions of cosmic rays with *terrestrial* matter have been investigated. If cosmic rays are present in interstellar and intergalactic space, they produce physical changes on extraterrestrial objects also. The question therefore arises if such changes are observable. The following considerations make it probable that this question is to be answered in the affirmative.

B. Radiations in Interstellar Space.—The following corpuscular and electromagnetic rays are traveling continually through interstellar space.

(1) *Light* from the *stars.*—Its total intensity I_L in an average point in our galaxy is estimated to be of the order

$$I_L = 5 \times 10^{-3} \text{ ergs/cm.}^2 \text{ sec.} \qquad (1)$$

(2) *Atomic rays* are ejected from novae, Wolf-Rayet stars, etc. These rays consist of atoms, ions and molecules, whose greatest individual kinetic energies are at least as high as 10^7 e.-v. The total transport of energy by atomic rays probably corresponds to an intensity I_A not smaller than

$$I_A = 10^{-4} \text{ ergs/cm.}^2 \text{ sec.} \qquad (2)$$

Atomic rays, so far, have not been considered in astrophysics. More information about them will be given in another publication.

(3) *Cosmic Rays.*—The problem of their composition and their mode of creation has not yet been solved. Individual cosmic ray particles may possess energies of 10^9 e.-v. and more. The total energy which is transported through space by the known high energy components of the cosmic rays corresponds to an intensity I_C not less than

$$I_C = 3 \times 10^{-3} \text{ ergs/cm.}^2 \text{ sec.} \qquad (3)$$

There can be no doubt that the gap between energies of 10^7 e.-v. to 10^9 e.-v. is filled by a variety of rays which may be either low energy cosmic rays or atomic rays more energetic than those which are emitted from bright common novae. Future observations on novae whose absolute visual brightness is greater than $M_{\text{vis}} = -9$ promise to clear up this point.

It is also desirable to analyse the light from the non-polar as well as from the polar aurorae in order to obtain more information about all those components of interstellar rays which do not penetrate deeply into the earth's atmosphere.

At the present time it is difficult to estimate the *total energy* transported by light, atomic rays and cosmic rays. The composite intensity I of all these rays is certainly greater than

$$I = 10^{-2} \text{ ergs/cm.}^2 \text{ sec.} \qquad (4)$$

Judging from the high surface brightness (ca. 5×10^{-3} ergs/cm.^{2} sec.) of the non-polar aurora it would seem that the intensity I is even considerably greater than estimated in (4). In the following we shall assume that in an average point in interstellar space of our own galaxy the total energy transport I is of the order

$$I = 0.1 \text{ ergs/cm.}^2 \text{ sec.} \qquad (5)$$

It must be kept in mind that for many purposes the effects of various rays which contribute to the intensity I must be considered separately. For other purposes only the over-all value of I is important.

C. Excitation of Emission Lines by Cosmic Rays and Atomic Rays.—Energetic corpuscles and photons which travel through interstellar space are capable of exciting emission lines which correspond to high stages of excitation. A closer scrutiny reveals that extended gaseous masses represent the most favorable objects for the production of emission lines by cosmic rays. Our attention therefore turns to the tenuous atmospheres of giant stars, interstellar gas clouds, comet tails, the upper parts of the earth's atmosphere and the like.

For the sake of illustration we shall confine the discussion to long period variable stars. These stars are known to be giants of very low surface temperature (ca 2000°K.). The fact that the spectra of long period variables show the Balmer lines in emission with high intensity has long constituted a puzzling problem. The energy necessary to excite the Balmer series is greater than 13.5 e.-v. which can only be furnished by *ultra-violet light* of wave-lengths shorter than $\lambda = 911$ Å or by *energetic particles.* Existing theories which try to explain the presence of either one of these two agents in the atmospheres of low temperature stars are not very convincing. As a new alternative I therefore propose to investigate the possibility that the emission lines in Mira stars are produced by energetic interstellar rays.

The interferometric diameters of long period variables are of the order of 2×10^{13} cm. (Mira ceti). The actual atmospheres of these stars may, however, well extend to distances of $R = 10^{14}$ cm. from the center of the star, because the interferometer probably measures only the diameter of a dense and luminous central part of the star. The place of origin of the emission lines is most likely to be sought for in the outlying and extended regions of the star's atmosphere. If we assume that all of the interstellar rays which penetrate this atmosphere are absorbed, the total energy E available per second is of the order

$$E = 4\pi R^2 I = 4\pi \times 10^{28} I \tag{6}$$

or

$$E \sim 10^{28} \text{ ergs/sec.} \tag{6a}$$

Since the star's atmosphere is presumably made up mostly of hydrogen, most of the absorbed energy will reappear in the form of hydrogen emission lines. The Lyman lines, being resonance lines of the normal state of hydrogen, cannot easily escape from the star's atmosphere. After emission they will be absorbed, reëmitted and reabsorbed again and again. This chain of events leads finally to a high concentration of monochromatic light whose wave-length is that of the first Lyman line $\lambda = 1215.7$ Å. The net result is that essentially only the Balmer lines escape from the star with high intensity. The arguments here given are essentially the same on which *Zanstra* based his successful interpretation of the spectra of planetary nebulae.

The high intensity of the resonance radiation $\lambda = 1215.7$ Å produces a high concentration of excited hydrogen atoms. These excited atoms may absorb radiation from the star itself as well as interstellar light. In this way the emission of the Balmer lines will be intensified.

Inasmuch as the total light emitted on the average from long period variables in the form of Balmer lines probably does not exceed 10^{31} ergs/sec., the above considerations suggest that interstellar rays may indeed be the prime cause for the presence of high excitation emission lines in the spectra of low temperature giant stars. It will be of interest to carry out the theory in more detail as soon as more information is available regarding the possible values of the intensities of the different radiations which are present in interstellar space.

In addition it must be investigated what part of the hydrogen resonance radiation is transformed into kinetic energy and is lost in the form of heat by absorption in various types of molecules and subsequent impacts of the second kind. These impacts become the more important the denser the atmosphere. If on the other hand the density of the star's atmosphere should be too low, the Lyman lines can themselves directly escape from the star. The efficiency of production of the hydrogen emission lines will therefore be highest for some definite density distribution and extension of a star's atmosphere.

As mentioned before, the presence of emission lines in the spectra of comet tails, of the night sky and of certain gas clouds in the Milky Way and in extragalactic nebulae represent additional phenomena which may possibly be caused by atomic rays and cosmic rays.

D. Transfer of Mechanical Momentum from Atomic Rays and Cosmic Rays to Stellar and Interstellar Matter.—For photons and particles whose velocity is nearly equal to that of light, that is, for cosmic rays, the specific transport of momentum (per unit time in the direction normal to a given unit area) is

$$j_c = I_c/6c. \tag{7}$$

For particles whose velocity v is appreciably smaller than c, that is, for most atomic rays, we have

$$j_A = I_A/3v. \tag{8}$$

If all of the radiation represented by the intensity I is absorbed, the pressure exerted on the absorbing medium is $p = j$. With the values of I_c and I_A adopted in (2) and (3) we obtain $p_c = 1.66 \times 10^{-14}$ dynes/cm.^{2} and $p_A = 3.3 \times 10^{-10}/v'$ dynes/cm.^{2} where v' is measured in kilometers per second.

Since atomic rays are more easily absorbed than cosmic rays they will be relatively most effective in imparting momentum to tenuous matter through which they pass. The possibility therefore suggests itself that the mechanical behavior of extended gas and dust clouds in interstellar space is not alone determined by gravitational forces and the pressure of light, but that the actions of interstellar corpuscular rays must be considered as well. The sharp outlines of such objects as the network nebula in Cygnus and the distinct contours of many interstellar dust clouds can perhaps be explained on this basis. In contradistinction to atomic rays, cosmic rays rather tend to disperse in course of time all local accumulations of interstellar gases.

E. Absorption of Cosmic Rays in the Milky Way.—Because of the eccentric position of the earth relative to the center of the Milky Way the absorption of cosmic rays on their passage through interstellar gas and dust clouds should produce a slight directional asymmetry of the intensity distribution of cosmic rays. This problem has recently been treated in these PROCEEDINGS.[1]

F. Secondaries from Cosmic Rays and Atomic Rays.—Individual particles of cosmic rays and atomic rays in course of time lose energy and are finally stopped entirely through formation of secondaries. The "mean free path" of cosmic rays is in general large compared with the linear dimensions of a galaxy (10^{23} cm.) whereas the mean free path of atomic rays inside of our Milky Way is probably less than one light-year. Cosmic rays and atomic rays are therefore both ejected and re-collected by stellar system, thereby completing a cycle which may play an essential rôle in the evolution of stars and galaxies.

Finally we mention that interesting possibilities would arise regarding the origin of the hardest components of cosmic rays if there existed parts of the universe in which the carriers of positive and negative electricity were reversed compared with the elementary particles known to us. Mutual annihilation of oppositely charged particles might then be expected to take place in certain regions of space.

G. Final Remarks.—The above considerations should be regarded as preliminary *programmatic* suggestions concerning theoretically possible extraterrestrial effects of cosmic rays and atomic rays. In order to proceed efficiently with this program it will be necessary to collect more data on the ejection of corpuscular rays from novae. As Baade and Zwicky[2] have suggested, the study of *super-novae* in particular promises to furnish the key to many phenomena related to interstellar rays, as well as to other fundamental problems of astrophysics.

[1] F. Zwicky, These PROCEEDINGS, **22,** 182–187 (1936).

[2] W. Baade and F. Zwicky, These PROCEEDINGS, **20,** 254 and 259 (1934); *Phys. Rev.*, **46,** 76 (1934).

THE EFFECT OF TEMPERATURE ON THE RESPIRATION OF THE EARTHWORM

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A large number of studies dealing with the effect of temperature on the respiration of poikilothermous animals have consistently shown an increase in the rate of gas exchange with a rise in temperature. This relationship has been described by the application of the Arrhenius equation (cf. Crozier[1,2]) which states that the velocity of essentially irreversible reactions is proportional to the exponential of $-\mu/RT$. The equation is written

$$V = e^{-\mu/RT} + C$$

where V is the velocity of the reaction being measured, e is the base of the natural logarithms, R is the gas constant, T is the absolute temperature, C is a constant of integration and μ is the critical thermal increment. In plotting the data and determining values for the constant μ, the form of the equation used is

$$\log K_2 - \log K_1 = \frac{\mu}{2.3R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

where K_1 and K_2 are the rates of respiration at the absolute temperatures T_1 and T_2. Temperature characteristics have repeatedly been found to yield values of approximately 11,000 and 16,000 calories for respiratory processes.