MECHANISM FOR THE PRODUCTION OF RELATIVISTIC ELECTRONS IN THE ATMOSPHERES OF NONSTATIONARY STARS

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TYPE I supernovae exhibit at maximum tremendous luminous intensities; in some cases these intensities are two orders of magnitudes greater than the intensity of the galaxy in which the supernova is located. The radiation from supernovae is nonthermal and is due to the synchrotron radiation of relativistic electrons.[1,2]

The author has offered observations to support the view that relativistic electrons responsible for the radiation of the Crab nebula arise in the stellar atmospheres.[3] Since the energy of these electrons is $10^{11} - 10^{12}$ ev, they cannot be produced in nuclear processes or as a result of induction acceleration processes. The latter mechanism is highly ineffective for electrons because of the high "magnetic bremsstrahlung" losses. Thus there is some basis for the suggestion that these electrons are produced in secondary processes and that the primary process is the acceleration of protons.[3]

We show below that this hypothesis may explain the characteristic features of the luminosity curves of type I supernovae and certain other nonstationary stars.

Baade has shown that the luminosity curve of a type I supernova consists of two parts: a maximum followed by a rapid reduction in intensity, and then a slower exponential drop with a half-life of 55 days. The second phase starts 50 — 100 days after the maximum. An attempt to explain this characteristic of the luminosity curve was made by Borst[4] who invoked radioactive decay, and by Burbridge et al.[5] who invoked fission of Cf^{254}. The shortcomings of the first explanation were indicated by Burbridge et al.[5] while those of the second have been indicated by the present author.[3] We may note that in reference 5 it was also indicated that the source of radiation of supernovae may be relativistic electrons as had been proposed earlier by us.[1,2]

The suggestion that the radiation of supernovae is due to relativistic electrons produced in secondary processes[3] can be used to explain the exponential decay of the luminous intensity if it is assumed that 50 — 100 days after the maximum there is no significant production of new relativistic protons and that the density in the shell remains constant in the region in which the secondary processes and electron radiation occur.

In the motion of a beam of particles in a gas with constant velocity and mean free path (λ), the number of noncolliding particles varies exponentially as $\exp(-x/\lambda)$, where λ is the particle mean free path, or as $\exp(-t/T)$ where T is the mean free time. The number of electrons which are formed is proportional to the number of protons that move in the shell and also varies exponentially. A calculation shows that the radiation time for relativistic electrons is approximately 100 sec, whereas the collision time corresponding to a reduction in intensity by a factor of two in 55 days is approximately 70 days, a number which is significantly larger. Thus the intensity is proportional to the number of relativistic electrons and also varies exponentially.

Taking the proton range in hydrogen[6] as 70 g/cm^2, it is possible to determine (using the time in which the intensity is reduced by a factor of two) the density in the shell $p \approx 3 \times 10^{-16}\ g/cm^3$ and the mass, starting with an expansion velocity of 10^8 cm/sec and an expansion time of 10^7 sec, corresponding to the beginning of the exponential phase. The mass which is obtained (10^{30} g) is in agreement with the astronomical data. The first part of the luminosity curve would seem to correspond to the period in which the formation of relativistic protons continues while the density changes.

This general behavior is exhibited by the luminosity curve of H Lac 1950.[7] However, superimposed on the first phase there are observed brief rapid reductions of intensity ("dips"); the second phase exhibits rapid, isolated intensity bursts. It is possible that the dips in the first phase are due to the fact that the luminosity curve reproduces the source density curve and its behavior is related to the weakening of the sources. The bursts in the second part of the curve apparently indicate the formation of new protons in the regions which are more dense than those from which most of the particles are emitted. This result follows from the greater curvature in the decay curve as compared with the main curve. It is important that the first part of the curve exhibits dips and sometimes bursts whereas the second part exhibits bursts only. Similar bursts and dips are observed in stars such as SS Cyg and R Cor Bor, indicating that the atmospheres of these stars may contain relativistic electrons of secondary origin. An exponential luminosity decay is also seen in stars such as UV Cet. From the point of view of the suggestion presented here it may be of interest to note that the composition of the primary component of cosmic rays exhibits the same anomaly[8] as the chemical composition of certain types of non-stationary stars.

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[1] I. M. Gordon, Dokl. Akad. Nauk SSSR **94**, 413 (1954).

[2] I. M. Gordon, Труды 4-го космогонического совещания (Proc. of the 4th Conf. on Cosmogony) U.S.S.R. Acad. Sci. Press, M., 1955, p. 121.

[3] I. M. Gordon, Труды астрономической обсерватории Харьковского гос. ун-та, (Proc. of the Kharkov State Univ. Astronomical Observatory) **12**, 15 (1957).

[4] L. Borst, Phys. Rev. **78**, 807 (1950).

[5] Burbridge, Hoyle, Burbridge, Christy, and Fowler, Phys. Rev. **103**, 1145 (1956).

[6] V. L. Ginzburg, Usp. Fiz. Nauk **62**, 37 (1957).

[7] G. Larssen-Leander, Stockholm Observatory Ann. **18**, 3, (1954).

[8] Koshiba, Schulz, and Schein, Nuovo cimento **9**, 1 (1958).

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160

THE LANDAU CORRECTION COEFFICIENT IN THE DETERMINATION OF THE VISCOSITY OF A LIQUID

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THE solution of the Navier-Stokes equation for a circular disc undergoing torsional vibrations in its own plane in an unbounded liquid yields the following expression for the coefficient of viscosity of a liquid

$$\eta = 4I^2 (\gamma - \gamma_0)^2 \theta / \pi^3 R^8 \rho N^2, \qquad (1)$$

where I is the moment of inertia of the disc, R is its radius, θ is the period of vibration of the disc in the liquid, ρ is the density of the liquid, N is the number of discs entering into the system, and γ and γ_0 are the damping coefficients of the disc in the liquid under study and in a vacuum. Equation (1) was obtained under the approximations $\gamma/\omega \ll 1$, $R/\lambda \gg 1$, $\theta_0/\theta \approx 1$, where θ_0 is the period of rotation of the disc in a vacuum. The difference $\gamma - \gamma_0$ is the proper absorption coefficient, whose presence is brought about by the action of the liquid on the upper and lower surface of the disc only. In view of the fact that in the derivation of (1) edge effects were not taken into account (in particular, the effects of the liquid on the lateral surface of the disc), they should be excluded in some way or other.

In the determination of the viscosity by means of (1), L. D. Landau introduced a correction coefficient and the equation for η was written in the form

$$\eta = 4I^2 (\gamma - \gamma_0)^2 \theta / \pi^3 R^8 \rho N^2 (1 + 2d/R + 2\lambda/R)^2. \qquad (2)$$

Here d is the thickness of the disc used in the systems, and λ is the penetration depth of the viscous wave.

In this paper, an experimental method is described for the measurement of the viscosity of a liquid by means of rotating discs which excludes the action of viscous forces on the lateral surface of the disc without the introduction of any correction coefficients. A test of the method was carried out on measurements in helium II.

The essence of the experiment is as follows. A compound disc of thickness D was divided parallel to the plane of the characteristic oscillations into two, three, etc., parts which formed a rather complicated but nonetheless single oscillatory system. Depending on into how many parts the disc was divided, several oscillatory systems with the same moment of inertia and the same lateral surfaces were obtained; however, in each individual case there was a different number of discs (N = 1, 2, 3, 6), in the system. The discs in this case were separated from each other by distances $l \gg \lambda$, where λ is the penetration depth.

If we determine the damping coefficients γ_N and γ_0 for these systems, both in helium II and in vacuo, and compute the expression $(\gamma_N - \gamma_0)/N$ for each system, then this expression, in view of the additivity of the damping, should give the total value of the damping (brought about both by the front surfaces and the lateral surfaces) of the individual disc entering into the various systems. Since the thickness of the individual discs $d_N = D/N$ is different in different systems, the ratios obtained from their values must differ from one another.

If we plot $(\gamma_N - \gamma_0)/N$ vs. d_N for a given temperature, and extrapolate this curve to $d_N = 0$, we obtain the damping brought about by the action of