drawer during the summer holidays. Such incidents, of which this is only one, gave the unfortunate and erroneous impression that hypothalamic releasing factors might not exist. Other researchers, who have actually experienced the pains of preparing as well as testing these materials, have undoubtedly had similar experiences.

Some investigators have intimated that they are ready to undertake clinical experiments with hypothalamic factors—"in the backyard," if necessary, since the toxicity of none of the factors has been worked out in man and none has been approved by the Food and Drug Administration (FDA) for clinical testing. Even if FDA should grant approval, experiments with the natural products would be so costly that they could be undertaken only by very few investigators.

I am writing this not to discourage the spirit of adventure, which has led to so many accidental discoveries, but to urge biologists to exercise some degree of moderation in their requests for these costly materials. Such a demand can be more fully satisfied only after the synthetic materials become available.

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15 March 1968

Cosmic Rays from Nearby Supernovae: Biological Effects

Terry and Tucker (*1*) have just speculated that cosmic radiation from exploding supernovae could have caused the extinction of many animals on earth in geologic times. They give an estimate that over a period of 6×10^8 years animals on the earth would have been exposed to a dose of 25,000 roentgens (r) (arriving in a few days or less) at least once, 1000 r at least four times, and so on. Such bursts of radiation could cause the extinction of many exposed animals without simultaneously extinguishing plant life. These calculations depend sensitively on the following major assumption which they made. "Since diffusion effects can be neglected for relativistic particles traveling over comparatively short interstellar distances, such as are of interest here, the relevant time interval is that for the release of the energy in the form of cosmic rays. . . . Therefore, it is safe to say that the dose *D* is received over a period of, at most, a few days."

This assumption conflicts seriously with most current theories of cosmic ray propagation within the galaxy, which describe cosmic ray particles as either diffusing through the interstellar medium or as moving along galactic magnetic field lines so twisted as to produce the remarkable degree of isotropy that experimentalists observe. In either case, the typical distance for straight-line propagation of cosmic ray particles from their source is taken to be approximately 3 light-years. As a result, cosmic rays reaching the earth even from the relatively nearby supernovae that Terry and Tucker refer to would travel tortuous paths en route. Instead of arriving in one sudden burst concentrated in a few days or less, their radiation would be spread over years. The biological effect described would therefore be appreciably smaller, and probably negligible.

To illustrate this we can consider the one supernova explosion in 6×10^8 years that Terry and Tucker describe, which produces the largest dose of 25,000 r. If this is due to a supernova that releases 10^{50} ergs in the form of cosmic rays, as they assume, it is approximately 10 light-years away. Cosmic rays diffusing to the earth would pass through more than three mean free paths en route. Standard diffusion model calculations (*2*) show that they would take approximately 40 years on the average to arrive. The peak radiation would be spread over a period of several years rather than several days.

Similarly, Terry and Tucker describe more distant supernovae that might occur once every 1.5×10^8 years and produce doses of 1000 r. These supernovae would average 50 light-years in distance, and their cosmic rays would arrive at the earth 1000 years afterward, with the peak radiation spread over hundreds of years. More distant supernovae would spread their doses over appreciably longer intervals, thereby reducing further their biological effect.

The above numbers are based on a diffusion model for propagation of cosmic rays with mean free paths of about 3 light-years. Other models would differ in detail but would share the characteristic of lengthening appreciably the period during which the total radiation described would impinge on animals.

Even if supernovae are assumed to release the far larger amount of cosmic ray energy, 10^{51} ergs, which Terry and Tucker refer to, the biological effects would be appreciably reduced for all but the very closest (and rarest) supernovae. Thus doses of 10,000 r might occur once every 50 million years, but each such dose would be spread over hundreds of years and would, therefore, produce much less damage to animal life than is assumed.

Physicists have long observed that nonsolar cosmic rays arrive at the earth steadily from all directions. This spatial and time isotropy probably is due to the tortuous paths cosmic rays follow in traversing the interstellar medium. The same characteristics of galactic space that produce this nonlinear motion would serve to spread appreciably in time the radiation dose produced by a nearby supernova. Only an explosion within several light-years of the earth would result in the catastrophic effects suggested by Terry and Tucker. Since very few stars of any kind are that close to us, nearby supernovae such as they require would be very rare indeed.

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References and Notes

1. K. D. Terry and W. H. Tucker, *Science* **159**, 421 (1968).
2. In the equation $t = R^2/\lambda v$, R is 10 light-years; λ, 3 light-years; and v, the speed of light. For a general discussion see, for example, P. Morrison, in *Handbuch der Physik*, S. Flügg, Ed. (Springer-Verlag, Berlin, 1961), vol. 46; or V. L. Ginsburg and S. I. Syrovatskii, *The Origin of Cosmic Rays*, H. S. H. Massey, translator (Pergamon Press, Oxford, 1964).
3. Supported in part by NASA grant NsG-58-60.

2 February 1968

Laster has argued that supernova explosions would not have the catastrophic effects we suggested (*1*), since the resultant radiation dose would be spread over a period of many years rather than several days. He maintains that the "spreading-out" of the dose would occur because cosmic ray particles do not travel in straight lines, but diffuse through the interstellar magnetic field. Similar objections have been raised by P. Morrison and others in private communications (*2*). It is our contention that enough of the radiation arrives in a sudden burst concentrated in a few days or less to produce an acute dose of radiation.

In our report we took the optimistic point of view that most of the high-energy flux was received in a short period; we avoided discussion of such factors as the effects of long-term chronic radiation, which is very difficult to estimate, and the dynamics of the expansion of a relativistic gas in the interstellar magnetic field. Concerning this latter point, it would appear that the expansion cannot be described in terms of the diffusion of individual particles. For distances less than about 100 light-years, the pressure in the cosmic ray gas is much greater than the pressure in the interstellar magnetic field, so the field is strongly modified by the cosmic ray gas and has little effect on its motion. The gas would push its way through the field and would arrive at the earth spread out over a period of only the order of a few light-days. However, if the interstellar matter in front of the gas were ionized, the situation would be more complicated. Current theories of collisionless shock waves in ionized gases indicate that the ions would be "snow-plowed" in front of the expanding gas, in which case the expansion must stop in a few light-years. The state of ionization in the interstellar medium surrounding a star before and just after a supernova explosion are not known; it depends on the density of circumstellar gas and on the radiation spectrum. However, the important point for our consideration is that, even if diffusion approximation holds, some flux will arrive from the radiations that travel in straight lines—cosmic rays with energies $\gtrsim 10^{17}$ ev and high-energy gamma rays. These particles will initiate extensive air showers of secondary particles that produce ionization at sea level and hence radiation doses. Here we will discuss only the gamma ray component.

During the early stages following a supernova explosion, a large number of gamma rays will be produced by the inverse Compton effect, bremsstrahlung and π^0 decay following proton-proton collisions. The exact number depends on the early radiation field, the density of the interstellar medium around the supernova, and the number of relativistic protons and electrons produced by the explosion, but it is reasonable to estimate that between 10^{48} and 10^{50} gamma rays with energies of about 10^{12} ev are emitted. The extensive air showers initiated by these photons will result in doses between 10 and 1000 rads, for an explosion 100 light-years away. Taking a number intermediate between these limits shows that doses of the order of 100 rads are to be expected from the high-energy gammas produced by explosions 100 light-years distant, a factor of 3 less than we had previously used for discussing the biologic effects. The numbers involved are uncertain, of course, but we feel that our basic hypothesis, namely, the amount of energy from a nearby supernova explosion that arrives at the earth in the form of a concentrated blast of high-energy radiation is sufficient to cause very dramatic biologic effects, remains quite plausible (*3*).

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References and Notes

1. K. D. Terry and W. H. Tucker, *Science* **159**, 421 (1968).
2. See also V. I. Krasovski and I. S. Shklovsky, *Dokl. Akad. Nauk SSSR* **116**, 197 (1957).
3. We have benefited from discussions with A. Dessler, T. O'Neil, and P. Morrison.

21 March 1968

Displacement Pattern of the Basilar Membrane: A Comparison of Experimental Data

Johnstone and Boyle (*1*) presented a new set of experimental data on the vibratory displacement of the basilar membrane in the guinea pig cochlea. Their measurements were obtained by application of the Mössbauer technique, and their results are the first of their kind since Békésy's classical observations (*2*). Furthermore, they presented a tuning curve for a place in the cochlear base, 1.4 mm from the stapes (*1*, Fig. 1), whereas all of Békésy's measurements were limited to the apical cochlear turn for technical reasons.

Johnstone and Boyle (*1*, p. 389) stated that before their study "no absolute values of these amplitudes of the basilar membrane were presented. . . ." Although many of Békésy's measurements were given without reference, he presented absolute values on several occasions (*2*, Fig. 6-43, pp. 464 and 481; *3*, Fig. 6). For instance, for a sound pressure level of 140 db he measured a displacement value of 7 $\times 10^{-5}$ cm in a human cadaver specimen.

In reference to their Fig. 1, Johnstone and Boyle further state (*4*, p. 390) that their own "tuning curves . . . resemble those obtained by Békésy but are more sharply peaked with a Q . . . of 2.5 (most of Békésy's curves have a Q [of] around 1.6 or less)."

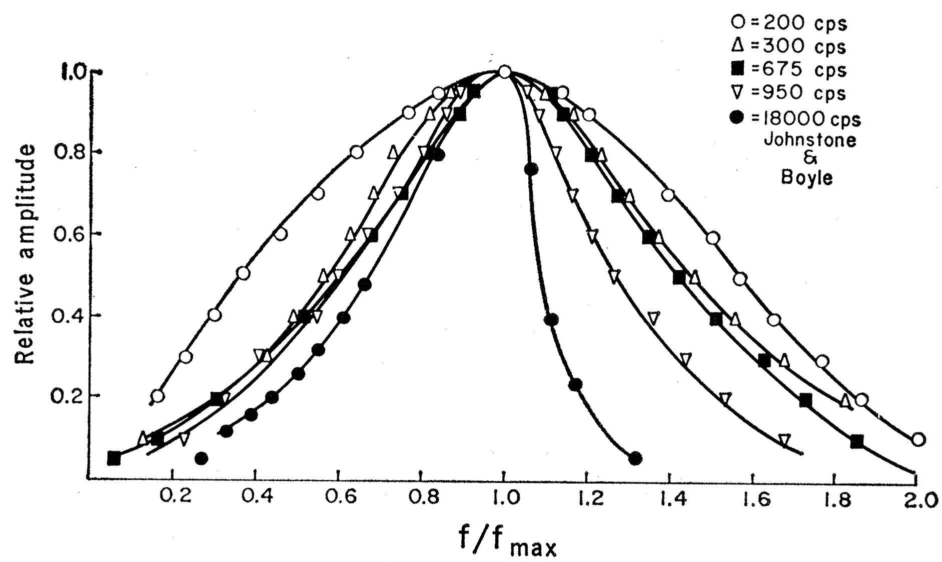

Fig. 1. Normalized tuning curves for the displacement of the basilar membrane in guinea pigs [Data from Békésy (*2*) and Johnstone and Boyle (*1*)].