‘THUNDER’: SHOCK WAVES IN PRE-BIOLOGICAL
ORGANIC SYNTHESIS

A. BAR-NUN
Dept. of Physical Chemistry, The Hebrew University, Jerusalem, Israel
and
M. E. TAUBER
Presently at NASA Ames Research Center, Moffett Field, Calif., U.S.A.

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Abstract. A theoretical study of the gas dynamics and chemistry of lightning-produced shock waves in a postulated primordial reducing atmosphere was conducted. It was shown that the conditions are similar to those encountered in a previously performed shock-tube experiment which resulted in 36% of the ammonia in the original mixture being converted into amino acids. The calculations gave the (very large) energy rate of about 0.4 cal/cm²/yr available for amino acid production, supporting previous hypotheses that ‘thunder’ could have been responsible for efficient large scale production of organic molecules serving as precursors of life.

A very high energy-efficiency was recently demonstrated by Bar-Nun et al. (1970) for the production of amino acids behind shock waves in a postulated primordial reducing atmosphere. The essential features of the shock synthesis which are responsible for the high efficiency are a rapid heating of the gas mixture to several thousand degrees, followed by rapid cooling. While the gas is at a high temperature it reaches a state of near, or complete, thermodynamic equilibrium, during which many molecules, radicals and atoms are stable and are present in relatively large concentrations. Amino acids, however, are not stable at these temperatures. During the rapid cooling, the species present at high temperatures recombine, presumably via a chain mechanism, to form relatively complex organic molecules, such as amino acids and, if the cooling rate is sufficiently large, not enough high energy molecular collisions occur to break-up these complex molecules. Slow cooling would have resulted in a composition which does not contain any appreciable concentration of amino acids or their building blocks. The shock synthesis bypasses two obstacles: the instability of amino acids at high temperatures and the low concentration of their building blocks at low temperatures. This is the qualitative explanation for the high efficiency observed experimentally (Bar-Nun et al., 1970).

Shock waves associated with large meteorites and thunder have been suggested as energy sources for the production of amino acids by Hochstim (1963) and Bar-Nun et al. (1970). The latter is especially attractive because of its abundance. (We have used the term ‘thunder’ for convenience and to distinguish it from the lightning leader. However, the time period of interest here is that in which the shock is strong and close to the source. Strictly speaking, thunder occurs considerably later and further away, when the shock wave has decayed to a sound wave.) Using the experimental efficiency
of about $5 \times 10^{10}$ molecules/erg and the present day frequency and power of thunder, it was hypothesized by Bar-Nun et al. (1970) that this process might have been a major source of amino acids in pre-biological times. However, it remained to be shown that thunder meets the two essential requirements for successful synthesis of amino acids, i.e., high initial temperature and rapid quenching. The purpose of this note is to report the results of an approximate study of the gas dynamics of thunder and some of the accompanying chemical changes in an assumed primordial atmosphere.

The composition of the atmosphere influences the propagation rate (shock speed) and the associated thermodynamic behavior of the thunder. In order to compare the present results with those of the experiment (Bar-Nun et al., 1970) a mixture of 72% methane, 25% ammonia and 3% water (by volume) was used, realizing that the composition of the primordial atmosphere is subject to considerable uncertainty.*

In the familiar process of lightning, the sudden release of electrical energy greatly raises the temperature and pressure in a narrow region of atmospheric gas along the path of the stroke (the leader). The hot, high pressure gas expands outward from the core and, in a very short time, forms at its front a supersonic blast wave, i.e., a sharp wave front across which pressure, temperature and density rise discontinuously. For present calculational purposes, the lightning-produced shock wave phenomena can be adequately approximated by the so-called cylindrical 'blast wave theory' (Lin, 1954) for a single lightning stroke. The 'theory' is based on the assumption that most of the lightning energy (that part which is not radiated away by the incandescent gas) is concentrated in an infinitesimally slender cylindrical column and is discharged instantaneously into the gas. Nevertheless, chemical and thermodynamic equilibrium are assumed to exist at all times, although this assumption may be invalid for a short period (on the order of 0.1 to 1 µsec) immediately after the lightning.

Using a rough average of values mentioned by Jones et al. (1968) and Krider et al. (1968), it was assumed that an energy of $2 \times 10^5$ J/m is transferred to the gas, and assuming an initial atmospheric pressure of one atmosphere, one obtains the shock velocities and distances from the core of the column shown in Figure 1A as functions of time. Note that about 1 µs after the lightning discharge, the shock wave is 2 cm from the core and has a velocity of 10 km/s; at 60 µs, the shock has moved to 15 cm and is travelling at only 1.25 km/s. Simultaneously, the temperature of the gas compressed by passage of the shock wave drops by about 5000 K, immediately behind

* McGovern (1969) suggests that a primary atmosphere of methane, 10-15% hydrogen, and some ammonia and water vapor existed for about 0.5 to $1 \times 10^9$ yr, eventually changing to one consisting mainly of free nitrogen, carbon dioxide, carbon monoxide and water vapor. In the primary atmosphere, nitrogen was present only in the form of ammonia and probably in very small concentrations, since most of it was dissolved in the oceans; in the secondary, oxidized atmosphere, amino acids cannot be produced (Miller and Urey, 1959). However, during an intermediate period of about $10^9$ yr, the hydrogen mole fraction may have been only $10^{-4}$ (McGovern, 1969), in which case free nitrogen could coexist with methane (Urey, 1968). For amino acids production, an atmosphere with sizeable concentrations of free nitrogen is more favorable than one containing small amounts of ammonia for an order of magnitude longer time. Hence, it is possible that most of the nitrogen containing compounds were produced during this relatively short period.