electronic singlet state lying at an energy of 43,800 cm^{-1} above the ground state. In addition to coronene and 1,2-benzanthracene, new absorption bands have also been observed for 1,12-benzperylene (510 and 490 nm; decay time ~100 nsec) and for 1,2:3,4-dibenzanthracene (480 nm; decay time ~50 nsec).

The time-resolution of the technique is at present limited to about 10 nsec by the decay time of the ruby laser pulse used for excitation. However, the image-converter camera presently has a time-resolution of 40 psec (*7*), while laser pulses as short as a few picoseconds have been reported by use of the phenomenon of mode-locking (*8*). We therefore believe that observations by laser photolysis and spectroscopy can eventually be extended to the picosecond time range (*9*).

J. R. NOVAK
M. W. WINDSOR
Chemical Sciences Department, TRW Systems, One Space Park, Redondo Beach, California 90278

References and Notes

1. J. R. Novak and M. W. Windsor, *J. Chem. Phys.* **47**, 3075 (1967).
2. J. B. Birks, D. J. Dyson, T. A. King, *Proc. Roy. Soc. London Ser. A* **277**, 270 (1964).
3. J. L. Kropp and W. R. Dawson, *J. Phys. Chem.* **71**, 4499 (1967).
4. TRW Instruments, model 1D, El Segundo, California 90245.
5. W. R. Dawson and M. W. Windsor, unpublished work; G. Porter and M. W. Windsor, *Proc. Roy. Soc. London Ser. A* **245**, 238 (1958).
6. J. L. Kropp, unpublished work, this laboratory.
7. W. W. Simmons and R. S. Witte, in *TRW Instruments Application Note 8.*
8. A. J. DeMaria, D. A. Stetser, W. H. Glenn, Jr., *Science* **156**, 1557 (1967).
9. J. R. Novak and M. W. Windsor, *Proc. Roy. Soc. London Ser. A*, in press (1968).
10. Supported in part by Air Force contract AF 33(615)-5331 and ONR contract N00014-67-C-0327. We are grateful to R. Briones for valuable advice on the layout and assistance with the operation of the laser and to Dr. R. Witte and Dr. R. Wuerker for the loan of equipment.

17 May 1968

Cavitation during Impact of Liquid Water on Water: Geochemical Implications

Cavitation and sonochemical processes have been suggested as widespread natural phenomena of any streaming or wavy body of water, in particular, of the ocean (*1*). Sonolysis in air-saturated water would result in nitrogen fixation (*2*). In view of the enormous amounts of wave energy in the ocean, this fixation may be an additional, important pathway in the nitrogen cycle (*1*). In the primordial methane-saturated ammonical ocean (*3*), sonolysis may lead to formation of many organic compounds, as has been demonstrated in the laboratory (*4*). The formation of complex organic molecules, including amino acids (*4*), by this mechanism is facilitated by the fast removal of the products of the high-temperature reactions into the nonreactive solvent which remains at ambient temperatures (*1*, *5*).

The problem of whether cavitation takes place when water impinges on water is the subject of this report. This occurs as a common natural phenomenon, for example, in waterfalls, fast streaming rivers, and particularly in stormy seas. For measurable chemical changes to occur in a sonolyzed system, a limited volume of liquid must be exposed for a considerable amount of time; and therefore, continuous recirculation of the liquid is required for rather long periods. Chemical changes detectable under these conditions may occur anywhere along the recirculating cycle, including in the pumping device, where rapid flow over solid surfaces is most likely to induce cavitation (*1*, *6*). For this reason, sonoluminescence was used as a criterion for the occurrence of cavitation in the region of impact of water on water. Preliminary experiments have shown intensive sonoluminescence in our experimental setup in the presence of bromine. This luminescence, however, was very long-lived ($t_{1/2}$ > 3 seconds) and could have originated from cavitation anywhere within the circulating system (total recirculation time 6 to 10 seconds). Therefore, the sonoluminescence used as criterion of cavitation in the region of impact was that of sodium at 589 nm, resulting from the excitation of sodium chloride

Table 1. Sonoluminescence of sodium in water-on-water impact region.

Volatile component	Nozzle	Overall scintillation rate (pulse/sec)	Peak channel No.	Scintillation rate in peak channel (pulse/sec)
Argon	Wide, short	5200	31	200
Argon	Wide, long	<30		
Argon	Narrow, short	7000	30	235
Oxygen	Narrow, short	3400	24	140
Oxygen + methanol *	Narrow, short	<30		

* $6 \times 10^{-2} M$ methanol.

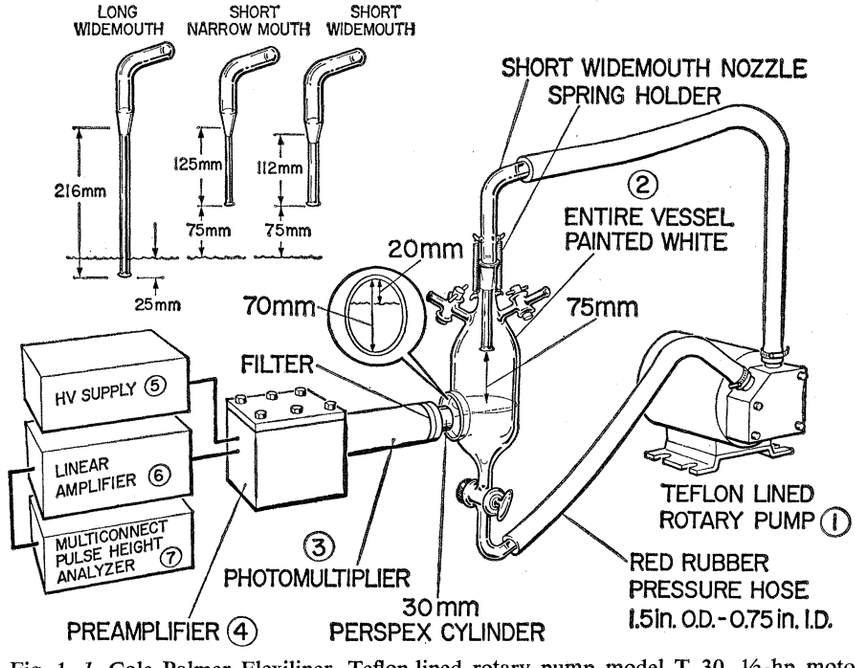

Fig. 1. *1*, Cole Palmer Flexiliner, Teflon-lined rotary pump model T–30, ½-hp motor; *2*, mixing vessel; *3*, EMI 2-inch end window 9558 QS 20 phototube with a Corning cutoff glass filter No. 368—cutoff at 570 nm. Optical coupling through a plexiglass light pipe with Cargille immersion oil; *4*, Nuclear-Chicago preamplifier model 31–14; *5*, Nuclear-Chicago high-voltage power supply model 8200; *6*, Nuclear-Chicago linear amplifier model 30–19; *7*, TMC multichannel pulse height analyzer model 404 C.

(0.8*M*), flash evaporated into the cavities (*7*).

The experimental setup is described in Fig. 1. The observation region has been studied with the use of three nozzles, two nozzles pound a water jet on the water surface, and the third is immersed about 20 mm below surface. The flow rates were 240 ml sec^{-1} for the wide nozzle (pressure difference, 8 mm-Hg) and 150 ml sec^{-1} for the narrow nozzle (pressure difference, 300 mm-Hg). The water impinged at a rate of 370 ml sec^{-1} cm^{-2} and 1500 ml sec^{-1} cm^{-2} for the wide and narrow nozzles, respectively (corresponding to a linear velocity of 3.7 and 15 m sec^{-1}, respectively). The sonoluminescence was measured with the multichannel pulse height analyzer, and the background count was subtracted for each channel (background was measured under identical conditions immediately before and after each measurement with the water flow stopped).

The results summarized in Table 1 are presented in arbitrary units of channel number and pulse count. A rough estimate would set the actual number of cavities in the impact area, in which excited sodium atoms were formed, about 100 times the recorded number. (This includes geometry and photomultiplier efficiency.) The scintillation pulse height spectrum, taken several times over periods of 100 or 200 seconds, was bell-shaped and ranged from channel 3 to about channel 50 (over a range of 200 channels). Each pulse in the pulse height spectrum represents a number of scintillations which occur within the preset resolution time of the analyzer and which presumably originate from the collapse of one and the same cavity. The results show that the overall sonoluminescence (i) increases with the linear velocity of the water, (ii) decreases in the presence of oxygen (compared with argon), (iii) is totally quenched in presence of 60 m*M* methanol, and (iv) is absent altogether when the water flows at the same linear velocity but passes the observation region without hitting a new water surface. From this behavior, which is characteristic of sonoluminescence induced by high frequency transducers (*6*, *7*), it may be inferred that cavitation takes place when water impinges on water at relatively low linear velocities.

The linear velocity of water in collapsing waves in the ocean is roughly estimated to be about 5 m sec^{-1} and above, which is the range of velocities investigated in this study. In view of the established parallelism between sonoluminescence and sonolysis in water (*8*) these results provide strong supporting evidence for the occurrence of sonochemical processes in the ocean. The latter conclusion, if verified under natural conditions, implies an additional route for nitrogen fixation as well as a probable pathway to the formation of simple and complex organic compounds in the primordial ocean.

MICHAEL ANBAR

Stanford Research Institute,
Menlo Park, California 94025

References and Notes

1. M. Anbar, *New Sci.* **30**, 365 (1966).
2. H. Beathe, *Z. Physik. Chem.* **163A**, 161 (1963); A. I. Virtanen and N. Ellfolk, *Acta Chem. Scand.* **4**, 93 (1950); *ibid.* **6**, 660 (1952); *ibid.* **11**, 230 (1957); H. Gabrecht, *Z. Physik* **135**, 85 (1953).
3. H. C. Urey, *The Planets* (Yale Univ. Press, New Haven, Conn., 1952).
4. M. Anbar, paper presented at ACS meeting, Atlantic City, Sept. 1968.
5. ——— and I. Pecht, *J. Phys. Chem.* **68**, 352, 1460, 1462 (1964); *J. Chem. Phys.* **40**, 608 (1964); *J. Phys. Chem.* **71**, 1246 (1967).
6. I. E. Elpiner, *Ultrasound: Physical, Chemical and Biological Effects*, F. L. Sinclair, Trans. (Consultants Bureau, New York, 1964).
7. P. Gunther *et al.*, *Z. Naturforsch.* **11a**, 882 (1956), *ibid.* **12a**, 521 (1957); *Z. Elecktrochem.* **61**, 188 (1957); *Ber. Bunsenges. Phys. Chem.* **63**, 43 (1959).
8. R. O. Prudhomme, *Bull. Soc. Chem. Biol.* **39**, 425 (1957).
9. I thank W. Gunter, Instrumentation Division, Ames Research Center, for assistance in constructing the scintillation measurement device; and J. Carter for technical assistance.
10. This work was carried out at the NASA Ames Research Center, Moffett Field, California, where M. A. was a senior research associate of the National Research Council, the National Academy of Sciences, Washington, D.C.

30 July 1968

Inhibitor of Bacterial Growth Released by Human Cells in Culture

Abstract. *Used medium from cultured human cells contains a factor that inhibits growth of the "less virulent" strains of pathogenic bacteria, but only retards growth of the "more virulent" strains. The factor is heat-stable, dialyzable, and unaffected by change in pH; it chromatographs as material of molecular weight between 700 and 1500. There is evidence that this factor is an α-ketoaldehyde attached to a carrier.*

During studies of the host-parasite relations of tissue-culture cells and bacteria, we noticed that certain strains of some bacterial species did not grow when inoculated into HeLa-cell monolayer cultures in antibiotic-free Medium 199 containing 10 percent calf serum, and that the tissue-cell sheet remained intact and healthy; there was no evidence of phagocytosis. All bacterial species tested could, however, grow in Medium 199 with or without 10 percent calf serum, the indication being that a serum constituent was not responsible for the inhibition of growth. Some strains of these bacteria could not survive in the used tissue-cell medium after it had been separated from the tissue cells that it had nourished; this finding was taken to indicate that the inhibition did not depend on the physical presence of the cells. The tissue cell–conditioned medium (CCM) therefore either lacked some nutrient essential for growth of the bacteria or contained an inhibitor of bacterial growth (BGI). Preliminary experiments proved the latter alternative to be true.

For observation of inhibition of growth, suspensions of susceptible strains of *Staphylococcus aureus* were prepared by washing of 18-hour growths from Columbia blood agar base medium (*1*) with Medium 199. These suspensions, in appropriate dilutions, provided the inocula for the test. A series of five tubes, each containing 1.0 ml of CCM and 1.0 ml of Medium 199 with serum, and a control series containing 2.0 ml of Medium 199 with serum, were prepared. In volumes of 0.1 ml, 10^7 bacteria (*2*) were inoculated into the first tube of each series, and 10^6 bacteria were inoculated into the second, with one-tenth as many successively into each remaining tube of each series—down to 10^3 bacterial cells. The tubes were incubated at 37°C and observed at specified times for growth. In this fashion a rough "titration" of the growth-inhibitive activity of the CCM was shown by comparison with growth in the controls.

Inhibition of growth depends on the concentration of the inhibitor and on the number of bacteria present. The BGI was present in CCM that had supported tissue-cell monolayer growth for periods ranging from 1 to 4 days. Filtrates from older cultures were not tested.

A survey was performed to determine whether BGI was active for different bacterial genera. Two series of tubes were inoculated as before. Table 1 lists some bacterial strains whose growth was or was not inhibited by BGI obtained from CCM that had supported the growth of HeLa cells for 66 hours. One should note that, apart