these regions, under this assumption, is $2 \times 10^{-3}$ count/sec, or $7 \times 10^{-4}$ dis $cm^{-2}$ $sec^{-1}$. An error in background determination would change all of the rates equally, leaving the differences unchanged.

The Apollo 16 data alone seem to indicate that $^{210}Po$ is found principally on the near side of the moon, with less on the far side. However, Apollo 15 data show a uniformly high rate from north of Mare Tranquillitatis, southeastward to the Van de Graaff region on the far side. In the regions of overlap, which are near the equator, the two observations agree.

Our global observations of $^{210}Po$ on the lunar surface provide the context for previous measurements. Table 2 is a list of the results of previous attempts to measure the $^{210}Po$ concentration on the lunar surface. The techniques used were both in situ measurements and terrestrial analysis of returned samples. There is a large spread among the measurements. Before our measurements it was very difficult to reconcile these widely divergent data points. They could not be explained by variation in the concentration of uranium, the source of $^{222}Rn$. Our data taken from orbit over a large region of the moon indicate that there are large point-to-point variations in $^{210}Po$ concentration. Thus, it is not surprising that measurements made at different places and at different times do not agree.

Also, since the rate of $^{210}Po$ decay observed is in all cases far in excess of the expected equilibrium rate with $^{222}Rn$, the emanation and diffusion of radon vary greatly in time. We previously reported a localized increase in $^{222}Rn$ activity in the vicinity of the crater Aristarchus, which we interpreted as an indication of internal activity (*1*). The spatial and temporal variation reported here gives further support to the idea that internal processes influence radon emanation on the lunar surface.

PAUL BJORKHOLM
LEON GOLUB
PAUL GORENSTEIN
*American Science and Engineering, Cambridge, Massachusetts 02139*

**References and Notes**

1. P. Gorenstein and P. Bjorkholm, in *Apollo 15 Preliminary Science Report* (NASA SP-289, National Aeronautics and Space Administration, Washington, D.C., 1972), pp. 18-1 to 18-7.
2. H. W. Kraner, G. L. Schroeder, G. Davidson, J. W. Carpenter, *Science* **152**, 1235 (1966).
3. J. A. S. Adams, P. M. Barretto, R. B. Clark, J. S. Duval, Jr., *Nature* **231**, 174 (1971); D. Heymann and A. Yaniv, *Nature Phys. Sci.* **233**, 37 (1971).
4. P. Gorenstein, L. Golub, P. Bjorkholm, in preparation.
5. P. Gorenstein and P. Bjorkholm, *Science* **179**, 792 (1973).
6. A. L. Turkevich, J. H. Patterson, E. J. Franzgrote, K. P. Sowinski, T. E. Economou, *ibid.* **167**, 1722 (1970).
7. T. E. Economou and A. L. Turkevich, *Geochim. Cosmochim. Acta* **2** (Suppl. 2), 2699 (1971).
8. R. M. Lindstrom, J. C. Evans, R. C. Finkel, J. R. Arnold, *Earth Planet. Sci. Lett.* **11**, 254 (1971).
9. R. L. Brodzinski, *Nature Phys. Sci.* **238**, 107 (1972).
10. We thank H. Gursky for discussions on this report. Supported by NASA contract NAS9-9982.

12 February 1973

■

## A Low-Temperature Thermal Process for the Decomposition of Water

Abstract. *The following three reactions, each of which has been shown to proceed at the temperature indicated above the arrow, are suggested as a cycle for the thermal decomposition of water:*

$$LiNO_2 + I_2 + H_2O \xrightarrow{300°K} LiNO_3 + 2HI$$

$$2HI \xrightarrow{700°K} I_2 + H_2$$

$$LiNO_3 \xrightarrow{750°K} LiNO_2 + \tfrac{1}{2}O_2$$

The use of hydrogen as a general fuel or energy carrier is being widely discussed (*1*) because it is nonpolluting and can be produced from energy sources other than fossil fuels. However, if hydrogen is to become the fuel of the future, it will have to be produced economically in large quantities. Present methods of production include the cracking of natural hydrocarbons and the conversion of water either by reaction with coal or through electrolysis. Only by electrolysis can hydrogen be generated from water without a drain on fossil fuel reserves, provided the electricity for the process originates in plants that are not fossil fueled.

The electrolysis of water requires the conversion of the primary energy, be it heat (nuclear, geothermal, or solar) or hydrostatic head, into electricity. If the hydrogen is to be used to produce heat, the manner in which 80 percent of the energy is utilized in the United States, there will be a loss in efficiency by going through the electrolysis process. In addition, the generating and electrolysis equipment represent a large capital investment which will be reflected in the cost of the final product.

Quite aside from the cost aspect there is the problem of the availability of electrical power. If it were desired to replace the thermal equivalent of all the fossil fuel currently consumed in the United States by electrolytic hydrogen, the electrical generating capacity would have to be increased at least 15-fold, and if only nuclear-powered capacity is admitted, at least 150-fold. Clearly, an alternative process to the electrolytic decomposition of water must be developed if hydrogen is indeed to become the energy carrier of the future.

A thermochemical process not requiring conversion of primary heat or solar energy into electricity would be ideally suited for the purpose if it could be conducted at sufficiently low temperatures. Funk (*2*) has shown that for a thermochemical process to operate below 2500°K it must consist of several steps. Some progress in this direction has been made with the four-step "Mark I" cycle of de Beni and Marchetti (*3*), which operates at temperatures not exceeding 1000°K. This temperature appears realizable with high-temperature gas-cooled reactors. It is desirable, however, to develop a process capable of operating in the range of temperatures of present-day nuclear reactors, geothermal sources, and potentially even converters of solar to thermal energy.

We present here a three-step chemical cycle which has the potential of decomposing water at temperatures not exceeding 750°K. The three reactions composing the cycle are

$$LiNO_2 + I_2 + H_2O \xrightarrow{300°K} LiNO_3 + 2HI \quad (1)$$

$$2HI \xrightarrow{700°K} I_2 + H_2 \quad (2)$$

$$LiNO_3 \xrightarrow{750°K} LiNO_2 + \tfrac{1}{2}O_2 \quad (3)$$

The temperature at which each reaction proceeds is placed above the arrow. Reaction 1 serves to separate the products by forming two easily separable compounds, $LiNO_3$ and HI. The two subsequent reactions make it possible to recover the products, elemental hydrogen and oxygen, and at the same time to recover the original reactants. The reaction requiring the highest temperature for its completion is the thermal dissociation of the alkali nitrate. Published data (*4*) place the decomposition temperature of $LiNO_3$ at about 750°K (at a dissociation pressure of 1 atm). For $NaNO_3$ and $CsNO_3$ the corresponding temperatures are from 50° to 150° higher. Withdrawal of the oxygen does not drive the reaction to completion because the oxygen pressure is a function of the activity of the nitrate in the molten mixture. Complete or nearly complete conversion, however, is really not essential except possibly for reaction 1. The use of nitrates other than the alkali metal nitrates does not appear to offer any advantages as most of the others seem to prefer to decompose by releasing nitrogen oxides and forming the metal oxide.

As to reaction 2, even with modern techniques (*5*) there has been no improvement over the classical kinetic and equilibrium studies of the hydrogen-iodine system by Bodenstein (*6*). It is well established that HI is 18 percent dissociated at 575°K, 25 percent at 800°K, and 29 percent at 1000°K, so that little is gained with temperatures above 700°K. The HI can easily be removed from the reaction mixture by distillation. After this stage it may be desirable to remove the water vapor with a regenerative dryer so as to conserve heat in the next step. The HI would then be decomposed in the presence of a porous membrane to take advantage of the different rates of diffusion to separate $H_2$ from HI and $I_2$. Alternatively, the separation may be achieved by quenching the equilibrium mixture. The point being made here is that the separation of $H_2$ from $I_2$ and HI should present no great problem.

Reaction 1 is, of course, the key to the cycle. An inspection of the standard electrode potential of iodine (+ 0.54 volt) and the oxidation-reduction potential of the nitrite-nitrate couple (0 volt) shows that in the standard state nitrite ion can be oxidized to nitrate by iodine. The kinetics of reaction 1 has been the subject of a number of investigations aimed at an understanding of the mechanism in the light and in the dark, since the reaction is photosensitive (*7*).

There appears to be no question that reactions 1, 2, and 3 will go as written. The crucial question is, Will they go under conditions that will make a practical cycle? This question can only be answered by the appropriate experiments.

BERNARD M. ABRAHAM
FELIX SCHREINER
*Chemistry Division, Argonne National Laboratory, Argonne, Illinois 60439*

### References and Notes

1. Technology, *Chem. Eng. News* (26 June 1972), p. 14; *ibid.* (3 July 1972), p. 16; *ibid.* (10 July 1972), p. 10; *ibid.* (2 October 1972), p. 33; T. H. Maugh II, *Science* **178**, 849 (1972); W. J. D. Escher, in *Proceedings of the Symposium on Non-Fossil Chemical Fuels* (American Chemical Society, Washington, D.C., 1972), p. 28.
2. J. E. Funk, in *Proceedings of the Symposium on Non-Fossil Chemical Fuels* (American Chemical Society, Washington, D.C., 1972), p. 79.
3. G. de Beni and C. Marchetti, in *ibid.*, p. 110.
4. M. Centnerszwer, *J. Chim. Phys. Physicochim. Biol.* **27**, 9 (1930); S. Gordon and C. Campbell, *Anal. Chem.* **27**, 1102 (1955); L. E. Gastwirt, thesis, Princeton University (1962).
5. A. Taylor, Jr., and R. H. Crist, *J. Amer. Chem. Soc.* **63**, 1377 (1941); H. Zeise, *Z. Phys. Chem. Abt. A* **190**, 56 (1941).
6. M. Bodenstein, *Z. Phys. Chem.* **13**, 56 (1894); *ibid.* **22**, 1 (1897); *ibid.* **29**, 295 (1899).
7. R. C. Banerji and N. R. Dhar, *Z. Anorg. Chem.* **134**, 172 (1924); N. R. Dhar and B. K. Mukerji, *Z. Elektrochem.* **31**, 622 (1925); A. Berthoud and W. Berger, *J. Chim. Phys. Physicochim. Biol.* **25**, 547 (1928); *Helv. Chim. Acta* **11**, 364 (1928).
8. Work performed under the auspices of the U.S. Atomic Energy Commission.

9 February 1973

■

## Heat Flux and Precipitation Estimates from Oceanographic Observations

Abstract. *Surface meteorological observations and salinity and temperature profiles were made in the intertropical convergence zone during July 1972. Over an 18-hour period, estimates of the heat budget in the top layer of the ocean and estimates of the total heat flux made by using aerodynamic parameterization equations balance within 10 percent. The salinity budget provides a precipitation estimate. Due to the stable stratification established by the salinity dilution in the wave-mixed layer by rain, the total heat flux to the atmosphere is being extracted from this shallow layer. As a result, large sea surface temperature drops occur regionally and may be capable of inhibiting atmospheric convection.*

During the second phase of the Soviet national tropical experiment in July 1972, two of us (Ostapoff and Tarbeyev) had the opportunity to conduct an oceanographic experiment on board the R.V. *Professor Zubov*. The objective of the study was to estimate total heat fluxes from oceanographic measurements on short time scales (less than 1 day) and under the disturbed conditions of the intertropical convergence zone (ITCZ). The *Professor Zubov* was positioned at 5°N, 21°W during the experimental period. The most significant result of this study is the short-term response of the top layer of the ocean to meteorological events such as precipitation from convective systems embedded in the ITCZ.

The meteorological conditions were not completely favorable inasmuch as the ship was at the southern edge of the ITCZ most of the time. Precipitation occurred only on 19 July, and this day was chosen for the analysis reported here as a case study.

The structure of the atmosphere was not typical of deep-reaching convection, as evidenced by the types of clouds, mostly altocumulus and stratocumulus. During 19 July cloud tops were observed by radar not to exceed 5 km, and the rain was rather steady. A rain bucket mounted on the flying bridge on the starboard side of the ship in lee of the wind collected a total of 17.5 mm of rain between 0923 and 2240 Greenwich mean time.

Surface meteorological observations were made routinely, as well as 2-hourly salinity-temperature-depth (STD) profiles down to 200 m. Here we present the data and compare the estimated budgets for heat and salt in the top layer of the ocean with estimates of the total heat flux made by using aerodynamic parameterization equations (*1, 2*).

The surface meteorological data obtained aboard the *Professor Zubov* were used to calculate the sensible and latent heat fluxes. The bulk aerodynamic equations were used for the flux calculations. Because relatively large instabilities in the atmospheric boundary layer exist during such events, coefficients were used which depend on the stratification (*1–3*).

The wind speeds were observed at 28 m (on top of the mast) by means of anemometers, and all other meteorological parameters were observed at a