rather than a functional lesion since electrolytic lesions, as well as microinjections of a cholinolytic inhibitor, improved learning. A cholinergic mechanism seems to be implicated since local injections of a cholinolytic agent reversed the effects of cholinergic stimulation.

The apparent increase in sensitivity of amygdaloid neurons following intense activation may be due to processes similar to posttetanic potentiation. The duration of the facilitatory effects in our experiments is of a different order of magnitude than that typically observed after tetanic stimulation. However, Goddard's (*11*) finding that repeated electrical stimulation of the amygdala produces similarly prolonged facilitatory effects on seizure thresholds suggests that the amygdaloid complex may be uniquely sensitive to such influences.

Although it is tempting to relate the apparent lability of cholinergic components of the amygdala to registration processes potentially useful in learning, our data do not require such an interpretation. An alternative explanation would stress changes in emotional sensitivity, but our animals did not demonstrate any evidence of excessive emotionality at the time of training. Goddard (*12*) has reported changes in some fear-motivated behaviors following microinjection of smaller doses of carbachol to the amygdaloid complex, but these injections did not alter the acquisition of active avoidance responses. The carbachol-induced inhibitory effect must be studied in appetitive learning situations before interpretations in terms of changes in emotional reactivity can be discounted.

JAMES D. BELLUZZI
SEBASTIAN P. GROSSMAN
Department of Psychology,
University of Chicago,
Chicago, Illinois 60637

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Why Is the Moon Gray?

If water ever was emitted from the lunar surface, as several scientists believe (*1*), there should have been a tendency for the surface to turn orange as a result of the oxidation of ferrous oxide in the rocks by photolytically liberated oxygen. The question therefore arises—"Why is the moon gray and colorless?" I suggest that the answer lies in the solar wind's bringing in atomic hydrogen to replace that lost by the photolytic decomposition of water vapor.

For a gaseous molecule leaving the lunar surface with a speed v (in excess of the escape velocity) the chance of escaping is $1 - v_E/v$ where v_E is the escape velocity (2.4 cm/sec). By averaging we obtain $0.28\ [\exp(-v_E/\bar{v})^2]/(v_E/\bar{v})$ where $\bar{v}$ is $(2kT/m)^{\frac{1}{2}}$, where T is the absolute temperature (400°K for the lunar day), k is the Boltzmann constant, and m is the mass of the molecule. Thus, for water, the escape probability per pass is 2×10^{-8}, and the escape time is substantial. Each pass takes about 240 seconds ($\bar{v}/g$) on the average; so with no time spent in the adsorbed state the escape time is about 300 years spent entirely in the lunar atmosphere. (Actually it will be twice as long because escape will not take place in the lunar night.) It will be longer if there is appreciable time spent in the adsorbed state between passes, as seems likely.

My essential point is that the escape time is so long that the solar ultraviolet light will dissociate the water molecule to give a hydrogen atom, which will escape, and a hydroxyl radical. The hydroxyl in turn will either oxidize the surface rocks or will be further photolyzed to give atomic hydrogen and oxygen. The oxygen will certainly oxidize the rocks on contact. Thus we may be able to use the color of the surface rocks on the moon as an indicator of the oxidizing or reducing nature of the lunar environment.

Other than the oxidizing influence of escaping water vapor we have the solar wind, which is reducing, and the color may give us a means of balancing these two influences—water causes atomic hydrogen to leave the moon, and the solar wind, being essentially pure hydrogen, counterbalances by bringing atomic hydrogen into the moon (*2*).

The solar wind consists, on the average, of about five protons per cubic centimeter traveling at about 300 km/sec (*3*). Thus about 10^8 hydrogen atoms each with an energy of 450 ev impinge each second on each square centimteter of the sunlit side, amounting in 4.5×10^9 years to the equivalent of ½ m of water uniformly spread over the lunar surface. As the hydrogen plasma consisting of equal numbers of protons and electrons impinges, electrons neutralize the approaching protons and 450-ev hydrogen atoms hit and stick on the lunar surface. Atomic hydrogen, especially when very energetic, is a most powerful reducing agent.

It seems likely that lunar water as well as that on earth evolved very early [some terrestrial life forms are 3 billion years old (*4*)]; therefore, according to our analysis, the moon may have started out as colored and it may have gradually been reduced to its present dull gray.

The argument that planetary and lunar water must have evolved in the early part of the history of the solar system is simply that the radioactivity heat source was much stronger in the beginning. If all of the heat were derived from radioactive potassium (half-life 1.25 billion years), the average age of the oceans would be about 3 billion years, on the assumption that the rate of water vapor emission is proportional to the rate of generation of heat. It seems likely that some such number is applicable even though U^{235} (half-life 0.7 billion years), U^{238} (half-life 4.5 billion years), and Th^{232} (half-life 14 billion years), as well as shorter-lived radioisotopes such as Pu^{244} (half-life 87 million years) were substantial additional heat sources.

Therefore, according to the Rubey (*5*) theory for the origin of the atmospheres and oceans, any lunar water liberated was probably released early in the lunar history. Subsequently it disappeared, probably oxidizing the rocks. Then, slowly, over the long eons, these may have been reduced by the solar wind. If the lunar rocks have been stirred in the last 3 billion years or so by any influences such as meteorites or vulcanism there may be buried oxidized rock containing ferric iron.

We apply the same reasoning to Mars which also has no magnetic field and thus is potentially subject to solar wind contact, although the presence of a light atmosphere on Mars (*6*), perhaps 1 percent of that on Earth, will cause the wind to be deflected by the ionosphere and thus avoid capture to some extent. If there had been no atmosphere, Mars would have had to put out enough water to cover its surface to a depth of ¼ m to have dominated over the wind and to have retained its color. The actual minimum will be less by the factor by which the martian ionosphere deflects the solar wind. Hopefully martian orbiter measurements may provide this factor.

W. F. Libby
Institute of Geophysics and
Planetary Physics, University of
California, Los Angeles 90024

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Irreversible Thermodynamics and Flow across Membranes

Bresler and Wendt (*1*) state that the solute permeability coefficient ω—which appears in the formulation by Kedem and Katchalsky (*2*) of thermodynamic equations of flow across membranes—depends strongly on J_v, the volume flow, and therefore cannot be used to describe properties intrinsic to the membrane, "except for the case where $J_v = 0$, when ω becomes constant." However, when Bresler and Wendt's Eq. 1 is *linearized* in J_v, the result is given by (*3*)

$$J_s = (D/RT\Delta x)\Delta\pi + \tfrac{1}{2}(C_s^A + C_s^B)J_v \quad (1)$$

where J_s is the total solute flow, D is the diffusion coefficient for the solute, R is the gas constant, T is the absolute temperature, Δx is the thickness of the membrane, and $C_S{}^A$ and $C_S{}^B$ are the solute concentrations in compartments A and B, respectively. If the coefficient of $\Delta\pi$ is identified with ω, and that of J_v with $\overline{C}_s$, an average concentration, Eq. 1 is seen to be identical to Bresler and Wendt's Eq. 2, which, in turn, is the result of the irreversible thermodynamic approach. Thus, the only limitation on the thermodynamic treatment is that it be restricted to sufficiently small forces and flows so that the relations between them are linear.

Gerald S. Manning
Rockefeller University,
New York 10021

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3. To obtain all the linear terms, it is necessary to expand the denominator in the right side of Bresler and Wendt's Eq. 1 out to second-order terms.

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In developing his expansion of the Hertzian equation cited in our previous report (*1*), Manning does not, as he claims, arrive at the *exact* equation given by Kedem and Katchalsky (*2*) for solute flux. Instead he develops an equation to which theirs is an approximation, provided that a further rather severe restrictive assumption is made, namely,

$$C_s{}^A/C_s{}^B \cong 1$$

For a nonselective membrane ($\sigma = 0$) (*1*), the following equations relate solute flow to volume flow. The Hertzian equation is given by

$$J_s = J_v \frac{C_s{}^B e^{-J_v\Delta x/D} - C_s{}^A}{e^{-J_v\Delta x/D} - 1} \quad (1)$$

Manning's approximation of Eq. 1 is given by

$$J_s = J_v \frac{C_s{}^A + C_s{}^B}{2} + \omega\Delta\pi \quad (2)$$

Kedem and Katchalsky's equation before approximations are made is as follows:

$$J_s = J_v \frac{C_s{}^A - C_s{}^B}{\ln C_s{}^A - \ln C_s{}^B} + \omega\Delta\pi \quad (3)$$

The limiting case for Eq. 1 at high volume flow is given by

$$J_s = J_v\, C_s{}^A \quad (4)$$

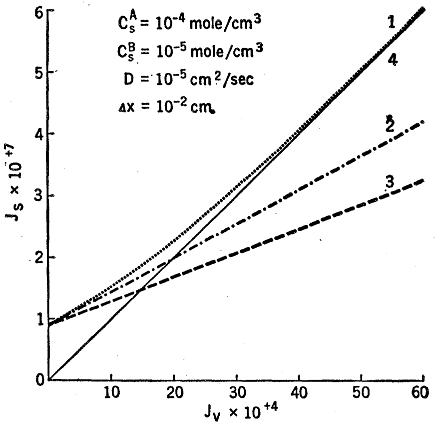

Fig. 1. Solute flow (in moles per square centimeter per second) as a function of volume flow (in milliliters per square centimeter per second) for Eqs. 1 through 4.

If we use a set of parameters for which ΔC_s is small but $C_s{}^A/C_s{}^B$ is significantly different from unity, we obtain the curves shown in Fig. 1. Inspection of Fig. 1 reveals, as expected, that at low values of J_v Eq. 2 is a useful approximation to the exact result given by Eq. 1. At high values of J_v Eq. 4 is the most useful. In no particular regime is Eq. 3 either exact or useful. Only if one makes two simultaneous, highly restrictive assumptions—that the flow is near zero and the concentration ratio is near unity (*not* concentration difference near zero)—does Eq. 3 become a reasonable approximation of Eq. 2, which in turn is an approximation of the exact result given by Eq. 1. In the thermodynamic derivation (*2*), Eq. 2 is regarded as an approximation of Eq. 3 which is incorrectly regarded as giving the more exact result. We feel that these facts emphasize the unsuitability of the irreversible thermodynamic approach (which requires the application of Onsager's reciprocity relation) for the system we describe. In *contrast* to irreversible processes such as combined diffusion and heat flow, the process we described has *inherent* mathematical nonlinearities which, *without recourse to experiment*, reveal that the system must be virtually at equilibrium before the flow equations are sufficiently linear so that Onsager's reciprocity relations can be legitimately applied.

E. H. Bresler
Veterans Administration Hospital and
Tulane University School of Medicine,
New Orleans, Louisiana 70140
R. P. Wendt
Loyola University, New Orleans 70118

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