condition. It may be seen that group behavior was determined both by the leaders (that is, there was a leadership hierarchy) and by the goal objects. These data were subjected to analysis of variance (4 leaders $\times$ 2 classes of goal objects $\times$ 4 complete replications of all conditions) and the first two effects were significant beyond the .05 level. Results were stable over the four replications: Kendall's coefficient of concordance was .77 ($P < .001$).

From the standpoint of object communication, the crucial trials in experiment 2 are the 48 trials on which one animal was shown food and the other was shown a novel object. Here there were 38 trials on which not only the leader but also the group majority proceeded first to the food, seven trials on which they proceeded to the toy, and three trials with a tied score ($P < .001$ by sign test). All seven failures of the group majority to go first to the food involved the least preferred leader, Gigi. Gigi's relative unpopularity is not hard to explain: she was the newest and biggest member of the group, and in these tests, as under routine conditions, she shared her food only with Polly (whom, incidentally, she actively tried to recruit as a follower). The other leaders shared their food fairly readily with all.

Usually each leader took a few steps toward the goal object that we had shown him (or her) earlier, and then stopped and looked back at the rest of the group. If the other leader was setting out or trying to recruit followers more vigorously than he (which usually occurred if the goal was a more highly preferred one), he often abandoned his own goal, accompanied the other leader, and then later led the group to the second goal. The leaders split from each other on 20 of 24 trials if both had been shown food, 9 of 24 trials if both had seen novel toys, and 21 of 48 trials if one had seen food and the other had seen a novel object. The first two figures are not greatly different from those obtained in earlier experiments in which two foods or two toys were visible to all animals at the time of response (*4*).

The data for individual animals would lead to the same conclusions as the group majority data of Table 1. Also, on 93 percent of all trials excluding those involving ties, whichever object attracted the largest number of animals was also the object that was eventually reached in the least amount of time. It made no difference which leader had been shown his object first.

Experiment 2 of course involves a simultaneous choice or "relative" discrimination, and experiments 1 and 3 involve successive or "absolute" discrimination of leaders and goal objects. How well can we predict the former type of data from the latter? The number of trials on which a given leader reached a given class of goal in less than 30 seconds in experiment 1 correlated very highly (Pearson's $r = .97$, $N = 8$ conditions, $P < .01$) with the group majority choice data of experiment 2. In other words, whichever member of the group characteristically got the most immediate reaction from his followers when he commenced to move out (that is, when the group had a single goal) was also likely to carry the group majority, if not the whole group, in cases where he had to compete with another leader of travel. However, it would be more accurate to speak here of a hierarchy of leadership behaviors rather than a hierarchy of individuals as such, for a given individual's "rank" varied with social conditions and with goals.

The next question is how well the data of both experiment 1 and experiment 2 could be predicted from the behavior of the leader when he was alone and could get all the food for himself (experiment 3, first $2\frac{1}{2}$ minutes). The answer is, not very well; Pearson's $r = .69$ and .62, respectively, and $P > .05$ when the dependent variable for experiment 3 is the number of goals reached within $2\frac{1}{2}$ minutes, and similar results would be obtained with other measures. A much better predictor is the number of trials in experiment 3 on which the leader reached the goal object within 30 seconds after the rest of the group had also been released ($r = .96$ and .90 with experiments 1 and 2, respectively; $P < .01$).

From the foregoing it is apparent that the chimpanzees discriminated the two classes of objects when these were presented one at a time on successive trials (experiments 1 and 3), as well as when they were presented simultaneously (experiment 2). Figure 1 shows the data of experiments 1 and 3 in such a way as to graphically illustrate both successive discrimination and the dependence of each leader's running speed upon his being followed by others.

Probably because the animals had already had considerable previous practice in the test situation, manual gesturing, vocalizations, and other such signals were seldom observed in the present experiments. We do not doubt that these signals might supplement the information available from purposive locomotion and thus further reduce a fellow chimpanzee's uncertainty about the environment. Also, we stress the fact that our data show only that purposive locomotion is a sufficient (not a necessary) cue. Indeed, in chimpanzees as well as in man one of the most impressive facts of all is the ability to get across the same general message by any number of alternative means. Whether or not interchimpanzee communication can be meaningfully compared with human language depends upon the point of view of the observer, but in our opinion the most fundamental similarities lie not in motor patterns or in linguistic considerations but at the level of perceptual and cognitive organization (*2, 9*).

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7. Clearer evidence that a chimpanzee leader knows the sign value of his own behavior for his followers and responds accordingly is the ability of the animals to withhold response to a preferred object as long as a dominant animal is watching—or even to deliberately mislead others and then sneak back for the goal: see E. W. Menzel (*4, 5*); J. van Lawick Goodall, *In the Shadow of Man* (Houghton-Mifflin, New York, 1971).
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Osmotic Power Plants

In his recent report (*1*) Norman concluded that, although salination of freshwater by seawater is technically feasible as a source of energy, it is uneconomical at present because the cost of the power, 20¢ per kilowatt-hour, is too high. As shown below, this statement may be corroborated in another way by consideration of capital costs and their amortization. However, it can also be shown that salination by a much saltier body such as the Dead Sea or the Great Salt Lake *should* be economical by the same criterion.

Case 1: Salination by seawater. First let us consider the original case of salination of freshwater by seawater. In this process the hydraulic pressure P must be *less* than the osmotic pressure π, so let us assume that P is 10 atm (π for seawater being 22.4 atm). The net energy delivered from the process will then be 10 m^3-atm per cubic meter of permeate passing through the membrane or 0.28 kilowatt-hour per cubic meter. This ratio may be termed the energy/permeate volume ratio.

Now let us consider capital costs. Existing reverse-osmosis equipment will cost on the order of \$100 per day per cubic meter of permeate (\$ day/m^3). This value of the capital cost/permeate rate ratio is for driving pressures of the order of 40 atm, but for our seawater salination case, where the driving pressure ($\pi - P$) is only (22.4 − 10) = 12.4 atm, the permeate flow rate per unit membrane area (flux) will be much lower, thus requiring more membrane equipment for a given power production rate, that is, a higher capital cost/permeate rate ratio. It is assumed therefore that for seawater salination this ratio will be at least \$250 per day per cubic meter. The capital cost per kilowatt is now readily calculated as

$$\$/\text{kilowatt} = (250)(1/0.28)(24) = 21{,}000 \qquad (1)$$

where 24 is the number of hours per day. Assuming that capital is paid for at the rate of 8 percent per annum, the amortization contribution to energy costs will be

$$\$/\text{kilowatt-hour} = (0.08)(21{,}000)/(365)(24) = 0.19 \qquad (2)$$

where 365 is the number of days per year. This cost is of the same order of magnitude as that reported by Norman and is too high.

Case 2: Salination by Dead Sea brine. It is clear from Eq. 1 that to make osmotic salination economical as an energy conversion process the capital cost/permeate rate ratio must be decreased or the energy/permeate volume ratio must be increased, or both. With the use of high-osmotic-pressure salinizing solution such as occurs in the Dead Sea, the Great Salt Lake, or similar bodies of water in Russia, China, and elsewhere, it is possible to accomplish *both* of these results.

Because of the high salt content of the Dead Sea (26 percent, including $MgCl_2$) and in view of the fact that osmotic pressure increases more than linearly as the total salt content increases, π for Dead Sea brine is of the order of 500 atm. Thus in the salination process it can support a P of at least 200 atm, for which the energy/permeate volume ratio would be 5.6 kilowatt-hours per cubic meter. Because of the higher value of P, the equipment would be heavier than in existing reverse-osmosis equipment and membranes would offer more resistance. On the other hand, the driving force ($\pi - P$) for permeate flux would be considerably greater. Even after allowance for dilution of Dead Sea brine by permeate, the logarithmic mean driving pressure is approximately 150 atm, as compared with 40 atm in present reverse-osmosis applications (and 12.4 atm in case 1 above). Because of these balancing factors, it is assumed that the capital cost/permeate rate ratio would still be \$100 per day per cubic meter of permeate, that is, the same as in present reverse-osmosis equipment.

By the method of calculation of Eq. 1, the capital cost per kilowatt of the salination equipment would now be

$$\$/\text{kilowatt} = (100)(1/5.6)(24) = 430$$

To this I add the cost of a turbogenerator, estimated at \$125/kilowatt, giving a total of \$555/kilowatt. This figure compares not unfavorably with the capital cost per kilowatt ratio for new power plants. The amortization contribution to the cost of energy production would now be only

$$\$/\text{kilowatt-hour} = (0.08)(555)/(365)(24) = 0.0051$$

These projected figures are indeed encouraging. To facilitate examination of the concept in some detail, the United States–Israel Binational Science Foundation awarded a grant (No. 337) to our Research Authority in May 1974. The aromatic polyamide membranes employed in this work were obtained from E. I. du Pont de Nemours & Company, Inc.

I am optimistic that this osmotic process will be used as an economical means of energy production. The use for this purpose of the Dead Sea, the Great Salt Lake, and other highly saline bodies of water may be considered as an application of solar energy. A less direct but more widespread application may involve the dissolution of salt mountains, and other possibilities exist.

In anticipation of such future utility, I propose the term "pressure retarded osmosis" for the osmotic process utilized.

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I am delighted to see Loeb's suggestion (*1*) that water salination power may in fact already be economical in some cases. Using the Dead Sea as a water sink will yield about 20 times as much energy as using the ocean. In my original proposal (*2*) I assumed, apparently incorrectly, that in such arid regions freshwater would be more valuable than energy so that freshwater would be purified and not allowed to mix with the sea. It would be ironical to see both desalination water and salination power sources operating in the same region. Of course, considerable energy can be obtained by introducing ocean water into the Dead Sea, as well as by Loeb's suggestion of dissolving salt deposits, but at the cost of large-scale changes in the natural water cycle.

Loeb's calculations assume that salination costs 2.5 times as much as similar desalination systems because of the lower operating pressure. As a physiologist I cannot comment on engineering design considerations. In view of the fact that membranes of poor selectivity can be used in this application, I would hope that research on low-pressure, high-flux membranes will result in sufficient savings to make water salination generally economical.

A rather different scheme for extracting salination energy was proposed some years ago by Pattle (*3*), who suggested using ion-selective membranes to separate freshwater and saltwater in a concentration cell.

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