When placed in shipboard tanks together with tar lumps, the isopods collected on the lumps and remained there almost continuously (*9*).

Lepas pectinata, a goose barnacle, was frequently found attached to the lumps, particularly the firmer, "older-looking" ones. At one station, 150 barnacles ranging from 2 to 8 mm in length (*10*) were attached to four lumps that displaced 40 ml. Lumps with barnacles attached were kept in an aquarium with running seawater pumped through an all-plastic system. All barnacles were removed except those between 1 and 2 mm long. Barnacle lengths were measured once a week for 3 weeks. The growth rate was approximately 1 mm per week. The largest barnacles found on the oil lumps were 8 mm long; therefore, it can be inferred that these barnacles are about 2 months old and that the lumps to which they are attached are at least that old.

Neither barnacles nor isopods appeared to suffer short-term ill effects when confined for several days with lumps of tar in minimal volumes of water at 15° to 20°C. However, the maximum length of barnacles found on tar lumps was 8 mm, but barnacles growing on floating pumice in the same region reached a length of 11 mm. The smaller size on the tar may indicate either that the tar is slightly toxic to barnacles or that the softer tar is a mechanically inferior substrate.

The saury, *Scomberesox saurus,* an epipelagic fish that is abundant in temperate seas, occurs commonly in neuston tows. In a sample of ten specimens collected in 38°28′N, 3°41′E on 2 June 1969 and ranging from 164 to 255 mm in standard length, we found large amounts of tar (*11*) in the stomachs of three. The saury is said to feed on small crustaceans and perhaps upon small fish (*12*). "Vegetable debris" was found in one saury stomach examined (*12*), which suggests that the species is not a very discriminate feeder. The saury, in turn, is fed upon by "porpoises and by all the larger predaceous fishes" (*12*). Thus, this ingestion of the tar by sauries provides a direct introduction of a material known to be toxic into the oceanic food web.

The oil lumps seemed to be covered with a grayish film, presumably composed mostly of bacteria. This assumption was supported by measuring the oxygen uptake (*13*) at 10°C of a lump with a displacement volume of 10 ml and with no barnacles attached before and after the water containing the lump was poisoned with Formalin. Oxygen consumption decreased by 125 mm³ per hour with the addition of the Formalin; the residual uptake was indistinguishable from zero. The value obtained for the respiration of the film was about 4 mm³ per hour per square centimeter.

Taken altogether our observations indicate that lumps of petroleum exist in surprisingly large amounts on the sea surface and have a complicated history during their residence there. These lumps form a chronic type of oil pollution, which may significantly affect the marine ecosystem.

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5. Generally, we measured the displacement volume of the tar lumps from the first two neuston tows of each of two nighttime watches (when there was a measurable amount). The neuston nets, which are about 1 m wide, were towed at about 3 knots. Duration of tow varied from 25 to 130 minutes and the surface area skimmed from about 2,200 to about 11,500 m². The data in Fig. 1 come from a net the bag of which was made of 00 plankton netting whose aperture size is 0.75 mm.
6. Pocket penetrometer, Soiltest model CL-700.
7. The saturated hydrocarbon fraction was prepared by chromatography of the whole tar on alumina and silica gel; *n*-pentane was used as the eluent. The waxy, semiliquid saturate fraction was then analyzed by gas chromatography on a ⅛-inch (outside diameter) column packed with 2.1 percent Apiezon L on Chromosorb G, DCMS. Hydrocarbons from *n*-decane (C_{10}) to *n*-dotriacontane (C_{32}) were identified. Pristane was abundant; the ratio of *n*-heptadecane to pristane was about 3 : 1. Normal paraffins exceeded the branched and cyclic saturates by a factor of 3 to 4. No odd carbon predominance was observed.
8. M. Blumer, in *Oil on the Sea,* D. P. Hoult, Ed. (Plenum, New York, 1969), p. 5.
9. Similar observations have been made by P. J. Herring [*J. Mar. Biol. Ass. U.K.* **49**, 766 (1969)], who notes in discussing the species' color-change mechanism that "the brown and black colours thus produced are an almost perfect match of the colours of the lumps of oil with which this species is so often associated may be no more than coincidental, but it almost certainly affords the animal some protection against predation. . . ."
10. Barnacle length was taken as the distance from the tip of the tergum to the junction of the body with the stalk.
11. A sample studied by thin-layer chromatography behaved as a typical crude oil residue.
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13. Oxygen uptake was measured in glass vials stoppered with an oxygen electrode. Rate was calculated from the slope of the resulting oxygen versus time curve. Ratio of water to tar in the vials was between 6 and 3 to 1.
14. Supported by National Science Foundation grants GZ-259 (to M.H.H.), GB-7355 (to J.M.T.), and GB-7108 (to R.H.B.). Shiptime was provided under NSF grant GA-1298 and contract Nonr-4029(00). We thank our shipmates on *Atlantis II* cruise 49 for their help, especially Captain E. H. Hiller and Dr. J. E. Craddock, overseer of the neuston fishing; we thank Dr. Max Blumer, who made and interpreted the chemical analyses; and we thank Dr. Blumer, Dr. Richard L. Haedrich, David Masch, and Dr. Paul T. McElroy for criticizing the manuscript. Contribution 2426 of the Woods Hole Oceanographic Institution.

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Secular Changes in the Lunar Elements

Abstract. *Corrections to the adopted values for centennial rates of change of four elements of the lunar orbit, the location of the FK4 equinox, and the obliquity of the ecliptic are presented. They are derived from analyses of lunar occultations distributed over several centuries. Generally, these corrections help to resolve existing discrepancies between theory and observations.*

Investigations of lunar motion from occultation observations covering the time periods 1627–1860 (*1*) and 1950–1968 (*2*) have recently been completed. These investigations have incorporated the Watts limb corrections (*3*) and improvements in astronomical constants, lunar theory, and star positions, as well as many other refinements over earlier investigations.

When the results of the two investigations are combined, fairly accurate values may be obtained for the rates of change of the lunar elements over a period of 1½ centuries (the small number of observations before 1780 contribute very little to the rates because of large observational errors). Values derived for rates of change of six elements are given below (in seconds of arc per century), together with their standard deviations:

$$\begin{aligned}
\Delta d\Omega/dT &= +\,4.31 \pm 0.37\\
\Delta d\tilde{\omega}/dT &= +\,1.11 \pm 0.40\\
\Delta dI/dT &= -\,0.04 \pm 0.09\\
\Delta de/dT &= +\,0.10 \pm 0.04\\
\Delta dE/dT &= +\,1.36 \pm 0.06\\
\Delta d\epsilon/dT &= -\,0.13 \pm 0.10
\end{aligned}$$

The elements are the longitude of node (Ω), longitude of perigee ($\tilde{\omega}$), inclination to ecliptic (I), eccentricity (e), equinox location (E), and obliquity of ecliptic (ε). Eccentricity e must be divided by 206265 to be returned to dimensionless units. These values are to be considered as observed corrections to the rates adopted in the Brown lunar theory (for Ω, $\tilde{\omega}$, I, e), the equinox implicit in the FK4 coordinate system (for E), and Newcomb's theoretical rate of change of obliquity (for ε).

In our opinion, the formal standard deviations given above may safely be doubled to obtain realistic error estimates, because of the difficulties inherent in making such error estimates from independent investigations. On that basis, we do not consider the rates for the inclination or the obliquity to be statistically significant. The solution for obliquity does not distinguish between Newcomb's theoretical obliquity motion ($\Delta\varepsilon = 0$) and the observed value ($\Delta\,\varepsilon = -\,0.3$) (*4*).

The rate of change of the eccentricity of the moon's orbit does appear to be statistically significant, although only marginally. Perhaps we have here an indication of the action of tidal friction on the shape of the moon's orbit, which contradicts the general assumption that tidal friction affects only the mean motion of the moon within observational accuracy.

The value $\Delta dE/dT$ represents the motion of the FK4 equinox relative to an ideal, or dynamical, equinox. By itself, it does not necessarily imply a correction to precession. However, it seems to be consistent with recent results (*5*), which imply a correction to lunisolar precession of $+\,1.10$ seconds per century, together with an equinox motion of $+\,1.20 \pm 0.11$ seconds per century.

The values of $\Delta\Omega$ and $\Delta\tilde{\omega}$ have been corrected for equinox motion by using the results found here for ΔE. Discordances between theoretical and observed values for these rates have been discussed by many authors, the most recent being Eckert (*6*). The corrections to the observed rates given here should help to resolve those discordances.

In particular, the parameters g' (mass distribution) and f (ratio of moments of inertia) discussed by Eckert would become $g' = +\,0.82$, $f = +\,0.65$, if the solution presented here is adopted. Such a g' value would require denser mass distribution near the lunar surface than at the moon's center.

Recent lunar orbiter results tend to fix g' near $+\,0.60$. If that value is correct, there is still a large, unexplained motion of the nodes of the lunar orbit of about $-\,6.3$ second per century, according to Eckert's results (*6*). If we also accept Baierlein's opinion (*7*), then the discrepancy is further increased by the amount of the geodesic precession and becomes $-\,8.2$ second per century.

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Helium Isotope Effect in Solution in Water and Seawater

Abstract. *The isotope effect in the solution of helium in water from 0° to 40°C has been determined by microgasometric measurements of the solubilities of pure helium-3 and helium-4. At 0°C helium-3 is less soluble than helium-4 in both distilled water and seawater by 1.2 percent. The observed fractionation factor is 0.988 ± 0.002 at 0°C and appears to decrease with increasing temperature at the rate of 0.0001 per degree Centigrade, although the existence of this trend is of limited statistical certainty. The measured isotope effect is in agreement with the ratio of helium-3 to helium-4 in surface ocean water reported by Clarke, Beg, and Craig.*

The recent discovery by Clarke *et al.* (*1*) of excess He^3 in the sea, attributed to primordial helium, focuses new attention on the importance of measuring the effect of isotopic fractionation in the solution of He^3-He^4 mixtures in seawater. Similarly, the degree to which He^3/He^4 ratios in natural gases (*2, 3*) are affected by solubility interaction with groundwaters (*4*) depends upon the isotopic fractionation factor. Finally, data on isotopic effects in the solution of gases in water are of interest with reference to the structure of water (*5, 6*). Therefore this report presents precise determinations of the differences between He^3 and He^4 solubilities at several temperatures in distilled water and in seawater as part of a more extensive series of rare gas solubility measurements made in this laboratory.

Solubility determinations were made by the Scholander microgasometric technique as used by Douglas (*7*) with minor modification (*8*). Pure He^3 and He^4 gas were used (*9*). After a simple temperature correction this method gives the Bunsen solubility coefficient, namely, the volume of gas (at standard temperature and pressure) absorbed per unit volume of liquid at the temperature of the measurement when the partial pressure of the gas is 1 atm.

Isotopic fractionation effects are reported in terms of the isotopic fractionation factor α, defined here as

$$\alpha = \frac{(He^3/He^4)\text{ aqueous phase}}{(He^3/He^4)\text{ gas phase}} = \frac{K_4}{K_3} = \frac{\beta_3}{\beta_4}$$

where K is the Henry's law constant and β is the measured Bunsen solubility coefficient. Thus, $(\alpha - 1) \times 10^2$ is the single-stage percentage enrichment of the He^3/He^4 ratio in the aqueous phase relative to that in the gas phase.

Values of β and $(\alpha - 1)$ for distilled water and for seawater with a salinity of 36.425 per mil are listed in Table 1. Values of $(\alpha - 1)$ calculated from the mean measured Bunsen solubility coefficients are given at various temperatures for each type of water. A standard error of 0.2 percent for each value of $(\alpha - 1)$ was calculated from the dispersion of the 52 individual solubility coefficient measurements. Systematic effects which do not cancel when the solubility ratio is taken are estimated to introduce an additional error of 0.1 percent in $(\alpha - 1)$.

If we compare the results for both types of water, the isotopic fractionation in seawater is, on the average, 0.2 percent greater than that in distilled water. The *t*-test and the rank sum test were used to evaluate the statistical significance of this difference. Both tests failed to establish a significant difference between values for distilled water and those for seawater at the 60 percent confidence level. Values of $(\alpha - 1)$ were therefore taken to be independent of salinity over the range studied.

The existence of a trend in $(\alpha - 1)$ with temperature is suggested by the observation that the values at 40°C show a greater fractionation than any of the values at lower temperature.