2. The current density for high utilization is optimized for low values of $y$ in $Ti_{1+y}S_2$, because the excess titanium occupies sites in the van der Waals layers, impeding the diffusion of lithium by pinning the layers together (*3*). These currents are comparable to those obtained in the intermediate-temperature (200°C) $Na/SbCl_x$ molten salt cell (*15*). They are only slightly less than those used in the high-temperature (400+°C) lithium/metal-sulfide cells (*16, 17*), where, for example, CuS was cycled at 50 ma/cm$^2$, $FeS_2$ and FeS at 40 ma/cm$^2$, and NiS and $Cr_2S_3$ at 10 ma/cm$^2$. Even higher current densities may be obtained by using molten salts at elevated temperatures. These high currents and the ready reversibility of the reaction are directly associated with the crystal structure, which remains essentially unchanged during reaction; no chemical bonds are broken in the host $TiS_2$ matrix during the insertion or removal of lithium (*5*). Holleck *et al.* (*18*) studied these cells and found good reversibility but reported very low current densities, 0.33 ma/cm$^2$.

The energy density of the $Li/TiS_2$ couple is found from Fig. 2 to be 480 watt-hour/kg, which is comparable to the energy densities calculated for Na/S cycling in the single-phase region and the LiAl/FeS high-temperature cells now under development. The values for the latter are 330 and 460 watt-hour/kg, respectively, and are anticipated to reach 100+ watt-hour/kg in practical cell configurations. As the $TiS_2$ ambient-temperature cell will require less deadweight associated with heat insulation and corrosion-resistant materials, it should also fall in this area, making it feasible for electric vehicle propulsion. Preliminary calculations and extended high-current operation near full capacity indicate that the required power densities are achievable with the $TiS_2$ cell (*19*).

In conclusion, $TiS_2$ has a high energy density and rate capability when coupled with a lithium anode, a high electrical conductivity, and a discharge-charge mechanism involving intercalation of lithium between the layers of the host's crystal structure that permits extended reversibility (*7*). Moreover, in contrast to most oxidants such as $Cl_2$, $TiS_2$ has a kinetically selective oxidizing power, making it highly reactive to species that can be intercalated but noncorrosive to its environment. This couple has potential as an ambient-temperature, as well as high-temperature, battery for electric vehicle propulsion. The $Na/TiS_2$ couple is less interesting because of the much greater free energy change with $x$ (*20*) and the presence of a number of crystalline phases, which places an upper limit of ~0.8 on $x$ at 25°C (*6*).

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21. This electrolyte is susceptible to decomposition on overdischarge and so is not suitable for commercial use. The cell was, however, deep-cycled—operated at >58 percent of capacity—at these rates for 16 cycles before any apparent degradation set in.
22. I would like to thank F. R. Gamble for introducing me to the layered sulfides and for his constant encouragement. In addition I gratefully acknowledge the help of my colleagues, R. R. Chianelli, M. B. Dines, B. G. Silbernagel, A. H. Thompson, R. W. Francis, L. H. Gaines, G. H. Newman, and B. M. L. Rao.

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# Masses of the Galilean Satellites of Jupiter

Abstract. *Numerical data derived from the observation of the four great satellites of Jupiter are compared with the values obtained through Sampson's theory by using the new JPL (Jet Propulsion Laboratory) system of masses. It is not possible to fit the coefficient of the free oscillation in the longitude of Ganymede, whose argument is* $l_3 - \bar{\omega}_4$ *(the mean longitude of Ganymede referred to the proper apse of Callisto), and the mass of Callisto derived from the path of Pioneer 10.*

The theory of the four great satellites of Jupiter—Io, Europa, Ganymede, and Callisto—involves almost 30 integration constants and physical parameters. These physical parameters are the masses of the satellites and the coefficients of the main zonal harmonics of Jupiter's field of gravitation. In classical theories they have been determined from observations simultaneously with the orbital elements. Today, study of the motions of space probes flying in the neighborhood of Jupiter allows these parameters to be determined independently. The first determination, performed at Jet Propulsion Laboratory (JPL), Pasadena, California, was made by analyzing the Doppler shift of the signals emitted by Pioneer 10 when it was near Jupiter (*1*). These results and the classical results of Sampson (*2*) and De Sitter (*3*) are shown in Table 1; they allow, for the first time, an objective comparison between some parts of the works of Sampson and De Sitter. In order to make this comparison we use the formulas given by Sampson in his theory (*2*, p. 173) and the JPL system of physical parameters to calculate some quantities that were determined by both from the observations. They are:

1) The coefficient of the induced equation of the center in the longitude of Io;

2) The coefficient of the induced equa-

Table 1. Modern and classical determinations of satellite masses and Jupiter gravity harmonics ($J_2$ and $J_4$). Abbreviation: $R_{Eq}$ is the equatorial radius of Jupiter.

| Parameter | JPL (*1*) | Sampson (*2*) | De Sitter (*3*) |
|---|---|---|---|
| Mass ($\times 10^{-5}\ m_{Jup}$) | | | |
| $m_1$ (Io) | 4.696 ± 0.06 | 4.497 | 3.81 ± 0.45 |
| $m_2$ (Europa) | 2.565 ± 0.06 | 2.536 | 2.48 ± 0.1 |
| $m_3$ (Ganymede) | 7.845 ± 0.08 | 7.988 | 8.17 ± 0.15 |
| $m_4$ (Callisto) | 5.603 ± 0.17 | 4.504 | 5.09 ± 0.6 |
| $J_2R_{Eq}^2$ ($\times 10^6$ km) | 75.04 ± 0.2 | 75.73 | 75.07 ± 1.5 |
| $J_4$ ($\times 10^{-6}$) | −650 ± 150 | | 690 |

tion of the center in the longitude of Europa;

3) The coefficient of the free oscillation in the longitude of Ganymede, whose argument is $l_3 - \tilde{\omega}_4$ (the mean longitude of Ganymede referred to the proper apse of Callisto);

4) The daily motion of the proper apse of Callisto; and

5) The daily motion of the proper node of Europa.

The results of such calculations and the values of these quantities derived by Sampson and De Sitter from the observations are shown in Table 2.

The most striking features of Tables 1 and 2 are the very small value found by Sampson for the mass of Callisto and the large difference between the observed and calculated values of item 3. These two facts are correlated in the sense that item 3 is the datum most directly related to the mass of Callisto.

In order to discuss these discrepancies, new values were calculated for items 3 and 4 through a rehandling of Sampson's theory. The modifications lead to a set of equations involving the coefficients of the free oscillations in the longitude of Ganymede, $e_4$, $e_4'$, $e_4''$, and $e_4'''$ (Sampson's notation) and the motion of the proper apse of Callisto. The calculation closely follows Sampson's work (including libration), except that the iteration is not made over the values of $e_4$, $e_4'$, $e_4''$, and $e_4'''$, but over $\dot{\tilde{\omega}}_4$ only. Solving the equations with respect to $e_4'''$ (eccentricity of Callisto), the results obtained are in the neighborhood of the actual values given by

$$e_4''' = \frac{0.007373 + 1.2872H}{1 - 1.013 \times 10^6 H}$$

where

$$H = (\dot{\tilde{\omega}}_4 - 6.5897 \text{ arc sec})/3600$$

For the values of the eccentricity of Callisto derived from the observations by Sampson and De Sitter, namely 0.0073725 and 0.007362, it follows very closely (by reason of the asymptotic behavior of the solution), that $\dot{\tilde{\omega}}_4 = 6.5897$ arc sec (per day). If this value is adopted, item 3 will be given by

$$2e_4'' = 318 + 4.25 \times 10^4 (e_4''' - 0.007373)$$

in arc seconds. If the observed value for the eccentricity is accepted, we have the new value 318 arc sec for item 3. This value is almost the same as that already obtained directly from Sampson's formulas, notwithstanding the slow convergence of the iterative procedure used by Sampson. The dependence of item 3 with respect to the full set of masses has also been computed. In the neighborhood of the actual masses we have

$$\Delta(3) = 4\Delta m_1 + 17\Delta m_2 + 7\Delta m_3 + 49\Delta m_4 \text{ arc sec}$$

where the unity of mass is $10^{-5}$ of the mass of Jupiter.

From these results it follows that it is not possible to fit the JPL system of masses and the observed values of $e_4''$ with Sampson's theory. This conclusion may be extended to theories of the same order as Sampson's theory, since the computation of item 3 through Laplace's theory leads to almost the same value (319 arc sec).

Table 2. Computed values, based on Sampson's theory and the JPL system of physical parameters, compared to classical determinations from the observations. The numbers in column 1 refer to the list of quantities in the text.

| Item | Value (arc sec) Computed | Sampson (*2*) | De Sitter (*3*) |
|---|---|---|---|
| 1 | 1720 | 1697.5 | 1676 ± 7 |
| 2 | 3650 | 3852.6 | 3850 ± 10 |
| 3 | 321 | 265.6 | 277 ± 26 |
| 4 | 6.59 | 6.692 | 6.31 ± 0.1 |
| 5 | −117.5 | −116.9 | −117.4 ± 0.2 |

Future research must decide on three alternatives: (i) the values of $e_4''$ obtained in different ways by Sampson and De Sitter are too small; (ii) the value of $m_4$ obtained at JPL from the paths of Pioneer 10 and Pioneer 11 is too high; or (iii) it is not possible to fit $e_4''$ and $m_4$ through a theory of the same order as that of Sampson.

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## Vibrational Spectroscopy of Chemisorbed Fatty Acids with Inelastic Electron Tunneling

Abstract. *We have measured and assigned the inelastic tunneling spectra of hexanoic acid chemisorbed onto an oxidized aluminum film. We present evidence for gauche-trans as well as all-trans conformers in the monolayer and evidence in support of a recent theory of tunneling intensities.*

Recently there has developed great interest in the relation between the microscopic structure and macroscopic properties of noncrystalline but macroscopically ordered organic systems such as liquid crystals, thin films, and biological membranes. Many techniques have been used to investigate the microscopic positional, orientational, and conformational order of these systems, and numerous theories relate such properties to macroscopic ones (*1*). A major limitation of experimental studies to date is their use of macroscopic samples. A new technique, inelastic electron tunneling spectroscopy (IETS) can measure the vibrational spectrum of monolayer, and even submonolayer, coverage of organic molecules on the oxide of a metal-oxide-metal junction (*2*).

Both infrared- and Raman-active vibrational modes can be observed in IETS with a resolution on the order of 10 $cm^{-1}$ at a temperature of 1°K over the spectral range 300 to 4000 $cm^{-1}$. A vibrational mode of frequency $\nu$ is observed as a peak in the second derivative of the voltage with respect to the current, $d^2V/dI^2$, at a voltage $V = (h/e)\nu$ ($h$ is Planck's constant and $e$ is the electron charge). The effect of the top metal electrode on the measured vibrational frequencies was less than ½ percent for vibrations below 1600 $cm^{-1}$ in a sensitive experiment (*3*).

Our crossed-film tunnel junctions (Al-oxide-Pb) were fabricated in a clean, high-vacuum evaporator. They were liquid-doped with a solution of the desired acid by general procedures described in detail elsewhere (*2*). In outline, a thermally oxidized Al strip (0.2 mm wide, 1000 Å thick) on a glass slide was doped with a dilute solution of the acid (*4*) in either benzene or methanol (the concentration was not critical, but on the order of 1 : 1000). After any excess solution had been spun off, the slide was returned to a high-vacuum evaporator where five Pb strips (0.2 mm wide, 2000 Å thick) were evaporated across the doped, oxidized Al strip.

The completed junctions were tested