VOL. 85, NO. A1 JOURNAL OF GEOPHYSICAL RESEARCH JANUARY 1, 1980

Comment on 'Methods of Monte Carlo Simulation of the Exospheres of the Moon and Mercury' by R. R. Hodges, Jr.

D. E. SHEMANSKY

Space Sciences Institute, University of Southern California, Tucson Laboratory, Tucson, Arizona 85713

The considerations entering the calculation of atmospheric distributions on exospheric bodies such as the moon and Mercury can be complex, and it is not surprising that misunderstandings arise in the literature. The purpose of this note is to restate the physical arguments involved in the generation of model exospheres and to point out misinterpretations of the *Shemansky and Broadfoot* [1977] and *Smith et al.* [1978] discussions. We appear now to be in complete agreement with the publication of the *Hodges* [1979] work on how the Monte Carlo method must be applied in model calculations, but the discussions of physical processes must be clarified.

The global atmospheric distribution on an exospheric body depends entirely on the exchange of energy at the gas-surface interface. If the gas at the surface were in detailed balance, one could immediately describe the volume energy distribution without further consideration. Although it was never explicitly stated, the assumption of detailed balance was made in all of the model calculations for the moon and Mercury with the exception of the very recent works [cf. *Smith et al.*, 1978]. The earlier calculations were made by using the purely mathematical device of assuming a saturated surface which delivered up particles in a Maxwellian distribution. Under this condition, every particle leaving the surface was a new source particle, and the source distribution therefore totally controlled the atmospheric distribution. The effect of these assumptions was to make the model exosphere exactly analogous to that calculated for the condition of an exobase formed by a gas in thermal equilibrium. The source particle energy distributions in all of these cases were thus chosen with the intent that under idealized conditions the atmosphere would be barometric. This fundamental assumption or a very similar assumption concerning the energy distribution in the gas-surface interaction is still built directly into the present *Hodges* [1979] calculation. The conclusions drawn by Hodges in respect to the energy distribution in the gas and thermal loss rates therefore depend on an assumed classical physical interaction at the surface.

It is clear that the atmosphere on an exospheric body cannot be in detailed balance. The energy distribution in the gas depends entirely on the physical chemistry of gas-surface coupling. The surface forms an infinite energy source and sink for the gas. It is therefore necessary to take some realistic account of the interaction regime in order to discuss atmospheric evolution and global distribution. The general nature of the energy exchange process for light gases has been discussed by *Shemansky and Broadfoot* [1977]. *Hodges* [1979] in referring to both the Shemansky and Broadfoot and the *Smith et al.* [1978] work has left out a very important aspect of the discussion of the accommodation process. In order to explain the nature of the misunderstanding, the major points of the Shemansky and Broadfoot and Smith et al. discussions are presented below.

The general conclusions drawn in the last-named works refer to a light gas exosphere in a steady state condition. In addition, the following list refers to an atmosphere in which source particles required to maintain the gas in a steady state are in a negligible minority relative to equilibrated particles. The volume energy distribution in the gas at a given point just above the surface is controlled by a number of related factors.

1. Downcoming particles do not contain energies above the escape energy. The escape process thus perturbs the atmospheric distribution to a lesser or greater extent, depending on the magnitude of the accommodation rate.
2. The accommodation coefficient depends not only on the physical interaction in a single encounter, but also on the surface geometry and the mean number of collisions in a given encounter with the surface.
3. If the accommodation coefficient is very low, the gas may not be in equilibrium with the immediate local surface area. Surface temperature gradients may thus produce altered energy distributions.
4. The delivery of energy from the surface to the gas particle in any single collision is limited by the lattice structure coupling. The high-energy tail of the distribution of a gas in equilibrium with a constant temperature surface is reduced in population relative to that in a Maxwellian gas with a parametric dependence on the Debye characteristic temperature of the surface.
5. A collision can be one of two kinds, free-free and free-bound-free. Residence time in an adsorption collision of helium with a surface is of the order of 10^{-10} s. The accommodation coefficient is temperature dependent.
6. The interaction energy of a particle colliding with a surface is determined mainly by the component of velocity normal to the local surface.

PARTICLE ENERGY DISTRIBUTION

In referring to the Shemansky and Broadfoot work, *Hodges* [1979] did not take cognizance of factors 4, 5, and 6 above. Very important factors in the arguments have thus been left out. As a result, the suggestion by Hodges that the apparent short global residence time for helium on the moon can be reconciled with the Shemansky and Broadfoot considerations by increasing the accommodation rate with multiple collisions is not valid. According to factor 4 the thermal escape rate at a given surface temperature is ultimately determined by the relative values of the Debye characteristic temperature and the particle escape energy. It is because of factor 4, as Shemansky and Broadfoot point out, that the principal particle loss mechanisms for Mercury and the moon are likely to be different. On Mercury the ratio of escape energy to the Debye characteristic temperature is large. Consequently, the escape of particles from Mercury according to Shemansky and Broadfoot is probably determined by ionization loss independent of the actual value of the accommodation coefficient. However, on the

Paper number 9A0973.
0148-0227/80/009A-0973$01 00

moon the Debye characteristic temperature is within a factor of 2 of the escape energy. The loss of particles on the moon is therefore probably still dominated by thermal escape and determined by the exact value of the accommodation coefficient as well as the detail of the particle energy distribution in the region of the escape energy.

DIRECTIONAL DISTRIBUTION AT THE SURFACE

The condition of the surface will certainly influence the directional distribution of gas particles at the surface, as Hodges points out. However, particle interaction at the surface does not involve specular reflection in general. The case discussed by Hodges in which the particle is in near grazing incidence is in a region of higher probability for an adsorption collision, as implied by factor 6 above. The probability distribution for bound-free transitions is far from that of a specular reflection. *Hodges'* [1979] selection of an angular distribution function is arbitrary.

SUMMARY

Hodges' [1979] principal conclusion appears to be that if all surface collisions of gas particles were free-free and the interaction provided a Maxwellian distribution in the gas with a sufficiently high accommodation rate, then the exosphere would very closely approach a barometric condition for the moon and Mercury. Loss rates would consequently be closely approximated by application of Jeans escape factor. I have no objection to this conclusion, and in fact *Shemansky and Broadfoot* [1977] make the same statement in their discussion. However, Hodges goes on to conclude that a possible 5-day global lifetime for helium on the moon [*Hodges and Hoffman*, 1974] does in fact suggest the existence of a near Maxwellian gas. He could arrive at this conclusion only by overlooking an important aspect of the accommodation process. Because of the omission, references to the *Shemansky and Broadfoot* [1977] and *Smith et al.* [1978] discussions are misleading. *Hodges* [1979] treatment of the surface as a continuum harmonic oscillator is equivalent to assuming that the gas is in thermodynamic equilibrium, as was the case in all of the earlier model calculations. In other words, there are no parameters in the calculations that describe properties of the surface material in an interaction regime with the gas atoms. It is clear that the exospheric gas cannot be in thermodynamic equilibrium. If we cannot assume thermodynamic equilibrium and there are no parameters in the calculation characterizing the coupling of the surface structure, the resultant energy distribution in the gas must be based on an unfounded assumption. A possible 5-day lifetime for global helium on the moon does not affect this argument, since the ratio of escape energy to Debye characteristic temperature is too low to allow a determination of thermal loss rates without better knowledge of surface interaction parameters. The loss of particles on the moon as Shemansky and Broadfoot pointed out could well be dominated by thermal escape, whereas the dominant loss process on Mercury is photo-ionization.

Acknowledgment. Supported under NASA contract NSG-7595.

REFERENCES

Hodges, R. R., Jr., Methods for Monte Carlo simulation of the exospheres of the moon and Mercury, *J. Geophys. Res.*, in press, 1979.

Hodges, R. R., Jr., and J. H. Hoffman, Measurements of solar wind helium in the lunar atmosphere, *Geophys. Res. Lett.*, *1*, 69, 1974.

Shemansky, D. E., and A. L. Broadfoot, Interaction of the surfaces of the moon and Mercury with their exospheric atmospheres, *Rev. Geophys. Space Phys.*, *15*, 491, 1977.

Smith, G. R., D. E. Shemansky, A. L. Broadfoot, and L. Wallace, Monte Carlo modeling of exospheric bodies: Mercury, *J. Geophys. Res.*, *83*, 3783, 1978.

(Received January 25, 1979;
revised April 24, 1979;
accepted June 29, 1979.)