GRAVITATIONAL EFFECTS ON MARS NEUTRON SPECTRA

W. C. Feldman, D. M. Drake, R. D. O'Dell,
F. W. Brinkley, Jr., and R. C. Anderson
Los Alamos National Laboratory, Los Alamos, NM 87545

The effects of gravity on martian neutron spectra were studied using the one-dimensional Boltzmann transport code ONEDANT (1) and a special cross section library used previously (2). Inclusion of gravity was accomplished by iterating a reflective outer boundary surface that introduces a source of radially reversed, inward-directed neutrons. This source has a flux intensity reduced from that of the albedo flux calculated in each previous iteration by the exponential decay factor $\exp(-\Delta T/\tau)$. Here ΔT is the surface return time of initially outward-directed neutrons and $\tau = 900$ s is the lifetime of the neutron to beta decay.

The neutron return time is a function of both the kinetic energy of each neutron as it leaves the surface, K, relative to its gravitational binding energy, V, and its direction cosine relative to the radial, μ. Specifically,

$$\Delta T = \frac{R_M\left(\frac{m}{2V}\right)^{1/2}}{\left(1 - \frac{K}{V}\right)^{3/2}}\left[\left(\frac{\pi}{2}\right) + A + \sin^{-1}\left(\frac{B}{[A^2 + B^2]^{1/2}}\right)\right] \tag{1}$$

where R_M is the radius of Mars, $A = \left[4\left(\frac{K}{V}\right)\left(1 - \frac{K}{V}\right)\mu^2\right]^{1/2}$, $B = \left(\frac{2K}{V} - 1\right)$, $(K/V) < 1$, and m is the neutron mass.

Neutron flux spectra, $\phi(K,\mu)$, at several depths within the planet as well as at the top of the atmosphere were calculated using ONEDANT coupled to the new gravitational boundary conditions. Although Eq. 1 assumes a spherically-symmetric planet, our ONEDANT calculations assumed planar symmetry. This last assumption introduces negligible error since the mean penetration depth of galactic cosmic rays, ~160 g/cm^2, is small compared to the thickness of the planet. Energy-angle flux spectra at arbitrary planetary radii, $R > R_M$, were then calculated from the albedo spectra at the top of the atmosphere, ϕ_A, using Liouville's theorem,

$$\phi_R(K,\mu) = \left(\frac{K_R}{K}\right)^{1/2}\phi_A(K,\mu)\exp(-\Delta T_R/\tau) \ . \tag{2}$$

Here $K_R = K - V\left(\frac{R - R_M}{R}\right)$ is the neutron kinetic energy at R,
$\mu_R = \left[1 - \left(\frac{R_M}{R}\right)^2\left(\frac{K}{K_R}\right)\left(1 - \mu^2\right)\right]^{1/2}$
is the direction cosine of the neutron relative to the radial at R, and ΔT_R is the time required for a neutron leaving the surface with kinetic energy K and direction cosine μ to reach R with kinetic energy K_R and direction cosine μ_R.

The neutron return time, ΔT_R, can be calculated analytically using expressions similar to Eq. 1. Typical values of ΔT for neutron kinetic energies near the maximum of the flux spectrum at $R = R_M + 361$ km fall in the range $1.2\tau < \Delta T < 2.2\tau$ depending on μ_R. Under the same conditions ΔT_R varies between $0.2\ \tau$ and $2.0\ \tau$.

Five surface compositions for Mars were assumed in order to survey the magnitude that gravity has on the albedo neutron spectra. These compositions consisted of dry ice represented by pure CO_2, pure water, and regolith having the composition measured by Viking (3) mixed with 0%, 1%, and 10% water by mass. In all cases the solid surface was covered by 16 g/cm^2 atmosphere having the composition measured by Viking (4). General conclusions from these calculations are as follows:

1) All angle-integrated flux spectra calculated with gravity included could be well represented by the same thermal and epithermal functions used previously (2) to represent spectra calculated without gravity. This observation holds equally well for flux spectra calculated below the regolith surface, throughout the atmosphere, at the top of the atmospheric (previously identified with the albedo neutron spectrum), and at the orbital altitude of the Mars Observer spacecraft, R.

2) The effect of gravity is to enhance all spectra preferentially at the lowest energies and to fill in the downward going hemisphere of velocity phase space, making the spectra nearly isotropic at the lowest energies.

3) In terms of the parameters that uniquely characterize all spectra as the superposition of thermal and epithermal functions, inclusion of gravity increases both the thermal and epithermal amplitudes, and decreases the temperatures of both the thermal and epithermal components.

4) The neutron number density at the surface of Mars, which is proportional to the production rate of capture gamma rays created there, is increased by only a few percent when gravitational effects are included. The reason for the smallness of this effect is that the overlying atmosphere is sufficiently thick to shield the martian surface from the gravitational boundary conditions imposed at the top of the atmosphere. Of course the effects of gravity become relatively more important as the top of the atmosphere is approached.

References: (1) R. D. O´Dell, F. W. Brinkley, and D. R. Marr (1982), Los Alamos National Laboratory report, LA-9184-MS, (2) D. M. Drake, W. C. Feldman, and B. M. Jakosky, J. Geophys. Res., submitted, (3) Toulmin et al. (1977), J. Geophys. Res., 82, 4625, (4) Owen et al. (1977), J. Geophys. Res., 82, 4635.