rotation as unchanged. I now assume that most of the planet is in hydrostatic equilibrium but that the surface has approximately the old ellipticity. Thus to obtain the value of Ω_1 which will make $e_h=0.0089$, $\Omega_1 \approx 1.3\Omega_2$ (from equation (2)).

To obtain some idea of the size and velocity which an impacting body may have to have in order to achieve this reduction in the angular velocity I consider a simple two dimensional situation where a body of mass m impacts with a velocity v tangentially to the surface of Mars and along its equator. I assume that the direction of impact is such as to reduce the rotation of Mars.

In an impact of this size dispersion of material would be expected to result and in a more exact treatment one would have to integrate the angular momentum about the axis of rotation of Mars for a distribution of secondary impacting bodies as well as for the primary object. Instead I assume a non-elastic rigid body impact which makes our treatment an approximate one. If the moment of inertia of Mars (about its axis of rotation) is $0.376Ma^2$ then from conservation of angular momentum

$$\begin{aligned} mv &\approx 0.376Ma(\Omega_1-\Omega_2) \\ &\approx 0.1Ma\Omega_2 \\ v &\approx 20(M/m) \end{aligned} \tag{1}$$

since $a\Omega_2 \approx 200$ m s^{-1}.

The orbits of the asteroids are very varied; some have eccentricities of 0.8 or greater. Some asteroids have orbits which take them past the orbit of Jupiter. I now select an orbit which will give a large impacting speed and which is compatible with existing asteroid orbits to see whether this will give a reasonable mass for the impacting body. The orbit chosen is one which has an ellipticity of 0.8 and which comes close to the orbit of Jupiter. For simplicity take the orbit of Mars as a circle with unit radius. Take the elliptical orbit to be $r_{max}=3$ and $r_{min}=\frac{1}{3}$ where r_{max} and r_{min} are the aphelian and perihelion distances. This gives a value of 0.8 for the ellipticity e, and r_{max} is just less than the mean radial distance of Jupiter.

If I now take the Sun as origin I have for the equations of the orbits of Mars and of the impacting body

$$x^2+y^2=1, \quad (x-c)^2+y^2/(1-e^2)=a^2$$

where $a=5/3$, $e=4/5$ and $c=ae=4/3$. For such an orbit (on calculations made using standard two-dimensional orbit theory) the speed of the impacting body at the moment of impact is ~ 30 km s^{-1} at an angle of $\sim 19°$ to the major axis of the elliptical orbit. The speed of Mars is ~ 24 km s^{-1} at an angle of $\sim 150°$ to the major axis of the elliptical orbit. So the impact speed relative to Mars is ~ 32 km s^{-1}. This value could be increased slightly if the acceleration due to gravitational attraction was to be taken into account. Substituting this value for v in equation (1) gives as the required mass of the impacting body the value $m \approx 0.7 \times 10^{-3}M$. If the impact is assumed to be tangential at latitude 45° (approximately that of the Hellas basin) then $m \approx 10^{-3}M$ but if it is at an angle of 45° to the vertical then $m \approx 1.4 \times 10^{-3}M$. These values for m are about the same as the mass of the largest asteroid, assuming that the densities of Mars and of the asteroid are the same.

These calculations were made on the assumption that the difference between the geometrical and dynamical ellipticities is due to collision only. If other factors such as convection[4] play a role the required size of the asteroid and the value of the orbital eccentricity of the impacting body may even be smaller.

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H. F. PETERSONS

Physics Department,
Imperial College,
London SW7, UK

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Permanent Address: Department of Applied Mathematics, The Australian National University.

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CO_2 and HCN in sunspots

THE triatomic molecules CO_2 and HCN have now been reported to be present in cool stars[1,2], and H_2O had already been detected in the sunspot spectrum[3–7]. Dissociation equilibrium calculations for three recent sunspot models[8–10] show that the molecules CO_2 and HCN are fairly abundant in sunspots. The results for the Zwaan model have already been published[11]; we further find that the abundances of CO_2 and HCN are comparable for all three models. We have therefore calculated equivalent widths of selected lines of these molecules to ascertain if they might show up in the infrared region of the sunspot spectrum. The strongest fundamental bands of HCN and CO_2 and a weaker band of CO_2 were included in our calculations. The selected J values correspond closely to the expected maximum Local Thermodynamic Equilibrium (LTE) population under sunspot conditions.

The sunspot model selected for the equivalent width calculations is that of Stellmacher and Wiehr[10]. The procedure for calculating the equivalent widths has been outlined earlier[12]. Two R (56) lines of CO_2 at wavenumbers 3,478.93 cm^{-1} and 2,384.49 cm^{-1}, belonging respectively to the bands (10^01–00^00) and (00^01–00^00) of the Σ–Σ transitions, were selected. The equivalent width of the former line at the centre of the disk turned out to be 0.032 mÅ suggesting an absence of the (10^01–00^00) band in the sunspot spectrum. Details of the centre-to-limb variation of equivalent width for the (00^01–00^00) line are given in Table 1.

Table 1 Equivalent width of (00^01–00^00) line

$\cos\theta$	1	0.7	0.5	0.3
Equivalent width (mÅ)	6.6	7.7	7.8	11.3

We are not aware of any observations of the (00^01–00^00) band of CO_2 in the 4.3 μm region of the sunspot spectrum and therefore a verification of these predictions with observations has yet to be done.

The R (25) line of HCN at 3,380.84 cm^{-1}, belonging to the band (00^01–00^00) of the Σ–Σ type transition, in the Stellmacher–Wiehr[10] sunspot model has an equivalent width of 0.072 mÅ at the centre of the disk. The fact that the other fundamental bands at 712 cm^{-1} and 2,089 cm^{-1} have lesser integrated intensities[13] leads us to suggest that the HCN fundamental bands may not show up in the infrared region of the sunspot spectrum.

M. C. PANDE
V. P. GAUR

Uttar Pradesh State Observatory,
Manora Peak,
Naini Tal, 263129, India

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