

Terrestrial oxygen implanted on lunar soils by Earth Wind (EW).

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Introduction: At the last LPSC, Ozima et al. [1] suggested that oxygen with extraordinary isotopic composition (mass-independently fractionated, MIF hereafter, with $\Delta^{17}\text{O} \sim 25\text{‰}$) found on lunar metallic particles by Ireland et al. [2] were attributable to terrestrial oxygen that was transported from the ionosphere by Earth Wind (EW). The recent observation of ions escaping from the Earth's ionosphere by GEOTAIL mission [3] supports this suggestion; The input flux of the MIF oxygen, which we estimated from the amount of the oxygen implanted on metal particles, was by about a factor of ten smaller than Earth-escaping O^+ flux at the lunar orbit. Since the Moon spends about 10% of a lunar day in the shadow of the Earth escaping ion flows, the oxygen ions in the EW (essentially consisting of O^+) can account at least for the amount of the MIF oxygen in lunar metals. Therefore, if the isotopic composition of the O^+ in the EW were shown to be similar to $\Delta^{17}\text{O} \sim 25\text{‰}$, this would give a robust support for the EW-oxygen hypothesis.

Objectives: The MIF O-isotopic composition observed in lunar metals was very close to that observed in ozone in the Earth's stratosphere, and it might be tempting to speculate that the terrestrial ozone may be responsible for the lunar MIF oxygen. However, because of its scarcity (less than 1 ppmv in the thermosphere) of ozone, any meaningful contribution of ozone oxygen in EW must be dismissed. If the MIF oxygen were to be due to EW, we must see that MIF took place above a few hundred km, where the Earth-escaping oxygen flow starts. Current infor-

mation on the isotopic composition of oxygen either by measurements (rocket, balloon, air craft, e.g. [4]) or theoretical calculation is limited to < 100 km, and is not useful in accessing the isotopic characteristics of EW-O. We made 1D numerical chemical model on the isotopic composition of O^+ including oxygen and nitrogen chemistry with ion, neutral, and electron processes in the altitude 100-600km.

Method: In order to examine the isotopic composition of O^+ (which includes $\text{O} = {}^{16}\text{O}$, $\text{P} = {}^{17}\text{O}$, $\text{Q} = {}^{18}\text{O}$) at > 100 km, we solved 20 sets of photochemical reaction equations including oxygen isotopes for several species in a local equilibrium condition. As imposed initial conditions, the number density of elements, solar flux intensity, and temperature with altitude were taken from commonly used literature [5]. Reaction rates for equations involving O were taken from literature [6]. We were much inspired by the insightful interpretation of MIF in ozone by Gao and Marcus [7] on the basis of photochemical reaction rate dynamics, and we examined the dependence of the isotopic composition of O^+ on relative magnitude of reaction rates R_{O} , R_{P} , and R_{Q} on the ion reaction (1), which appeared to be important from our trial calculation. For an absolute value of R_{O} we take a literature value [6].

Although the basic scheme of our calculation is standard and similar to those by previous workers [e.g. 8], our calculation is the first attempt in examining the isotopic composition of O^+ in high altitude (> 100 km).

Results: Fig.1 shows calculated number density profiles of e^- , O_2^+ , and O^+ (O includes P and Q). We also show International Reference Ionosphere (IRI) electron number density model [9] for comparison with our calculated e^- profile. We think that the fair agreement of the calculation with the model indicates the validity of our calculation. It is interesting to note that O^+ number density overwhelms that of O_2^+ above ~ 300 km, being consistent with the observation that Earth escaping ions are essentially O^+ .

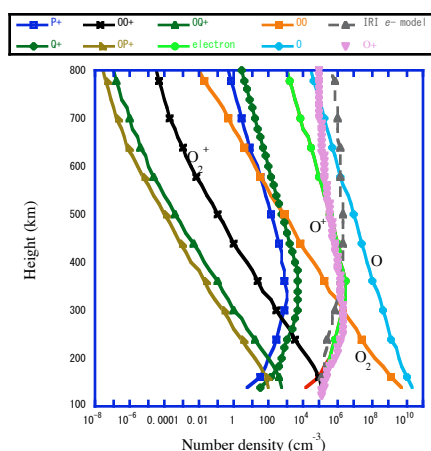
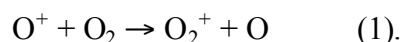


Fig. 1 Number densities of ions and electron with altitude. Number densities of O , O_2^+ and e^- are from literature [5, 9].

Fig.2 shows O^+ isotopic ratios calculated for arbitrarily chosen values of R_p/R_O and R_Q/R_O for 0.7, 0.8, and 0.9 for the reaction,



As seen in Fig.2, $\Delta^{17}O$ values of O^+ exceed those of the lunar MIF oxygen around ~ 300 km, where O^+ density becomes maximum (Fig.1). This is encouraging for our EW hypothesis, and we are currently investigating whether or not the assumed relative reaction rates are theoretically feasible by calculating reaction rates on the basis of molecular reaction rate dynamics.

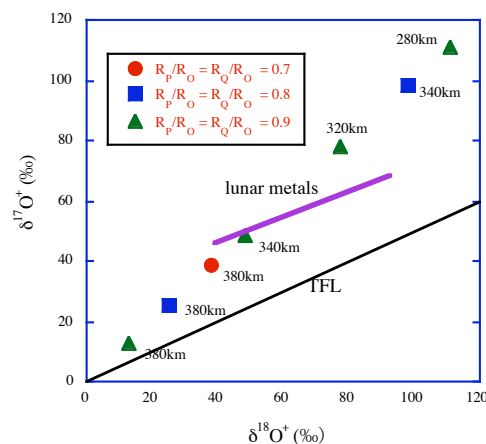


Fig. 2 Isotopic ratios of O^+ at different heights. Depending on relative magnitude of reaction rates, they show large MIF. A thick line (purple color) represents an approximate range for lunar metal particles [2].

Conclusion: Numerical calculation of photochemical reactions on the isotopic composition of O^+ in the thermosphere (>100 km), where Earth escaping ion flow starts gives $\Delta^{17}O$ values overlapping the value reported on lunar metallic particles by Ireland et al [2]. Together with our previous conclusion that the amount of the MIF oxygen implanted in lunar soil can be accounted for by the Earth escaping O^+ flux, the present numerical calculation appears to encourage a hypothesis that the MIF lunar oxygen may be due to oxygen escaping from the Earth's ionosphere. If the hypothesis were confirmed, this would yield unparalleled means to tackle the evolution of biotic atmosphere in the Earth.

References: [1] Ozima M. (2007) *LPS XXXVIII*, 1129-1130. [2] Ireland T. R. et al. (2006) *Nature* 440 776-778. [3] Seki K. et al. (2001) *Science* 291 1939-1941. [4] Boering K. A. et al. (2004) *GRL* 31 LO3109. [5] Hedin A.E. (1991) *JGR* 96(A5) 8981-8992 [6] DeMore et al. (1994) *JPL Publication* 94-26, Matzing H. (1991) *Adv. Chem. Phys.* 80 315-402. [7] Gao Y. Q. and Marcus R. A. (2001) *Science* 293 259-263. [8] Lyons J. R. (2001) *GRL* 28 3231-3234. [9] Bilitza D. (2001) *Radio Science* 36 261-275.