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Electron Scavenging in the Night-Time Mesosphere - A Collection of Empirical Data

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Introduction

The mesosphere's plasma (the *D*-region) consists of:

(*a*) positive ions, N^+,

(*b*) electrons, N_e, and

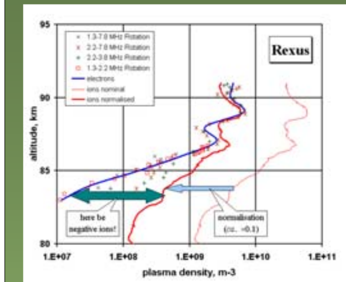
(*c*) other negatively charged particles N^- (ions or aerosols).

For charge neutrality there must be equal numbers of positive and negative charges, *i.e.* $N^+ = N_e + N^-$.

ad (*a*): can be measured by a suitable electrostatic probe; absolute values critically depend on aerodynamics,

ad (*b*): the best procedures for absolute values use radio wave propagation methods; moderate height resolution,

ad (*c*): is obtained by forming the difference between positive ions and electrons ($N^- = N^+ - N_e$).



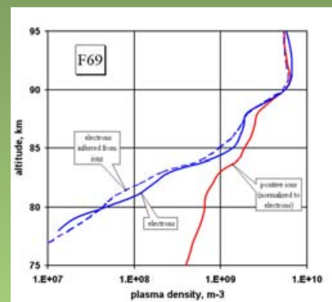
Night Conditions

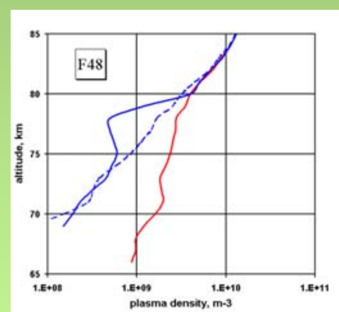
Negatively charged particles (other than electrons) are formed by attachment (rate β) of free electrons to molecules. This reaction is balanced by recombination of negative and positive ions (ion-ion recombination α_i). Other reactions balancing the formation of negative ions are *via* atomic oxygen or photodetachment; these paths can be ignored below about 85 km and at night. Therefore under full night conditions in the mesosphere (solar zenith angles >98°) the following simple relation between the number densities of neutrals M, positive ions N^+, and free electrons N_e applies (after Friedrich and Torkar, 1995):

$$N_e = \frac{N^+}{1 + \frac{\beta}{\alpha_i}\frac{M^2}{N^+}}$$

in other words, given a knowledge of β and α_i one can infer N_e from N^+. A typical laboratory value for β is 10^{-31} cm^6 s^{-1} (Phelps, 1969) and $4{\cdot}10^{-7}$ cm^3 s^{-1} for α_i (Peterson *et al.*, 1971), hence β/α_i should be $2.5{\cdot}10^{-25}$ cm^{-3}. In the example on the right (rocket F69) a somewhat lower β/α_i of $5{\cdot}10^{-26}$ cm^{-3} yields the best agreement.

The rocket F48 is a case where obviously one β/α_i for all altitudes does not adequately produce inferred electron densities and a height dependent β/α_i must be used.





Expected Dependence

In the variabilty of β/α_i from case to case, we expect the following systematic variation:

1) ionisation: during high ionisation free electrons are formed faster than they can attach,

2) solar zenith angle: even after sundown the sunlight scattered by the geocorona varies with solar zenith angle,

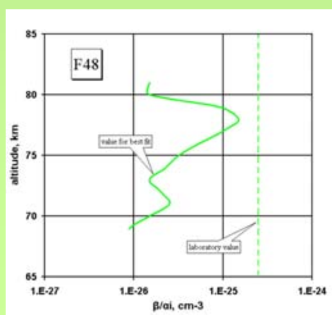
3) moonlight: although much weaker than direct sunlight, it may still suffice to photodetach,

4) temperature: chemical reactions are always temperature dependent,

5) season: according to theoretical models there should be more meteoritic smoke in winter than in summer (Megner *et al.*, 2008), and

6) altitude: assuming ablated meteors to be the source of the dust, smoke particles grow as they sediment (and scavenge more electrons).

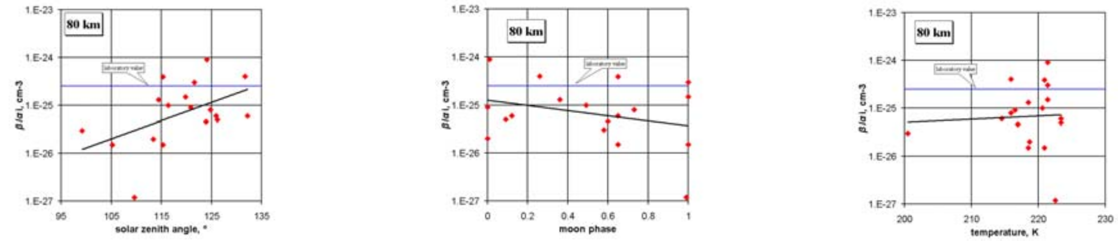
The scatter in the data, however, we attribute to day-to-day variations of aerosol fluxes.



Data Base for the Reality Check

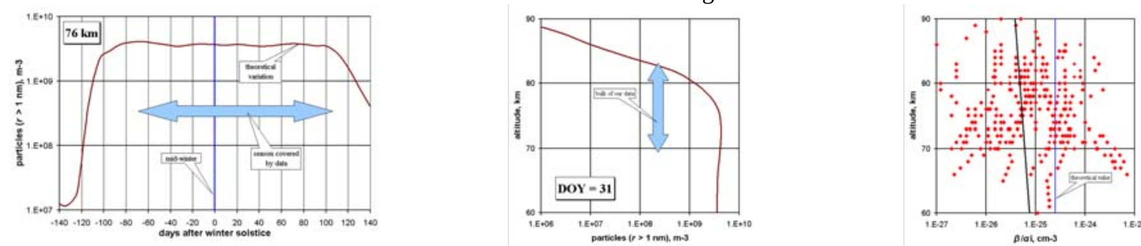
The useable data for this exercise are restricted to: (*a*) full night, (*b*) "good" electron densities (*i.e.* measured by a wave propagation method), and (*c*) positive ion profiles extending down to heights where their numbers exceed those of electrons. Most atmospheric parameters come from the MSIS model modified by data taken in Northern Scandinavia (Friedrich *et al.*, 2004), only for one rocket flight (Rexus) do we have concurrent temperature measurements. We happen to have only data from Northern Scandinavia which meet these requirements. Hence the darkness condition restricts our seasonal coverage from 18th October to 9th April by 28 rocket flights from 1968 to 2004. Based on the theoretical considerations we need to search for a 6-dimensional dependence (*i.e.*, altitude, temperature, season, zenith angle, moon phase, and ionisation) of β/α_i, a daunting task with a grand total of only 336 data points!

The Good News



At all altitudes β/α varies indeed positively with solar zenith angle and negatively with the phase of the moon which suggests that light scattered in the geocorona or reflected by the moon can photodetach. An increase with temperature is explicable by a decrease in the ion-ion recombination. The mean dependencies on solar zenith angle (χ in deg), moon phase ($0 < M < 1$), and temperature (in K) ***over all altitudes*** are $10^{0.039\chi}$, $10^{-0.52M}$, and $10^{0.013T}$, respectively.

The Irrelevant and the Conflicting Results



According to the theoretical model the aerosol particles hardly vary in the period covered by our data and we therefore ignore season in the analysis. The height dependence is inconclusive, but does at least not contradict the theoretical variation predicted for our median day (DOY = 31). For most rocket flights we have no information concerning the ionisation and we therefore use riometer absorption as a proxy. The variation of β/α_i with riometer absorption (~ ionisation) turns out to be slightly positive in contradiction to intuitive expectation.

Conclusions

The ratio between electron attachment and ion-ion recombination at night scatters widely and has a mean value about a third of what one expects from the laboratory results. However, qualitatively its mean behaviour largely agrees with theoretical expectations, namely its variation with scattered sunlight, moon light, and temperature which lends credence to the data. One explanation for the huge scatter may be atomic oxygen occuring below the ledge (at about 83 km) as *e.g.* measured by Dickinson *et al.* (1985) under very disturbed ionospheric conditions. Alternatively electrons may be lost by attachment to particles much larger than molecules; for such a scenario the relation between electrons, neutrals and positively charged particles requires another presentation than used here.

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