

**AIR ION MOBILITY SPECTRUM  
AT A RURAL AREA**

**URMAS HÕRRAK**

This study was carried out at the Institute of Environmental Physics, University of Tartu.

The Dissertation was admitted on October 29, 2001, in partial fulfilment of the requirements for the degree of Doctor of Philosophy (environmental physics), and allowed for defence by the Council of the Department of Physics, University of Tartu.

Supervisors:

Prof. Hannes Tammet, Institute of Environmental Physics,  
University of Tartu  
Dr. Jaan Salm, Institute of Environmental Physics,  
University of Tartu

Opponents:

Prof. Sven Israelsson, Department of Earth Sciences,  
Division of Meteorology, University of Uppsala, Sweden  
Dr. Kalju Eerme, Tartu Observatory, Tõravere, Estonia

Defence: December 17, 2001, at the University of Tartu, Tartu, Estonia

© Urmas Hõrrak, 2001

Tartu Ülikooli Kirjastuse trükikoda  
Tiigi 78, Tartu 50410  
Tellimus nr. 812

# CONTENTS

LIST OF ORIGINAL PUBLICATIONS .....	3
MAIN ARGUMENTS PROPOSED TO DEFENCE.....	3
1. INTRODUCTION.....	4
1.1. Nature of air ions .....	4
1.2. Characterization of air ions.....	4
1.3. The balance of ions in the atmosphere.....	5
1.4. Environmental importance of air ions .....	6
1.5. Earlier research.....	7
1.6. Main objectives of the present study .....	11
2. THE MEASURING STATION .....	12
2.1. Location.....	12
2.2. Meteorological characterization .....	12
2.3. Air pollution .....	13
2.3.1. Dependence of air pollution on wind direction.....	13
2.3.2. Summary of NO <sub>2</sub> measurements.....	14
2.3.3. Characterization of air pollution by Sheftel method.....	15
3. INSTRUMENTATION AND DATA PROCESSING.....	16
3.1. General layout of the system .....	16
3.2. Air tract.....	16
3.3. Air ion spectrometers.....	17
3.4. Sensors.....	18
3.5. Electrical aerosol spectrometer.....	19
3.6. Estimation of the air ion fraction concentrations.....	19
3.7. Measurement accuracy .....	20
4. STATISTICAL CHARACTERIZATION OF AIR ION MOBILITY SPECTRUM.....	21
4.1. Average mobility spectrum of air ions .....	21
4.2. Variability of air ion spectra .....	22
4.3. Average characteristics and variability of small ions .....	23
4.4. Average characteristics and variability of intermediate ions.....	23
4.5. Average characteristics and variability of large ions .....	24
5. BURSTS OF INTERMEDIATE IONS.....	25
6. CLASSIFICATION OF AIR IONS AND CORRELATION BETWEEN THE CONCENTRATIONS OF MOBILITY CLASSES .....	30
6.1. Problem of the classification of air ions .....	30
6.2. Principal component and factor analysis of the set of fraction concentrations.....	31
6.3. Statistical classification of air ions .....	33
6.4. Correlation between the concentrations of air ion mobility classes .....	34
7. THE MEAN MOBILITY OF SMALL AIR IONS .....	36
7.1. Average characteristics .....	36
7.2. Time series of the mean mobility.....	36
7.3. The mean mobility and the evolution of small ion mobility spectra.....	38
7.4. Diurnal variation .....	40
7.5. Annual variation.....	41
7.6. Correlation of the mean mobility with meteorological parameters.....	41
7.7. Correlation of the mean mobility with the fraction concentrations of mobility spectra .....	43
7.8. The multiple regression analysis.....	45
8. ANNUAL VARIATIONS OF AIR ION MOBILITY CLASSES .....	47
8.1. Concentration of small air ions .....	47
8.2. Concentration of intermediate and light large air ions.....	48
8.3. Concentration of heavy large air ions .....	49
9. DIURNAL VARIATIONS OF AIR ION MOBILITY CLASSES .....	51
9.1. Concentration of small air ions .....	51
9.2. Concentration of intermediate ions .....	53
9.3. Concentration of light large ions.....	54
9.4. Concentration of heavy large air ions .....	55
10. CONTRIBUTION OF AIR ION MOBILITY CLASSES TO AIR CONDUCTIVITY .....	58
11. AIR ION MEASUREMENTS AS A SOURCE OF INFORMATION ABOUT ATMOSPHERIC AEROSOLS .....	62
11.1. Introduction.....	62
11.2. Measurements .....	62
11.3. Preliminary data analysis .....	64
11.4. Transformation of the spectra .....	66
12. CONCLUSIONS .....	68
REFERENCES .....	70
ABSTRACT .....	77
SUMMARY IN ESTONIAN .....	78
ACKNOWLEDGEMENTS.....	80

## LIST OF ORIGINAL PUBLICATIONS

- I Hörrak, U., Iher, H., Luts, A., Salm, J. and Tammet, H. (1994) Mobility spectrum of air ions at Tahkuse Observatory. *J. Geophys. Res. Atmospheres* **99**, 10697–10700.
- II Hörrak, U., Salm, J. and Tammet, H. (1995) Outbursts of nanometer particles in atmospheric air. *J. Aerosol Sci.* **26**, S207–S208.
- III Hörrak, U., Salm, J., Tamm, E. and Tammet, H. (1996) Derivation of the size spectrum of aerosol particles from a mobility spectrum. In *Nucleation and Atmospheric Aerosols*, edited by M. Kulmala and P.E., Wagner, Pergamon, pp. 562–565.
- IV Hörrak, U., Salm, J. and Tammet, H. (1996) Statistical characterization of air ion spectra at Tahkuse Observatory 1993–1994. *Proc. 10th Int. Conf. Atmos. Electr.*, Osaka, pp. 72–75.
- V Hörrak, U., Mirme, A., Salm, J., Tamm, E. and Tammet, H. (1998) Air ion measurements as a source of information about atmospheric aerosols. *Atmospheric Research* **46**, 233–242.
- VI Hörrak, U., Mirme, A., Salm, J., Tamm, E. and Tammet, H. (1998) Study of covariations of aerosol and air ion mobility spectra at Tahkuse, Estonia. *J. Aerosol Sci.* **29**, S849–S850.
- VII Hörrak, U., Salm, J. and Tammet, H. (1998) Bursts of intermediate ions in atmospheric air. *J. Geophys. Res. Atmospheres* **103**, 13909–13915.
- VIII Hörrak, U., Salm, J. and Tammet, H. (1999) Classification of natural air ions near the ground. In *11th International Conference on Atmospheric Electricity*, edited by Christian, H.J., NASA, MSFC, Alabama, pp. 618–621.
- IX Hörrak, U., Salm, J. and Tammet, H. (2000) Statistical characterization of air ion mobility spectra at Tahkuse Observatory: Classification of air ions. *J. Geophys. Res. Atmospheres* **105**, 9291–9302.
- X Noppel, M. and Hörrak, U. (2000) Simulation of the mobility spectrum of charged particles during bursts in atmospheric air. *J. Aerosol Sci.* **31**, S700–701.
- XI Vana, M., Hörrak, U. and Tamm, E. (2000) Comparative study of the ultrafine aerosol particle and intermediate air ion concentration bursts in the atmosphere. *J. Aerosol Sci.* **31**, S176–S177.
- XII Tamm, E., Hörrak, U., Mirme, A. and Vana, M. (2001) On the charge distribution on atmospheric nanoparticles. *J. Aerosol Sci.*, **32**, S347–S348.
- XIII Hörrak, U., Salm, J. and Tammet, H. (2001) Diurnal variation of charged atmospheric aerosols in nucleation and Aitken mode ranges. *J. Aerosol Sci.* **32**, S169–S170.

## MAIN ARGUMENTS PROPOSED TO DEFENCE

1. Traditional classification of air ions according to mobility or size is an intuitive convention. However, the air ions can be classified using an objective criterion. According to the principal component analysis, the mobility spectrum in the range of  $0.00041\text{--}3.2\text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  (diameters of 0.36–79 nm) is divided into five classes: small cluster, big cluster, intermediate, light large, and heavy large ions. The boundaries between the classes are  $1.3\text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  (diameter of 0.85 nm),  $0.5\text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  (1.6 nm),  $0.034\text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  (7.4 nm), and  $0.0042\text{ cm}^2\text{V}^{-1}\text{s}^{-1}$  (22 nm). The five principal components that are closely correlated with the respective ion classes explain 92% of total variance of air ion mobility spectra.
2. Concentrations of the aerosol particles and air ions in weakly polluted rural air are well correlated; the correlation coefficients in a size range of 10–80 nm are 93–98%. These aerosol particles are almost quasi-steady charged. Consequently, air ion measurements could be used as a source of information about atmospheric aerosols.
3. The photochemical nucleation can initiate a burst of intermediate ion concentration (charged aerosol particles in the size range of 1.6–7.4 nm) and subsequent evolution of aerosol ion size spectra below 80 nm. The generated new aerosol particles grow toward sizes 10–15 nm during 2–3 hours. In general, the disturbed region of air ion size spectra affected by the bursts is 1.1–34 nm ( $0.002\text{--}1.0\text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ ) including the groups of big cluster ions, nanometer particles and a fraction of Aitken particles.
4. The average diurnal variation of the concentration of heavy large ions (charged Aitken particles of diameter 22–79 nm) in the warm season is opposite to that in the cold season. The different processes of aerosol particle generation (combustion versus radiolytic processes) could explain the contrast in the average diurnal variations.
5. The factors that are related to the variation of the natural mean mobility of small ions are: solar radiation (followed by diurnal variation of relative humidity and air temperature), concentration of aerosol particles (followed by a variation in concentration of heavy large ions of 52–79 nm), nucleation events (followed by the bursts of intermediate ions). These factors can explain about 50% of the variance of mean mobility.
6. The mean mobility of small air ions is a factor that can affect the conductivity of atmospheric air. The deviation of mean mobility from the average could cause changes in conductivity (induced by small ions) from about –12% to +15% and from –14% to +26% for positive and negative polarity, respectively.