

AEROSOL PHYSICS I

EXAMINATION

01.11.2022



Institute for Atmospheric and Earth System Research



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Points per exercise are indicated in brackets. Total points: 30!

Use the following numbers, whenever needed:

Ideal gas constant:

$$R = 8.31 \text{ kg} \cdot \text{m}^2 \cdot \text{K}^{-1} \cdot \text{mol}^{-1} \cdot \text{s}^{-2}$$

Air viscosity:

$$\eta = 1.8 \cdot 10^{-5} \text{ kg} \cdot \text{m}^{-1} \cdot \text{s}^{-1}$$

Vacuum permittivity:

$$\epsilon_0 = 8.85 \cdot 10^{-12} \text{ s}^4 \cdot \text{A}^2 \cdot \text{m}^{-2} \cdot \text{kg}^{-1} \cdot \text{m}^{-1}$$

Elementary charge:

$$e = 1.602 \cdot 10^{-19} \text{ A} \cdot \text{s}$$

Refractive index of water = 1.33

Diffusion coefficient of a 50 nm diameter particle in standard conditions:

$$D = 2 \times 10^{-9} \text{ m}^2 \cdot \text{s}^{-1}$$

1. A smoker draws smoke with a flow of 0.5 liter per second for 2 seconds through a cigarette with a mass concentration $30 \text{ g} \cdot \text{m}^{-3}$. Assume all particles have the same density of $1 \text{ g} \cdot \text{cm}^{-3}$ and size (diameter) 500 nm.
- What is the number concentration and total particle number inhaled? **(1 Pts.)**
 - The inhale creates a slight pressure drop compared to the atmosphere ($p_{\text{throat}} = 700 \text{ mbar}$, i.e. $\sim 0.7 \text{ atm}$). Given that the mean free path of air molecules at 1 atm is 66 nm, calculate the mean free path of air molecules at the lower pressure. Is the motion of the smoke particles described by continuum or non-continuum dynamics? **(2 Pts.)**
 - The throat is approximated by a straight cylindrical tube with diameter 3 cm. Are the losses characterized by turbulent or laminar deposition? Calculate the relevant dimensionless number, assume that the air viscosity is constant with pressure, but use a gas density of 0.9 kg m^{-3} at 0.7 atm (careful, these are not standard conditions!) **(2 Pts.)**
 - Deep in the lungs these particles flow through a bend with a 80 degree angle, where the diameter of the bronchi is now 0.2 mm, the flow rate is only 1 cm^3 per second and the mean free path of the air is 125 nm due to even lower pressure. Which dimensionless number determines whether the inhaled particles follow the flow field through that bend? Calculate the slip correction and the fraction of particles passing through the bend **(3 Pts.)**
 - The smoker exhales a plume of 50 nm particles in a perfectly straight line in front of them, and the cloud begins to dissipate by Brownian displacement. 5 minutes later, what is the concentration gradient dn/dx at $x=0$, in units of n_0 per centimeter. Assume no turbulence or air motion of any kind during your answer. **(2 Pts.)**