METHODS OF EXPERIMENTAL PHYSICS:

L. Marton and C. Marton, *Editors-in-Chief*

Volume 18

Fluid Dynamics

PART A

Edited by

R. J. EMRICH

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Department of Physics
Lehigh University
Bethlehem, Pennsylvania

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CONTRIBUTORS

Numbers in parentheses indicate the pages on which the authors' contributions begin.

RON F. BLACKWELDER, *Department of Aerospace Engineering, University of Southern California, Los Angeles, California 90007* (259)

R. J. EMRICH, *Department of Physics, Lehigh University, Bethlehem, Pennsylvania 18015* (240, 315, 341)

W. MERZKIRCH, *Institut für Thermo- und Fluiddynamik, Ruhr-Universität Bochum, 4630 Bochum, Federal Republic of Germany* (345)

A. N. PAPYRIN, *Institute of Theoretical and Applied Mechanics, USSR Academy of Sciences, Siberian Division, Novosibirsk 630090, USSR* (194)

R. I. SOLOUKHIN, *Institute of Heat and Mass Transfer, Byelorussian Academy of Sciences, Minsk 220728, USSR* (194)

E. F. C. SOMERSCALES, *Department of Mechanical Engineering, Rensselaer Polytechnic Institute, Troy, New York 12181* (1)

FOREWORD

We know of no one more qualified that Professor Raymond Emrich to have edited this volume of "Methods of Experimental Physics"—"Fluid Dynamics." Together with a number of outstanding and eminent contributors, Professor Emrich has produced a volume that we believe will be of unusual value to the physics community. Because of the central role of fluid phenomena in so many of the subdisciplines of physics as well as in engineering and the life sciences, the usefullness of this volume may be extraordinarily broad. Our gratitude goes to all involved.

L. Marton
C. Marton

PREFACE

Fluid dynamics is a somewhat unusual part of physics in the twentieth century. Fluids are so universally used in every experiment in physics that the techniques are considered standard and "well known." When the fluid dynamic parts of his apparatus misbehave, the physics experimentalist feels that the solution is one to be "left up to the engineers." There is good justification for this view because plumbing, pressure gages, thermometers, pumps, and fans are so reliable that one takes it for granted that one may simply order what is needed from a scientific supply house catalog. However, there is an active research body, involving people trained as physicists, valiantly searching for an understanding of the "first approximation to nonequilibrium." Besides the large group in industry, departments of mechanical, aerospace, chemical, and nuclear engineering in universities, as well as chemistry, geology, meteorology, oceanology, and biology departments contain groups who are fully occupied with research in fluid dynamics. Although in the United States and Canada there is only a tiny minority in physics departments, the American Physical Society serves as a rallying point where these diverse groups get together to share their knowledge. This volume, which has been bound as Parts A and B, has been prepared by some devoted members of this group and their friends abroad. It has been written for members of the group who are expert in other fields and for the graduate students in all these disciplines who need to measure liquid and gas velocity, density, temperature, pressure, and composition. The authors' goal has been to explain the principles of physics employed in making measurements, and to give some practical design information. Often our basic knowledge of an overwhelmingly important aspect of fluid dynamics—turbulence—is so rudimentary that the principles in a measuring system are undefinable. Fluid dynamicists then fall back on an organized guessing method called "dimensional analysis" as a guide for presenting what is known empirically. As physicists read the articles herein, and find the authors appealing to dimensional analysis to try to organize the complex observations of fluid behavior, they may be inclined to conclude that fluid dynamics is the "science of the undetermined constant that isn't constant." They are then ready to read the final chapter of Part B, titled "Dimensional Analysis and Model Testing Principles," which is a method of theoretical physics as well as of experimental physics.

I am happy to express my appreciation and thanks to all of the contributors whose time and effort have made this volume available to the scientific community, and especially to C. W. Curtis, W. Merzkirch, R. I. Soloukhin, and E. F. C. Somerscales. I also thank the late Dr. L. I. Marton and Dr. Claire Marton for proposing the volume and for their support and encouragement in the years of its preparation. Much credit also is due to the staff of Academic Press.

RAYMOND J. EMRICH

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* Section 1 1 4 5, "Fabry–Perot Spectrometer," is by A N Papyrin and R I Soloukhin

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1. MEASUREMENT OF VELOCITY

1.1. Tracer Methods*

List of Symbols†

A	$18/(\sigma + 0.5)$ [dimensionless]
A_D	Area of moving particle image on the emulsion [cm^2]
B	$3/[2(\sigma + 0.5)]$ [dimensionless]
B_t	Brightness of the source [$W/(cm^2 \cdot sr)$]
b	size of negative [cm]
C	$9/[(\pi)^{1/2}(\sigma + 0.5)]$ [dimensionless]
C_D	drag coefficient [see Eq. (1.1.3)] [dimensionless]
c	diameter of the limiting circle of confusion [cm]; camera constant [cm]
D	$6H/[\pi\, d\mu_F(\sigma + 0.5)]$ = normalized force [cm/s]; duct diameter, see Table II [cm]
D_C	width of camera field of view [cm]
D_L	width of incident light beam [cm]
d	particle diameter [μm]
d_D	diameter stationary particle image on the emulsion [μm]
F_D	luminous flux density incident on the emulsion [W/cm^2]
$F_{i\lambda}$	monochromatic flux density of light incident on a flow tracing particle† [$W/(cm^2 \cdot \mu m)$]
f	interruption frequency [Hz]; focal length of lens [cm]
f_1	$\{\omega[\omega + C(\pi\omega/2)^{1/2}](B - 1)\}/\{[A + C(\pi\omega/2)^{1/2}]^2 + [\omega + C(\pi\omega/2)^{1/2}]^2\}$
f^2	$\{\omega[A + C(\pi\omega/2)^{1/2}](B - 1)\}/\{[A + C(\pi\omega/2)^{1/2}]^2 + [\omega + C(\pi\omega/2)^{1/2}]^2\}$
g	Acceleration of gravity = 981 cm/s^2
I_λ	Monochromatic angular scattering cross section [cm^2/sr]
I'_λ	$I_\lambda/(\pi d^2/4)$ = monochromatic angular scattering coefficient [sr^{-1}]
i_1, i_2	Intensity functions for scattered radiation, subscripts 1 and 2 indicate the planes of polarization; see Eq. (1.1.23) and Fig. 9 [sr]
K	Multiplying factor that allows for departures from the conditions required by Stokes' law; see Table II [dimensionless]
k	Wave number $= 2\pi/\lambda$ of light [μm^{-1}]
k_B	Boltzmann's constant $= 1.38046 \times 10^{-25}$ [J/K · molecule]
l	Distance of particle from wall [μm]
M	Magnification = image distance/object distance [dimensionless]
m_P	Mass of particle $= \rho_P \pi d^3/6$ [g]
N	f-number of the lens = focal length/lens diameter [dimensionless]
N_S	Stokes number $= [\nu_F/(\omega d^2)]^{1/2}$ [dimensionless]
n	Number of particles

* Chapter 1.1 is by **E. F. C. Somerscales**, except for Section 1.1.4.5, which is by **A. N. Papyrin** and **R. I. Soloukhin**.

† This list is for Sections 1.1.1–1.1.3 and includes only terms not defined in the text or terms that are used frequently in the discussion.

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