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BIOMEDICAL ENGINEERING**

BIOLOGICAL AND MEDICAL PHYSICS, BIOMEDICAL ENGINEERING

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Alexander I. Zhmakin

Fundamentals of Cryobiology

Physical Phenomena
and Mathematical Models

With 23 Figures

 Springer

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To Tanja

Preface

The best way to become
acquainted with a subject is
to write a book about it.

Benjamin Disraeli

Cryobiology is a true multidisciplinary science involving concepts from biology, medicine, and physics. Its field comprises the study of any biological object or system (e.g., proteins, cells, tissues, organs, or organisms) under the temperatures below the normal (ranging from hypothermic conditions to cryogenic temperatures): cold-adaptation of organisms; cryoconservation of biological objects; conservation of organs under hypothermic conditions; lyophilization; cryosurgery. Origins of cryobiology could be traced down to ancient Egyptians; probably the first scientific account of this science is the monograph by Sir Robert Boyle “New Experiments and Observations Touching Cold” (London, 1683). Twentieth century witnessed a rapid development of cryobiology related to the progress of the cryogenic equipment (closed systems based on liquid nitrogen, Joule–Thomson cooling with mixed gases, etc.), developments of monitoring techniques, extension of the list of diseases that have been successfully treated by cryomedicine, and consolidation of research by foundation (simultaneously in 1964) of two major scientific societies in this field – The Society for Cryobiology and The Society for Low Temperature Biology.

There are a lot of good books on cryobiology that can be divided into two groups: (1) the ones that treat the whole field of cryobiology – these ones are somewhat out-of-date and (2) the books on specific applications of cryobiology such as cryosurgery or cryoconservation. The present book gives a modern view covering all aspects of cryobiology, with the most attention given to

the underlying physical phenomena and corresponding mathematical models, including numerical ones, since numerical simulation now is recognized as a third tool – along with experiment and theory – for knowledge generation.

The author is aware that “a single conversation across the table with a wise man is better than 10 years mere study of books” (*Henry Wadsworth Longfellow*), but still he hopes that this book will be useful to both physicists and biologists and to the undergraduate students in these disciplines as well as to those practioners who would like to understand what is going in the patient’s body during operation.

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Acronyms

AFP	Antifreeze protein
AFGP	Antifreeze glycoprotein
AI	Artificial insemination
ALE	Arbitrary Lagrangian Eulerian
ART	Assisted reproduction technique
ATP	Adenosine triphosphate
CCR	Critical cooling rate
CRR	Cooperatively rearranging regions
CP	Cryopreservation
CPA	Cryoprotective agent
CPMD	Car-Parinello ab initio molecular dynamics method
CPU	Central processing unit
DMA	Dymethylacetamide
DNA	Deoxyribonucleic acid
DSC	Differential scanning calorimetry
DMSO	Dimethylsulfoxide
EFS	Mixture of ethylene glycol, Ficoll, and sucrose
EG	Ethylene glycol
FDM	Finite difference method
FEM	Finite elements method
GTPC	Green tea polyphenolic compounds
HIFU	High intensity focused ultrasound
II	Intracellular ice
IIF	Intracellular ice formation
INA	Ice nucleating agent
IRE	Irreversible electroporation
ISF	Interrupted slow freezing
IVF	In vitro fertilization
IVM	In vitro maturation
HB	Hydrogen bond
HDA	High-density amorphous ice

XIV Acronyms

HSP	Heat shock protein
HU	Hounsfield unit
LDA	Low-density amorphous ice
MD	Molecular dynamics
MC	Monte Carlo
MM	Molecular mechanics
MPI	Message passing interface
MUCA	Multicanonical algorithm
NMR	Nuclear magnetic resonance
ODE	Ordinary differential equations
OHP	Oscillating motion heat pipe
OZ	Ornstein-Zernike
PES	Potential energy surface
PVP	Polyvinylpyrrolidone
PEG	Polyethylene glycol
QM/MM (QM/MD)	Hybrid quantum mechanics–classical MM(MD) method
RBC	Red blood cell
RDF	Radial distribution function
RF	Radio frequency
RNA	Ribonucleic acid
ROI	Region of interest
ROS	Reactive oxygen species
SAS	Solvent accessible surface
SAW	Self-avoiding walk
SCP	Supercooling point
THA	Thermal hysteresis activity
TEBV	Tissue engineered blood vessel
SWCN	Single-wall carbon nanotube
VHDA	Very-high-density amorphous ice
UTS	Ultra thin straw