THERMODYNAMICS FOR ENGINEERS

SI VERSION

JESSE S. DOOLITTLE

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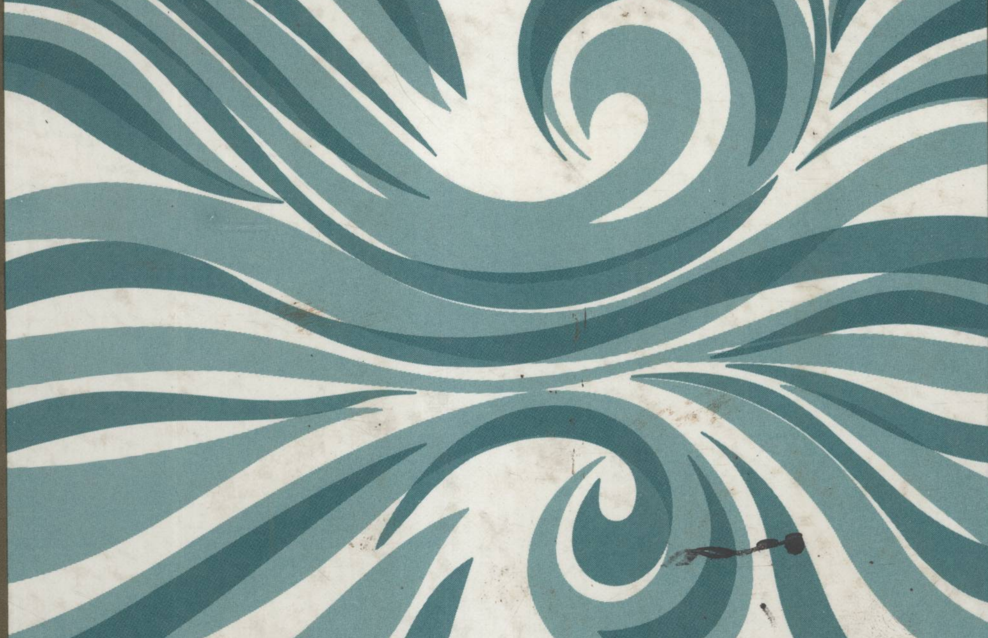

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THERMODYNAMICS FOR ENGINEERS

PREFACE

The scope of engineering thermodynamics is very broad. No one textbook can meet the needs of all undergraduate students in this field. As a general approach, we believe that all engineering students should gain an understanding of energy and energy transformations as formulated in the first and second laws of thermodynamics.

We present the first and second laws first from the macroscopic or classical viewpoint. This approach enables the students to relate these concepts to ideas with which they are familiar. In the discussion of these laws the necessary material is introduced relative to the properties and the behavior of matter. Particular consideration is given to gases and vapors, whenever matter is involved in energy transfers and transformations.

We believe that this approach will enable engineering students in one semester to gain a basic understanding of the subject and to recognize its importance. A very meaningful one-semester course can be devised by studying Chapters 1 through 6 and Chapters 9 and 10. Time permitting, Chapters 13 and 14 may be added.

For those students taking a two-semester course, it may be desirable to include Chapters 7 and 8 in the first semester work. For second semester students, applications of basic thermodynamic principles are directed to engineering areas such as chemical thermodynamics, thermodynamics of fluid flow, gas and vapor cycles, refrigerating cycles, and air conditioning. Because we believe that kinetic theory, microscopic thermodynamics, and statistical thermodynamics are essential for students to gain a deeper understanding of the subject, we present the fundamental aspects of these topics.

In addition to conventional power-producing devices, an ever-growing emphasis is being placed on direct energy conversion, particularly photovoltaic cells, magnetohydrodynamics, and fuel cells. The thermodynamics of direct-energy conversion is discussed on an elementary basis for the benefit of those students who do not wish to take elective courses in the subject, or who do not plan to go on to graduate school.

The last Chapter deals with the elementary concepts of heat transfer. It is made available here for the benefit of those students who do not intend to take a separate course in the subject. Furthermore, since so much of thermodynamics is concerned with heat transfers to and from systems, it is helpful to understand the basic principles of this process.

Many problems are given at the end of each chapter. In general, they are designed to teach students to use fundamental concepts in solving engineering problems as well as to illustrate fundamental principles. Many of the problems have been devised to show the effects of changes in various parameters on the performance of engineering devices. For example, the answers to various problems in the vapor cycles chapter show the precise effect of initial conditions, exhaust pressure, reheating, and feedwater heating on the efficiency of steam cycles. Because many instructors believe that students should not be given answers to problems ahead of time, no answers are given in the text. However, if some instructors wish to give answers to their students, they can find answers in the solution manual that will be available to them.

Recognizing the trend toward the use of the International System of Units (SI), we use these units throughout the book. Although changes are being made, the dimensions of much industrial equipment are still given in inches or feet. For example, common pipes are manufactured to specified dimensions (both the nominal and actual diameters) in inches. In Appendix 15, the nominal diameter is given in inches. The equivalent diameter and also all other dimensions are given in centimetres.

We express our appreciation to Linda Jackson for her excellent help in the preparation of the manuscript.

Jesse S. Doolittle
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SYMBOLS AND ABBREVIATIONS

SYMBOL	MEANING
A	Area
A	Ampere
A	Helmholtz function
a	Specific Helmholtz function
a	Absorptivity
a	Acceleration
a	Acoustic velocity
B	Magnetic field strength
C	Constant (general)
c	Specific heat
c_v	Specific heat for a constant-volume process
c_p	Specific heat for a constant-pressure process
c_x	Specific heat for a polytropic process
cm	Centimetre
C.O.P.	Coefficient of performance
$(\text{C.O.P.})_r$	Coefficient of performance for refrigeration
$(\text{C.O.P.})_{\text{h.p.}}$	Coefficient of performance for a heat pump
Chem. E.	Chemical energy
D	Diameter
E	Voltage
E	Emissive power
eV	Electron volt
F	Force
F_A	Shape factor
F_e	Emissivity factor
f	Fugacity
f	Saturated liquid (as a subscript)
fg	Change in properties during phase change (as a subscript)

SYMBOL	MEANING
ft	Foot
G	Mass rate of flow per unit area
G	Gibbs function (free energy) = $H - TS$
g	Specific Gibbs function
g	Gram
g	Acceleration due to gravity
g	Saturated vapor (as a subscript)
g_i	Possible number of quantum states
Gr	Grashof number
H	Enthalpy
h	Specific enthalpy
h	Hour
h	Planck constant
h	Surface or film heat-transfer coefficient
h_c	Convective surface or film heat-transfer coefficient
h_r	Radiant surface or film heat-transfer coefficient
I	Moment of inertia
I	Electric current
I	Intensity of radiation
J	Current density
J	Joule
J	Quantum number
J_s	Entropy current
K	Kelvin
K	Combined thermal conductivity
K_p	Chemical equilibrium constant
K.E.	Kinetic energy
k	Boltzmann constant (gas constant per molecule)
k	Specific heat ratio ($= c_p/c_v$)
k	Thermal conductivity
kg	Kilogram
kg mole	Kilogram mole
kW	Kilowatt
lb-mole	Pound mole
l	Distance
ln	Natural logarithm
log	Common logarithm

SYMBOL	MEANING
LMTD	Log mean temperature difference
M	Mach number
m	Mass
m	Metre
mm	Millimetre
$\dot{m}$	Mass rate of flow
$\bar{m}$	Mass per mole
MW	Megawatt
N	Newton
N	Number of moles
N	Number of cells
$\bar{N}$	Cycles per minute
n	Number of molecules
n	Polytropic process exponent
n_0	Number of molecules per mole
$\bar{n}$	Quantum number
Nu	Nusselt number
0	As a superscript refers to stagnation
P	Power
P.E.	Potential energy
Pa	Pascal
Pe	Peclet number
Pr	Prandtl number
p	Pressure
Q	Heat
$\dot{Q}$	Heat flow rate
Q	Heating value
Q_{comb}	Heat of combustion
q	Charge per electron
R	Rankine
R	Specific gas constant
R_0	Gas constant per mole
R	Electric resistance
Re	Reynolds number
r	Distance between magnetic poles
r	Compression ratio
r	Radius

SYMBOL	MEANING
r_t	Combined electrical resistance
r	Rotational (as a subscript)
S	Entropy
s	Specific entropy
s	Second
T	Absolute temperature
$\bar{T}$	Torque
t	Degrees Celsius or Fahrenheit
$\bar{t}$	Time
t	Translational (as a subscript)
U	Internal energy
U	Overall coefficient of heat transfer
U_k	Internal molecular kinetic energy
U_p	Molecular potential energy
u	Specific internal energy
V	Volume
V	Volts
v	Specific volume
v	Vibratory (as a subscript)
v	Vapor (as a subscript)
W	Work
W_m	Mechanical work
W_e	Electrical work
$\dot{W}$	Rate of doing work
W'	Possible number of macroscopic states
W	Watt
$\bar{W}$	Weight
w	Specific weight
X or x	Unknown (general)
x	Quality, mass fraction of vapor in a two-phase mixture
x	Thickness
y	Moisture content, mass fraction of liquid in a two-phase mixture
Z	Compressibility factor
Z	Figure of merit
Z	Quantum partition function
z	Height
β	Coefficient of volume expansion

SYMBOL	MEANING
ϵ	Emissivity
ϵ	Energy level
η	Efficiency
η_m	Mechanical efficiency
η_n	Nozzle efficiency
η_t	Thermal efficiency
λ	Wavelength
ν	Kinematic viscosity
ν	Frequency
μ	Viscosity (absolute)
μ	Joule–Thomson coefficient
Ω	ohm
ρ	Density
ρ	Reflectivity
$\mathcal{V}$	Velocity
$\bar{\mathcal{V}}_{\mathrm{rms}}$	Root mean square velocity
τ	Transmissivity
τ	Thomson coefficient, thermoelectricity
$\propto$	Seebeck coefficient, thermoelectricity
π	Peltier coefficient, thermoelectricity
ϕ	Work function, thermionic generation
$\mathcal{P}$	Possible number of microscopic states
ϕ	Relative humidity
ω	Specific humidity
σ	Symmetry number (molecular)
σ	Internal electric conductivity
Π	Product of

CONTENTS