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MANUAL OF METEOROLOGY

MANUAL OF METEOROLOGY

VOLUME III

THE PHYSICAL PROCESSES OF WEATHER

BY

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To

SIR J. J. THOMSON, O.M.

Master of Trinity

SIR RICHARD T. GLAZEBROOK, K.C.B.

Fellow of Trinity

These recollections, reflexions and refractions of the youthfulness of the Cavendish Laboratory are affectionately inscribed

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PREFACE

THE Preface to Part IV which introduced this Manual to the reader in 1919 contemplated as a preliminary a historical introduction and a statement of the general meteorological problem at the present day, to be followed by Part I "a general survey of the globe and its atmosphere," Part II "the physical properties of air," and Part III the setting out of "the dynamical and thermal principles upon which theoretical meteorology depends and which find their application in Part IV." It was further contemplated that Parts II and III might be included in a single volume.

The historical introduction claims its place as Vol. I, and the general survey of the globe and its atmosphere as Vol. II.

The endeavour to represent the debt which meteorology owes to the achievements of experimental physics has resulted in an alteration of the plan. The thermal principles operative in the atmosphere were found to be an essential part of the study of the physical properties of air. And the mode of treatment led automatically to the consideration—and then to the reconsideration—of the customary meteorological methods of dealing with the reaction of the atmosphere to the thermal treatment which it receives in the natural course.

The reconsideration opened out upon some suggestions for the use of entropy as a meteorological element in various ways that invited exploration. In particular it has been found possible to regard an *isentropic surface* as a practical alternative for sea-level or some other *horizontal surface* on which to place the facts about weather. Only the beginnings of the exploration have been made and it is hoped to enlist the reader's assistance in its prosecution.

To break off that exploration in order to include the recital of the achievements of Newtonian dynamics in the domain of meteorology would be a change of key-note more suitable for another volume, to include what has already been printed in Part IV, than another chapter which would leave Part IV as a detached appendix. The new volume is the more natural since the original Part IV is already out of print.

So the portion which was to be the physical properties of air appears as a separate volume, III, with the more descriptive title *The Physical Processes of Weather*, and the statement of the dynamical principles on which theoretical meteorology depends is postponed to form, with Part IV, a prospective Volume IV with the title *Meteorological Calculus, Pressure and Wind*.

Apart from obligations noted on page 9 to authors and collaborators for help in the substance of the work and the mode of its arrangement a number of acknowledgments are here gratefully recorded:

to the Meteorological Office, Air Ministry, for the continued assistance of Miss Elaine Austin, and for access to many original documents and publications;

to H.M. Stationery Office for permission to reproduce Fig. 26 from the *Meteorological Magazine*, and Fig. 32 from the *Marine Observer*, and a number of extracts from the publications of the Meteorological Office: the source of each is duly noted in the text;

to the Royal Society for permission to reproduce illustrations and text of Professor C. T. R. Wilson, Dr G. C. Simpson and Dr G. M. B. Dobson; to the Royal Meteorological Society for the loan of the block of Fig. 120, and of the original photographs for Fig. 123; to Macmillan and Co. Ltd., for permission to reproduce from *Nature* Fig. 30, and numerous extracts from the *Dictionary of Applied Physics* and other sources which are noted in the text; to Longmans, Green and Co. Ltd., for the extracts from Maxwell's *Heat*, from Campbell's *History of the Cavendish Laboratory*, and from John Tyndall's works; and to Mrs Tyndall for her concurrence and for suggestions in connexion therewith; to the author and publishers of McAdie's *Principles of Aerography*, for permission to quote the extract on Ice-storms, peculiarly applicable to the navigation of airships; to E. Stanford and Co. Ltd., for the outline of the map on Mollweide's projection for Chapter X;

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NAPIER SHAW

31 *October* 1929

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SYMBOLS

Unalterable constants: $\pi = 3{\cdot}14159$, $e = 2{\cdot}71828$, $\log_{10} e = 0{\cdot}43429$, $\log_e 10 = 2{\cdot}30258$.

For the best of reasons efforts have been made to systematise and arrange a notation for the symbols which are required for the multitude of quantities employed in the analysis of physical processes and the mathematical operations which those quantities may have to undergo. The efforts which we have in mind at the moment are those of the International Commission on the Unification of Physico-Chemical Symbols extended by a special committee of the Physical Society of London[1], McAdie's list of symbols to secure uniformity in aerographic notation[2], and the array of symbols employed by L. F. Richardson[3].

H. Jeffreys has called attention to diversity of practice with reference to latitude and longitude[4].

The material available for a system of symbols consists of the 26 letters of the Latin alphabet, 24 letters of the Greek alphabet with some traditional mathematical signs[5].

The Gothic alphabet is also available but is little used in manuscript, still less in typescript. Some additional symbols from other alphabets are used by Richardson.

We may remind the reader that one phase of the problem which this list of symbols suggests has been solved for meteorological observations on the analogy of the traditional mathematical signs, by international agreement upon a list of symbols for weather, international hieroglyphics, specially devised for recognisable writing as set out in chapter II of volume I. We have tried to make use of the idea in the symbols for distinguishing the energy of long-wave radiation from that of short-wave radiation on p. 164 and the representation of radiation by opposing arrows on p. 200.

The 26 letters of the Latin alphabet, judiciously used, can supply 104 symbols, capitals and small letters, roman and italic; and the Greek alphabet 35 symbols, thirteen of the upper case letters are identical with the Latin capitals.

Besides the author, who writes or types, there is also the printer to be considered. He has traditions for his guide in the selection of type as between uncial and cursive, roman and italic. A writer often leaves the printer to his discretion and draws no distinction himself between u.c. and l.c., rom. or ital. Some understanding is accordingly required.

So far as our observation goes many writers on physical subjects draw no appreciation of difference between the six classes of type; but, with care, one can detect an inclination for the use of:

(i) lower case italic letters for algebraical variables such as x, y, z, t or for unknown constants, a, b, c;

(ii) lower case or upper case roman for numerical constants of known value, h, c.

These two almost imply

(iii) lower case, or upper case, roman for symbols of algebraical operation;

(iv) lower case or upper case roman to denote the units in which a quantity is expressed numerically; one of the two should suffice, namely lower case g, m, h.

[1] *Physical Society Proceedings*, vol. XXVI, 1913–14, p. 381; vol. XXVII, 1914–15, p. 305.
[2] *Annals of the Astronomical Observatory of Harvard College*, vol. LXXXIII, pt. 4, Cambridge, Mass., 1920, p. 169.
[3] *Weather Prediction by Numerical Process*, Camb. Univ. Press, 1922, pp. 224–7.
[4] *Q. J. Roy. Meteor. Soc.* vol. XLVIII, 1922, p. 30.
[5] 'Mathematical notation through the centuries,' T.L.H., *Nature*, vol. CXXIV, 1929, p. 4.

The resolutions of the Committee of the Physical Society include:

TYPOGRAPHICAL

Capitals and small letters. For electrical quantities varying harmonically, capitals should stand for the amplitude and small letters for the value at any instant.

Greek letters. Where possible, Greek letters should be used for angles and for specific quantities.

Subscripts. The use of subscripts for components of vectors should be discouraged. As a general rule subscripts should be avoided.

Abbreviations for names of units. Ordinary type should be used for the symbols of units, and not clarendon.

In agreement with the recommendations of the International Electrotechnical Commission, the International Commission on the Unification of Physico-Chemical Symbols, and other bodies, the Committee recommend:

That italic, not roman, letters be used as symbols for the magnitudes of quantities in all branches of physics. This applies to capitals as well as to lower-case letters.

To these four let us add:

(v) A symbol should be regarded by the printer as a symbol and not the abbreviation of a word. It does not require to be followed by a ., but may have its comma like an ordinary substantive when there is a succession.

(vi) There seems no good reason why a double letter or a syllable should not be employed instead of borrowing a symbol already in use, especially is this the case with regard to (iv). There seems no reason for example why mic should not be used to indicate micron instead of employing the much used symbol μ, just as sec is used for a second of time.

We have found the use of *tt* and *bb* quite convenient; we have contemplated saving symbols by using *ii* for angle of incidence, *rr* for angle of refraction, and *nn* for index of refraction.

(vii) Traces of system are apparent in the notation for fluxions $\dot{x}$, $\ddot{x}$, and for such related quantities as for a mean value and the departures therefrom $\bar{x}$, x', or for the original position of a particle affected by a wave and its displacement from that position x, ξ.

(viii) Accents (except those used to denote minutes and seconds of angle) and suffixes are at the discretion of the writer and printer.

In the symbolism of this book we have endeavoured (not always successfully) to keep these eight guiding principles in mind.

In order not to interrupt a train of thought it is natural for a writer on any occasion to use the first symbol that the point of his pen happens to form, guided by some reminiscence of previous habit or by the subconsciousness that a new idea should not claim a new symbol until it has established its respectability. Needless to say, a reader who is concerned with a writer's single paragraph views the matter from a different point of view; much loss of time (among other things) is involved in the uncertainty as to what a writer might actually mean by symbols of dual or triple significance. Knowledge of the practice of others is a step towards organisation. We have accordingly tabulated the usage that is to be found either in this volume or other volumes bearing on the same subjects and present the result here. The list is by no means complete but it may be helpful as indicating the symbols that a "compleat" meteorologist may meet with in the course of his reading.

Authority for the quotation of the meaning of the several symbols is indicated as follows:

(0) this Manual; (1) other meteorological books; (1*) McAdie or Richardson; (2) ancient physics including thermodynamics and optics; (2*) recommendations

of the Committee of the Physical Society; (3) modern physics, electricity, radiation, electron theory; (4) astronomy; (5) dynamics and hydrodynamics; (6) statistics and algebra; (7) aeronautics.

The abbreviation *var* means that the symbol is found as a *variable* in an algebraical equation.

TABLE OF SYMBOLS USED IN THIS VOLUME

Arranged according to the alphabets employed, namely: upper case roman, lower case roman, upper case italic, lower case italic, greek uncial, and greek minuscule.

UPPER CASE ROMAN

A Absorption band (2); absolute temperature (1); Ångström unit (*passim*); heat-equivalent of work (1*); ampere (2*).

Å Ångström (1*).

B Absorption band (2); constant of integration in expressions for intrinsic energy and total heat of vapour (2); magnetic induction (2*).

C Constant (1*); electric capacity (2*); coulomb (2*).

D Total differential.

E East (*passim*); energy (1*); voltage (2*).

F Magnetic flux (2*); farad (2*).

G Gramme in C.G.S.; conductance (2*).

H Height of homogeneous atmosphere (0); magnetic force (2*); henry (2*).

I Electric current (2*); intensity of magnetisation (2*).

J Mechanical equivalent of heat (2); joule (2*).

K Turbulence transmission of heat and motion (1*); electric capacity (2*).

L Latent heat (0, 2); self-inductance (2*); west longitude (4).

M Magnetic moment (2*); mutual inductance (2*).

N North (*passim*); number of atoms or molecules (2); Avogadro's constant (1*).

O Radius of earth (0).

P Electric polarisation (2*); power (2*).

Q Heat-energy (1*); electric charge (2*).

R Gas-constant (0, 1*); electric resistance (2*).

S South (*passim*); second in C.G.S.; entropy (1*).

T Temperature, absolute or tercentesimal (0, 2) (with suffix to denote the scale 1*); period (2*).

U Velocity of sound (2); internal energy (1*).

V Speed of waves (0); voltage (2*); volt (2*).

W West (*passim*); energy and work, see w (2*); watt (2*); external work (1*).

X Absorption band (2); cross-section of pipe or nozzle (2); reactance (2*).

Y Absorption band (2).

Z Absorption band (2); impedance (2*).

LOWER CASE ROMAN

a Temperature absolute (0, 1); absorption band (0, 2); acceleration (1*).
b Beaufort letter (0, 1); linear distance, constant (0); bar or unit of pressure (1*).
c Specific heat (0, 1, 2); velocity of light (3); Beaufort letter (0, 1); any coefficient (1*).
d Symbol of differentiation (0); Beaufort letter (0, 1).
e Base of logarithms (0, 1*); Beaufort letter (0, 1).
e_l Electron (1*).
f Beaufort letter (0, 1); force (1*).
f_c Centrifugal force (1*); f_r deflective force of earth's rotation (1*).
g Gramme (0); Beaufort letter (0, 1); acceleration of a falling body (1*).
g_o Gravity at lat. 45° and sea-level (1*).
g_v Gravity-potential (1*).
g_a Gal or unit of acceleration (1*); $g_{a\mu}$ milligal (1*).
h Hour (0, 1, 2*, 4); Beaufort letter (0, 1); Planck's element of action (1*).
i Impulse or momentum (1*).
j Joule (0, 2); work or kinetic energy (1*).
k Kilometre (1); kilograd (1*).
km Kilometre (0).
kb Kilobar (1*); kb_v pressure of water-vapour (1*).
l Length-unit in dimensional equation (0); linear distance, constant (0); Beaufort letter (0, 1); length (1*).
m Metre (1*, *passim*); Beaufort letter (0, 1); mass-unit in dimensional equation.
m Preferably min, minute (*passim*).
m_s Mass (1*); m.w molecular weight (1*).
mm Millimetre (1*, *passim*).
mb Millibar (0, 1, 1*).
mgb Megabar (1*).
n Number of occurrences (0); frequency of waves (0).
n_o Number of gas-molecules per cc at 1000 kb and 1000 T_k (1*).
o Beaufort letter (0, 1).
p Beaufort letter (0, 1); pressure (1*).
q Beaufort letter (0, 1); power (1*).
r Beaufort letter (0, 1); radius (1*).
r_c Radius of curvature of isobar in km (1*); r_{eq} earth's radius at equator (1*).
s Second (*passim*), on some occasions preferably sec (0, 1); Beaufort letter (0, 1); space (1*).
fs Daily total of radiation (0).
t Temperature, constant (0); time-unit in dimensional equations (2); time (1*); Beaufort letter (0, 1).
t_p Period of complete oscillation (1*).
tt Temperature tercentesimal, constant (0).
u Beaufort letter (0, 1); inertia (1*).
v Beaufort letter (0, 1); volume (1*).
v_l Velocity (1*).
v_s Viscosity (1*).
w Beaufort letter (0, 1); weight (1*).
x Beaufort letter (0, 1); co-ordinate, *var* (1*).
y Beaufort letter (0, 1); co-ordinate, *var* (1*).
z Beaufort letter (0, 1); co-ordinate, *var* (1*).

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UPPER CASE ITALIC

A Amplitude in a Fourier series (0, 6); azimuth angle (0); area (0); temperature absolute (1); reciprocal of mechanical equivalent of thermal unit (2*).

B Beaufort number, *var* (0); amplitude in a Fourier series (0, 6); barometric pressure (1).

C Cooling effect of Joule and Thomson (2*).

D Saturation density of water-vapour (0); angle of deviation of a ray of light (0); infinitesimal increase accompanying the motion, of...(1*); dynamic depth (1); density of medium (2).

E Entropy, *var* (0); angle of elevation (0); saturation vapour-pressure (0); earth's radius (0, 1); electric charge (0); total radiation (1); radiant activity in a "parcel" (1*); subscript for eastwards (1*); intrinsic energy (2*).

F Surface-friction (1); electric force (0); pressure in lbs/ft² (0); various functions (1*).

G Velocity of geostrophic wind (0); subscript for ground-level (1*); pressure-gradient (1); thermodynamic potential $T\phi - H$ or $H - T\phi$ (2*).

H Height, *var* (0); height of homogeneous atmosphere (0, 1); relative humidity, *var* (0); quantity of heat, *var* (0, 2); subscript for upwards (1*); dynamic height (1); total heat $E + PV$ of vapour (2*).

I Intensity of radiation (0); brightness (1*).

J Intensity of radiation (0); mechanical equivalent of thermal unit in gravitational units (e.g. foot-pounds) (2*).

K Coefficient (2); thermal conductivity (2*).

L Free lift of pilot-balloon (0, 1); length-unit in dimensional equations (2); subscript for upper surface of vegetation (1*); latent heat of vaporisation (0, 1, 2, 2*, see L).

M Mass (0); mass-unit in dimensional equations (2); momentum per area of stratum (1*); mass or molecular weight (2*).

N Energy, *var* (0); number of observations (0, 6); subscript for northwards (1*).

$N\sim$ Long-wave radiation (0).

N_ω Short-wave radiation (0).

O

P Pressure in millibars (0); pressure (2*); $\int p\,dh$ across stratum (1*).

Q Quantity of heat (0, 2*); electric charge (0, 1); horizontal temperature-gradient (0); total radiation (1); liquid water per area of stratum (1*).

R Radius (0); mass per area of stratum (1*); gas-constant (1*, 2*, *passim*, see R).

S Horizontal pressure-gradient (0); long-wave radiation from the sky (1); entropy per area of stratum (1*); ratio of hours of sunshine to the maximum possible (1); specific heat of vapour at constant pressure (2*).

T Temperature (0, 1, 2); temperature reckoned from absolute zero (2*); potential temperature and megatemperature (0); volume of the disturbing particle (2); time-unit in dimensional equations (2); time (1*).

U Velocity-component (5); velocity of translation (0); velocity (2*).

V Velocity-component (5); velocity (0); vapour-pressure (1); difference of potential (0); specific volume of vapour (2*).

W Weight of balloon (0); surface-wind (0, 1); water-substance per area of stratum (1*); work (2*).

X Force (0, 5); radius of curvature (0); any variable (0).

X, *Y* Subscripts indicating horizontal rectangular components (1*).

Y Force (5).

Z Force (5); vertical velocity of balloon (0); in theory of stirring (1*).

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LOWER CASE ITALIC

a A constant or coefficient (0, 6); amplitude in a Fourier series (0, 6); specific weight of air at any point at any moment (7); radius of the earth (1*); constant in van der Waals' formula $(V-b)(P-a/V^2)=RT$ (2*); specific gravity of water-vapour referred to dry air (0).

b A constant (0, 6); gas-constant (1*); co-volume in van der Waals' equation (2*); decay-coefficient (2*).

bb Pressure-gradient, *var* (Buys Ballot) (0).

c Constant (0, 6); eddy-viscosity (1*); co-aggregation volume equals a/RT in approximate formula $V=RT/P+b-c$ (2*).

c Preferably c, specific heats of air (0, 1, 2); velocity of light (3, 4).

d Deviation, *var* (0, 6); partial pressure of dry air (0); density of water-vapour (0); density of gaseous air (0); vertical distance (1).

d Preferably d, symbol of differentiation (1*, *passim*).

e Pressure of water-vapour, *var* (0, 1); voltage (2*); charge on an electron (3); base of logarithms (1*, 2*, *passim*, see e).

∂e Distance eastwards (1*).

f Relative humidity (0); pressure of wind, *var* (0); internal friction (2); pressure of saturated vapour (1); frequency (2*); various functions (1*).

g Acceleration of gravity (1*, 2*, *passim*).

g Preferably g, gramme (1, 2).

h Height or thickness, *var* (0, 1); quantity of heat, *var* (0, 2); height above mean sea-level (1*); total heat of liquid (2*).

h Preferably h, Planck's constant (3).

i $\sqrt{-1}$ (*passim*); angle of incidence (0, 2); subscript for arbitrary height (1*); electric current (2*).

j Angle of refraction (0); special co-ordinate in soil (1*).

k A constant or coefficient (0, 2); an angle in optics (0); thermal conductivity (1*); thermal diffusivity (2*, see *K*); kilo (2*).

l Length, distance (1*); self-inductance (2*).

l Preferably l, symbol of length in dimensional equation.

l, m, n Direction cosines (4, 5, 6).

m Mass, *var* (0); mass of an electron (3); integral number (0, 6); momentum per volume (1*); index (2*); mass of water-vapour in unit mass of moist air (1); magnetic pole (2*); mutual inductance (2*); milli- (2*).

m Preferably m, symbol of mass in dimensional equation.

$m\mu$ Millimicro- (2*).

n Integral number (1*, *passim*); index (2*); volume in gas-equation (2); frequency (2*); ratio of specific heats (2*).

∂n Distance northwards (1*).

o

p Pressure, *var* (0, 1, 1*, 2), in kg/m² (7); vapour-pressure of liquid or saturation pressure (2*); pico 10^{-12} (2*).

q Vapour-pressure (0); horizontal temperature-gradient (0); electric charge (2*); "dryness fraction" or "quality" of mixture of liquid and vapour (2*).

q Preferably q, constant in pilot-balloon formula (0, 1).

r Radius-vector (1*, *passim*); elevation due to refraction (1); angle of refraction (2); correlation coefficient (0, 1, 1*, 6); relative humidity (1); resistance (2*).

s Density of water-vapour (0); horizontal pressure-gradient (0); diffusivity of soil for temperature (1*); specific heat of vapour at constant volume and specific heat of liquid or solid (2*); salinity of sea-water (1).

t Time, *var* (1*, *passim*); temperature, *var* in various units (0, 1, 2); temperature in °C (2*).

t Preferably t, symbol of time in dimensional equation.

tt Temperature tercentesimal, *var* (0).

u Velocity (2*); velocity-component in Cartesian and cylindrical co-ordinates, *var* (5); thermal capacity per volume (1*).

v Velocity-component in Cartesian co-ordinates, *var* (5); velocity (0, 1*); specific volume, *var* (0, 1, 2); vapour-pressure in mb (1); specific volume of liquid (2*); voltage (2*).

w Velocity-component in Cartesian co-ordinates, *var* (5); density of water (0); mass of water-substance per volume (1*); energy and work (2*).

x Horizontal co-ordinate, *var* (1*, *passim*); deviation of *X* from mean (0); water-vapour associated with unit mass of dry air (0, 1); reactance (2*).

y Horizontal co-ordinate, *var* (1*, *passim*); deviation of *Y* from mean (0).

z Vertical co-ordinate, *var* (*passim*); impedance (2*); depth in ground (1*).

GREEK UNCIAL

Γ Geopotential (0, 1); radiant energy absorbed at interface per area and per time (1*).

Δ Small increment (1*); standard density of dry air (0).

Θ Latitude (1); tercentesimal temperature (0); eddy-heat per mass (1*).

Λ

Ξ Mass of water evaporating from interface per horizontal area and per time (1*).

Π

Σ Sign of summation (1*, *passim*).

Υ, Φ Relate to vertical velocity in the stratosphere (1*).

Φ Entropy of vapour (2*); absorption band (2); magnetic flux (2*).

Χ Absorption band (2).

Ψ Absorption band (2); pressure in water in soil (1*).

Ω Absorption band (2); ohm (2*); $= 2\omega \sin \phi$ (1*); angular velocity (0).

GREEK MINUSCULE

α Angle (*passim*); right ascension (4); phase of maximum (0, 6); angle of deflexion of surface-wind from gradient (0, 1*); coefficient relating to entropy (1*); specific volume (1); coefficient of absorption (1).

β Lapse-rate of temperature (0); gradient of superposed field (0); angle due to frictional force (1*); coefficient relating to entropy (1*); coefficient of absorption (1); latitude (4).

γ Ratio of specific heats (0, 2, 2*); gradient (1*); temperature-gradient (1); electric conductivity (2*).

γ_p Pressure-gradient (1*); γ_{vl} velocity of gradient-wind (1*); γ_p, γ_v thermal capacities per mass (1*).

δ Declination (4); finite difference operator (1*, *passim*); ratio of two specific weights (7); a coefficient of absorption (1); logarithmic decrement (2*).

∂ Symbol of partial differentiation (*passim*).

ϵ Modulus of decay (0); a small correction (1); specific gravity of water-vapour (1); energy per mass (1*); change of translational molecular energy per 3·66 T_k (1*); factor depending on entropy (0).

ζ Vorticity (0); zenith distance (1*).

η Coefficient of viscosity (2); emissivity (1*); absorptance of stratum (1*); efficiency (2*).

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θ Polar co-ordinate, *var* (*passim*); co-latitude (5); zenith distance (4); temperature, *var* (1, 2); temperature absolute (1*); potential temperature, *var* (0, 1); coefficient of conduction of heat (1*); temperature reckoned from absolute zero or from freezing-point (2*).

θ_r Virtual temperature, *var* (1).

ι Eddy-conductivity in light winds (1*).

κ Coefficient of conductivity, eddy-diffusion, etc. (0, 1, 2); electric inductivity (2*); molecular diffusivity (1*); ratio of specific heats at constant pressure and constant volume (1*).

λ Wave-length (0, 2); latitude (1); longitude (0, 1*); longitude always eastwards (1*).

μ Micron (1*, *passim*); index of refraction (0, 2); coefficient of viscosity (2, 7); joint mass of vapour, water and ice per mass of atmosphere (1*); permeability (2*); micro- (2*).

$\mu\mu$ Millimicron (1*, *passim*); pico- 10^{-12} (2*).

ν Coefficient of viscosity (1); kinematic viscosity (7); frequency (2); mass of liquid water per mass of atmosphere (1*).

ξ Turbulivity (1*).

ξ, η, ζ Departures in co-ordinates of position (5).

o Eddy-viscosity (1*).

π Ratio of circumference of circle to diameter (*passim*).

ρ Density of air (0, 1, 1*, 2, 7); absorption band (2); resistivity (2*); density (1*, 2*).

σ Stefan's constant (0, 1, 1*, 3); surface-charge (0, 2, 3); absorption band (2); standard deviation (0, 6); specific heat of air (0); entropy per mass of atmosphere (1*).

τ Absorption band (2); period (0, 6); potential temperature (1*).

υ Internal energy per mass of atmosphere (1*).

ϕ Polar co-ordinate, *var* (*passim*); latitude (0, 1, 1*, 4); zenith distance (1); phase-angle (0, 6); entropy, *var* (0, 2); entropy of liquid (2*); gravity-potential (1); velocity-potential (1).

χ In theory of stirring (1*).

ψ Stream function (5); ratio of two pressures (7); gravity-potential (increasing upwards) (1*); longitude (1).

ω Absorption band (2); angular velocity of the earth's rotation (0, 1, 1*).

$\omega_1 = \frac{d\omega}{dt}$ Angular acceleration, *var* (1*).

LIST OF WORDS

used in special senses or not yet incorporated in the *New English Dictionary* that have been found convenient for the avoidance of misunderstanding or for the sake of brevity

For winds (Introduction to the *Barometer Manual for the Use of Seamen*)

Geostrophic wind: that part of the horizontal component computed from the barometric gradient which is dependent on the rotation of the earth.

Cyclostrophic wind: that part of the horizontal component computed from the barometric gradient which depends on the radius of the small circle representing the direction of motion of the air at the moment.

Anabatic wind (Greek for wind going upward): the motion of air on a slope exposed to the warming influence of the sun.

Katabatic wind (Greek for wind going downward): the downward motion of air independent of the barometric gradient on a slope which is cooled by terrestrial radiation or by snow or ice.

For rate of variation of meteorological elements with height

Lapse-rate (*Meteorological Glossary*): rate of loss with height—generally of temperature: in place of gradient which from its origin should mean the fall of temperature along a horizontal line, a quantity of some importance but not much used in practice.

Counterlapse (Vol. III): the reverse of lapse, the recovery of temperature with height, a substitute for the word inversion which is suggestive of something "the wrong way up" unless the words "of vertical temperature gradient" are included.

For the specification of the atmosphere

Millibar (V. Bjerknes): approximately one thousandth part of a "normal atmosphere," a multiple of the c,g,s unit in which all measures of pressure should be expressed in the course of unavoidable "correction," whether the instrument be graduated ostensibly in inches or millimetres, as part of the comity of the physical sciences.

Geodynamic metre (Upper Air Commission): a practical unit for the expression of geopotential representing the "lift-effort" or energy required to lift unit mass from one point to another in the earth's gravitational field.

For the main divisions of the atmosphere

Stratosphere (Teisserenc de Bort): the region of the atmosphere, beyond the troposphere, in which there is little change of temperature with height.

Troposphere (Teisserenc de Bort): the region of the atmosphere from the ground upwards within which there is notable change of temperature with height, sometimes positive sometimes negative, tending towards the limit of adiabatic change for gaseous air at the tropopause.

Tropopause (E. L. Hawke, *Meteorological Glossary*): the region which marks the upper limit of the troposphere and the lower limit of the stratosphere at which the lapse-rate of temperature shows a notable transition from a large positive value to one which is generally insignificant and sometimes reversed.

In place of certain uses of the word "temperature" (Vol. III)

Thermancy: to indicate the property of a body upon which the energy of its radiation depends, and which, in the case of a gas, is a numerical expression of the translational kinetic energy of the molecules contained in unit mass. Absolute temperature is the customary expression; but the word "temperature" is claimed by those who "understand it" only when it is expressed in degrees Fahrenheit or Centigrade.

The thermancy of a gas at the temperature of $n°$ C can be expressed with close approximation as $273 + n$, which brings it into easy relation with the tables of physical constants; otherwise the thermancy of air at the freezing-point of water might be set at 1000, and an universal measure of temperature deduced from it, as suggested by A. McAdie. In Vol. III the thermancy is expressed provisionally as "temperature on the tercentesimal scale."

For the study of the thermodynamics of the atmosphere.

Potential temperature (von Bezold): the figure obtained when the observed temperature is "reduced" by adiabatic process to a standard pressure.

Potential pressure (Vol. III): the figure obtained when the observed pressure is "reduced" by adiabatic process to a standard temperature.

Megatemperature (Upper Air Commission): the potential temperature obtained by "reducing" the observed temperature to "standard pressure" of 1000 mb.

Tephigram (Vol. I): the curve, with temperature and entropy as co-ordinates, which represents the condition of the environment traversed by a sounding-balloon, an aeroplane, kite or other means of recording pressure and temperature.

Depegram (Vol. II): the curve on the same diagram, the temperature at any point of which represents the dew-point corresponding with the same pressure on the tephigram.

Liability (Vol. III) of the environment, indicated at a point of the tephigram, expresses the amount of energy that might be developed by the action of the environment on unit mass of air at the point with the temperature and pressure of the environment and with a specified condition as to humidity.

Underworld (Vol. III): a portion of the earth's surface separated from the rest by intersection with an isentropic surface *rising* from its boundary.