

Appendix

TABLE A1. Temperature dependent properties of gases in air at 101 kPa.

<i>T</i> C	ρ mol m ⁻³	ν mm ² /s	D_H mm ² /s	D_v mm ² /s	D_c mm ² /s	D_o mm ² /s
0	44.6	13.3	18.9	21.2	13.9	17.7
5	43.8	13.7	19.5	21.9	14.3	18.3
10	43.0	14.2	20.1	22.6	14.8	18.8
15	42.3	14.6	20.8	23.3	15.3	19.4
20	41.6	15.1	21.4	24.0	15.7	20.0
25	40.9	15.5	22.0	24.7	16.2	20.6
30	40.2	16.0	22.7	25.4	16.7	21.2
35	39.5	16.4	23.3	26.2	17.2	21.9
40	38.9	16.9	24.0	26.9	17.7	22.5
45	38.3	17.4	24.7	27.7	18.2	23.1

Specific heat of air: $c_p = 29.3 \text{ J mol}^{-1} \text{ C}^{-1}$

Molecular mass of air: $M_a = 29 \text{ g/mol}$.

Molecular mass of water: $M_w = 18 \text{ g/mol}$.

TABLE A2. Properties of water

<i>T</i> C	ρ_w MG/m ³	λ kJ/mol	ν mm ² /s	D_H mm ² /s	D_o mm ² /s	D_v mm ² /s
0	0.99987	45.0	1.79	0.134		
4	1.00000	44.8	1.57	0.136		
10	0.99973	44.6	1.31	0.140		
20	0.99823	44.1	1.01	0.144	0.002	0.002
30	0.99568	43.7	0.80	0.148		
40	0.99225	43.4	0.66	0.151		
50	0.98807	42.8	0.56	0.154		

Specific heat of water $75.4 \text{ J mol}^{-1} \text{ C}^{-1}$

Latent heat of freezing 6.0 kJ mol^{-1}

Thermodynamic pycrometer constant at 20 C 0.000664 C^{-1}

TABLE A3. Temperature dependence of saturation vapor pressure, slope of the vapor pressure function, black body emittance, radiative conductance, and clear sky emissivity.

Temp K	Temp C	$e_s(T)$ kPa	Δ PaC ⁻¹	B W m ⁻²	g_r mol m ⁻² s ⁻¹	ϵ_α
268.2	-5	0.422	32	293	0.149	0.66
269.2	-4	0.455	34	298	0.151	0.67
270.2	-3	0.490	36	302	0.153	0.67
271.2	-2	0.528	39	307	0.154	0.68
272.2	-1	0.568	42	311	0.156	0.68
273.2	0	0.611	44	316	0.158	0.69
274.2	1	0.657	47	320	0.160	0.69
275.2	2	0.706	50	325	0.161	0.70
276.2	3	0.758	54	330	0.163	0.70
277.2	4	0.813	57	335	0.165	0.71
278.2	5	0.872	61	339	0.167	0.71
279.2	6	0.935	65	344	0.168	0.72
280.2	7	1.001	69	349	0.170	0.72
281.2	8	1.072	73	354	0.172	0.73
282.2	9	1.147	77	359	0.174	0.73
283.2	10	1.227	82	365	0.176	0.74
284.2	11	1.312	87	370	0.178	0.74
285.2	12	1.402	92	375	0.179	0.75
286.2	13	1.497	98	380	0.181	0.75
287.2	14	1.597	104	386	0.183	0.76
288.2	15	1.704	110	391	0.185	0.76
289.2	16	1.817	116	396	0.187	0.77
290.2	17	1.936	123	402	0.189	0.77
291.2	18	2.062	130	407	0.191	0.78
292.2	19	2.196	137	413	0.193	0.79
293.2	20	2.336	145	419	0.195	0.79
294.2	21	2.485	153	425	0.197	0.80
295.2	22	2.642	161	430	0.199	0.80
296.2	23	2.808	170	436	0.201	0.81
297.2	24	2.982	179	442	0.203	0.81
298.2	25	3.166	189	448	0.205	0.82
299.2	26	3.360	199	454	0.207	0.82
300.2	27	3.564	209	460	0.209	0.83
301.2	28	3.778	220	466	0.211	0.83
302.2	29	4.004	232	473	0.214	0.84
303.2	30	4.242	244	479	0.216	0.85
304.2	31	4.492	256	485	0.218	0.85
305.2	32	4.754	269	492	0.220	0.86
306.2	33	5.030	283	498	0.222	0.86
307.2	34	5.320	297	505	0.224	0.87
308.2	35	5.624	311	511	0.227	0.87
309.2	36	5.943	327	518	0.229	0.88
310.2	37	6.278	343	525	0.231	0.89

Continued on next page

TABLE A3. (continued)

Temp K	Temp C	$e_s(T)$ kPa	Δ Pa	B W m^{-2}	g_r $\text{mol m}^{-2} \text{s}^{-1}$	ε_α
311.2	38	6.629	359	532	0.233	0.89
312.2	39	6.996	376	538	0.235	0.90
313.2	40	7.382	394	545	0.238	0.90
314.2	41	7.785	413	552	0.240	0.91
315.2	42	8.208	432	559	0.242	0.91
316.2	43	8.650	452	567	0.245	0.92
317.2	44	9.113	473	574	0.247	0.93
318.2	45	9.597	495	581	0.249	0.93

TABLE A4. Conversion factors

Length	1 m = 100 cm = 1000 mm
Area	1 m ² = 10,000 cm ² = 10 ⁶ mm ²
Volume	1 m ³ = 10 ⁶ cm ³ = 10 ⁹ mm ³
Density	1 Mg/m ³ = 10 ³ kg/m ³ = 1 g/cm ³
Pressure	1 kPa = 10 mb
Heat	1 Joule = 0.2388 cal
Heat flux	1 Watt = 0.8598 kcal/hr
Heat flux density	1 W/m ² = 0.8598 kcal m ⁻² hr ⁻¹
	1 W/m ² = 1.433 × 10 ⁻³ cal cm ⁻² min ⁻¹
	1 W/m ² = 2.388 × 10 ⁻⁵ cal cm ⁻² s ⁻¹

TABLE A5. Physical constants

Speed of light in vacuum	2.997925 × 10 ⁸ m/s
Avagadro constant	6.02252 × 10 ²³ mol ⁻¹
Planck constant	6.6256 × 10 ⁻³⁴ Js
Gas constant	8.3143 J mol ⁻¹ C ⁻¹
Boltzmann constant	1.38054 × 10 ⁻²³ J C ⁻¹
Stefan-Boltzmann constant	5.6697 × 10 ⁻⁸ W m ⁻² C ⁻⁴

Index

Absorptivity
 definition, 152
 of animal coats, 177, 178
Albedo, *see* Reflectivity
Airmass number, 158
Air temperature
 averaging time for mean, 18
 fluctuations, 19
 profile, 16
Annual damping depth, 115
Atmospheric stability, 96, 97
Atmospheric temperature, 15, 16

B

Beer's law, *see* Bouguer's law
Body area
 general formula, 209
Body temperature of humans, 210
Bouguer's law, 157, 158
Buoyancy, 64, 96

C

Carbon dioxide, 37, 235
Climate space, 200–201
Comfort, 220, 221
Conduction
 definition, 3, 4
 of heat in animal coats, 194–197
Convection, 99–101
 combined forced and free, 105
 definition, 3, 4
Conversion factors, 281

D

Damping depth, 25, 115
Darwin, Charles, 212
Dew point temperature, 42
Diabatic influence function, 97
Diabatic profile correction, 96
Diffusion
 coefficients, 88
 molecular, 88–90
 in soil, 114
 through stomates, 90
Dimensionless groups, 100
DuBois formula, 209

E

Eddy correlation, 93
Eddy diffusivity, 94
Eddy size, 105
Eddy viscosity, 94
Einstein, Albert, 8
Emissivity
 definition, 152
 of natural surfaces, 163
Energy budget
 application, 200
 concept, 185, 186
Energy budget equation, 185, 200
 with sweating, 197, 198
Energy exchange, 3
Equivalent blackbody temperature, 198–200
Evapotranspiration, 225, 233, 234

Extinction coefficient, 158
of crop canopies, 249–252

F

Fetch, 94
Flick's diffusion law, 77, 87
First law of thermodynamics, 59
Flux equations for a turbulent atmosphere, 94
Flux measurement by eddy correlation, 93
Fourier's heat law, 77
Free convection, 93
Friction velocity, 68, 94

G

Gibbs free energy of water, 54
Grashof number, 100
Gravitational potential, *see* Water potential
Gross photosynthesis of crop, *see* also Photosynthesis

H

Heat flux equation, 79
Heat storage in animals, 186
Heat stress index, 216, 217
Heat waves, 19
Humidity, *see* Relative humidity
Humid microenvironments, 50
Hydraulic conductivity, 129

I

Ideal gas law, 38
Irradiance, 150

K, L

Kirchhoff's law, 154
Lambert's cosine law, 154
Latent heat
cutaneous, 199
respiratory, 190
transport, 4
of vaporization, 37
Leaf area index, 247, 248
Leaf temperature, 224–227

Long-wave radiation, *see*
Radiation, long-wave
Looping plume, 64

M

Mass Flux, equation for, 79
Mass transport, 4
Matric potential, *see* Water potential
Metabolic rate
active, 189, 190
of animals, 189, 190
basal, 189, 190
of humans, 210
of poikilotherms, 189
Microclimate, 3
Microenvironment, 3
temperatures, 15
Mie scattering, 161
Momentum transport, 4, 94

N

Net photosynthesis of crops, 223, 224
Newton's law of viscosity, 77
Nusselt number, 100

O

Ohm's law, 79
Operative temperature, 198, 199
Optimum leaf form, 244, 245
Osmotic potential, *see* Water potential

P

Penman equation, 225, 233, 234
Penman transformation, 219, 232
Photon, 147
Photon flux, 148
Photosynthesis, 235–238, 241, 242
in canopies, 259–263
Physical constants, 281
Plank's law, 159
Plank's photon energy equation, 147

- Prandtl number, 100
- Pressure potential, *see* Water potential
- Psychrometer constant, 44
equation, 44
- R**
- Radiant emittance, 150, 162, 163
of blackbody, 149, 162, 163
- Radiant flux, definition, 149
- Radiation
absorbed by animals, 160
attenuation of, 157, 158
blackbody, 159
budgets, 165
diffuse, 167
directional relations, 140
exchange, 4
frequency of, 147
long-wave atmospheric, 161
in nature, 150
in plant canopies, 248
spectral distribution, 159–162
- Rayleigh scattering, 161
- Reflectivity, 157, 172, 177
definition, 152
of soils and vegetation, 172
- Relative humidity, 42, 43
- Resistance
to convective heat transfer, 101, 105
to convective mass transfer, 101, 105
thermal, of animal coats and tissue, 186–188
- Reynolds number, 100
- Roughness parameters, 61, 68
- S**
- Schmidt number, 100
- Scintillation, 19
- Sensible heat flux, 5
- Short-wave radiation, *see* Radiation
- Soil
diurnal damping depth, 25, 115
heat flux equations, 113, 114
heat flux at surface, 115
heat storage, 113
temperature, 113–118
water potential, 129
- Solar declination, 168, 169
- Solar elevation angle, 168
- Solar radiation, *see* Radiation
- Speed of light, 281
- Stefan-Boltzman equation, 162
- Sunlit leaf area, 258, 259
- Survival
in cold, 211–213
in heat, 215–219
- Sweat rate, 216, 217
- T**
- Temperature
of air, 15–23
of exhaled air, 191
fluctuations, 18
of soil, 15, 23
- Temperature profile
equation, 20
diabatic correction, 96
- Thermal diffusivity, of soil, 114
- Thermal resistance
of clothing, 196
effect of wind on, 196
- Tierra del Fuego, 212
- Transient state, 201, 202
- Transmissivity, 152
- Transpiration, 231–234
- Transport
convective, 99–105
diffusive, 88–90
laws, 77, 78
radiative, 147–150
turbulent, 63–67, 93, 94
- Turbulence
characteristic, 69
kinetic energy of, 96
mechanical, 65
production of, 64
scales of, 64
thermal, 64
- Turbulent transport, *see* Transport, turbulent

U, V

Units, 9

Vapor density

 ambient or air, 47

 at saturation, 40, 41

 temperature dependence of,
 280, 281

Vapor diffusion, *see also*

 Resistance

Vapor flux, equation for, 81

Von Karman constant, 68

W

Water

 balance of animals, 204

 liquid phase, 58–60

 properties, 279

 vapor flux, 81

 vapor pressure, 40

Water potential

 of animal fluids, 55

 of blood, 57, 58, 60

 components, 55, 56

 of fungi, 58, 60

 in relation to gas phase, 58, 59

 of soil, 55, 129, 131

Wet bulb temperature, 42–44

Wien law, 160

Wind

 effect on coat resistance, 196

 fluctuations, 66

 vector components, 65

 within crop canopies, 72, 73

Wind profile, 67

 adiabatic correction, 96

Z

Zero plane displacement, 68