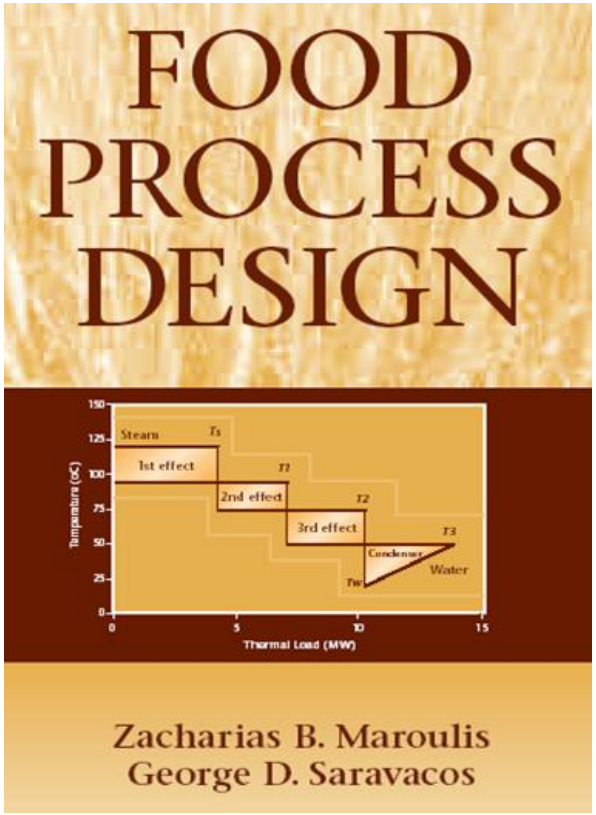
Θερμοφυσικές Ιδιότητες Νερό, Ατμός, Αέρας.

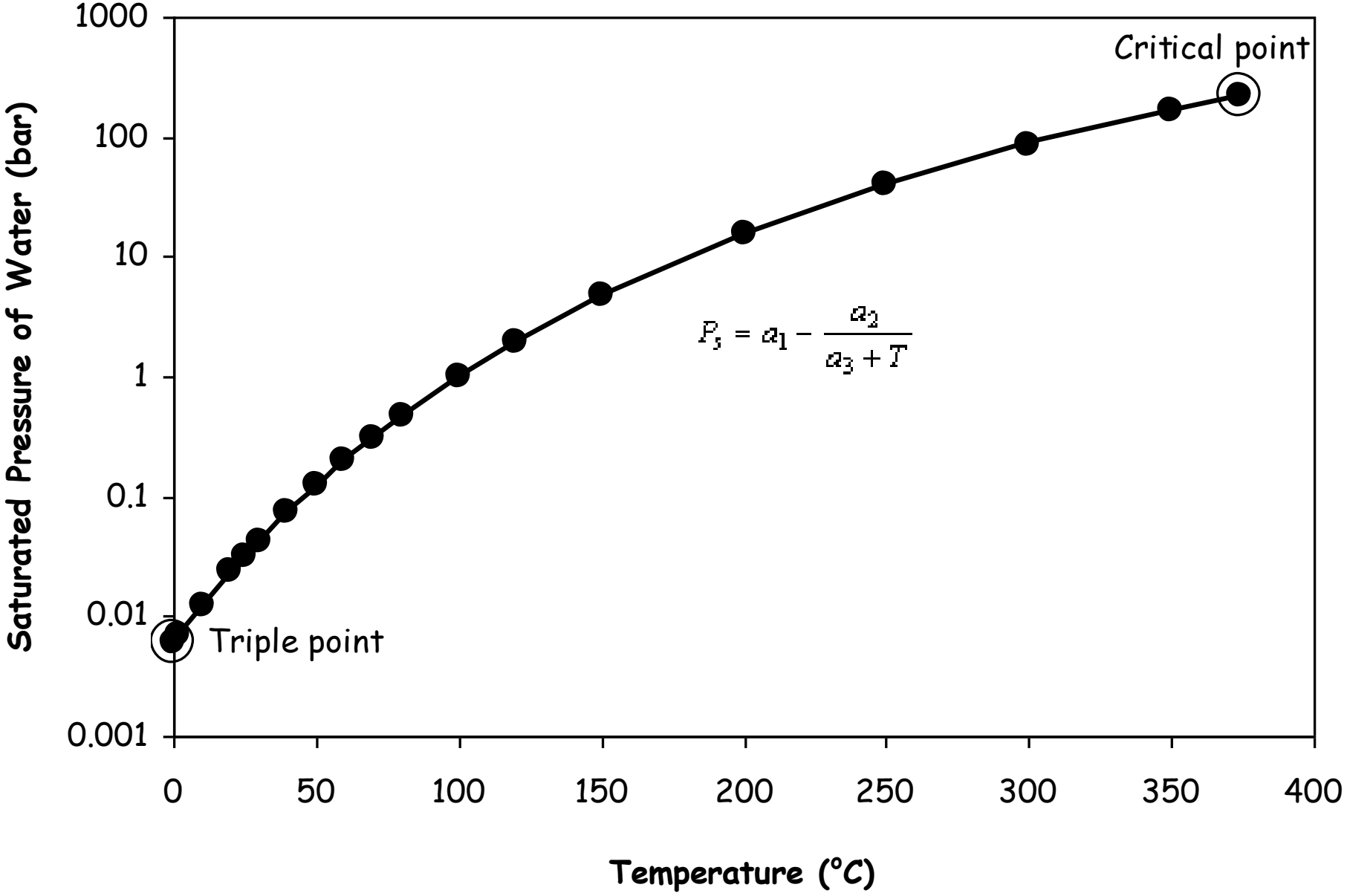


1. Saturated Pressure of Water

Table A.1 Saturated Pressure of Water

$$P_s = a_1 - \frac{a_2}{a_3 + T}$$ Antoine equation

P_s	bar	Saturated pressure of water
T	ºC	Temperature
$T_t < T < T_c$		Range of application
T_t	= 0.01 ºC	Triple point temperature
T_c	= 374.14 ºC	Critical temperature
a_1	= 1.19 10^1	Antoine constants
a_2	= 3.95 10^3	
a_3	= 2.32 10^2	


1000
100
10
1
0.1
0.01
0.001
Saturated Pressure of Water (bar)
Critical point
Triple point
$P_s = a_1 - \frac{a_2}{a_3 + T}$
0
50
100
150
200
250
300
350
400
Temperature (°C)

2. Latent Heat of Vaporization of Water

Table A.2 Latent Heat of Vaporization of Water

Equation 1

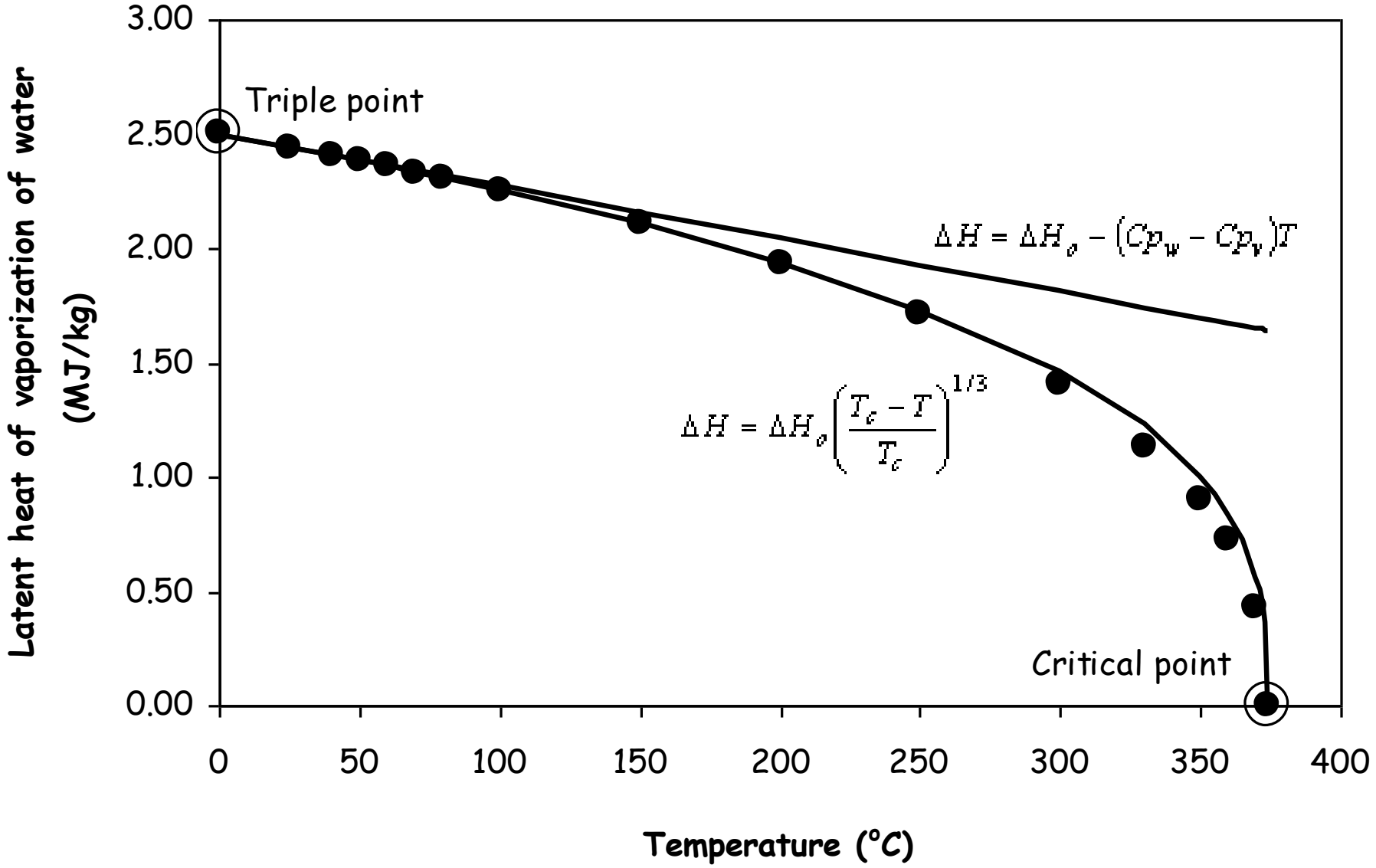
$$\Delta H = \Delta H_o - (Cp_w - Cp_v)T$$

0–150°C		Range of application
ΔH	MJ/kg	Latent heat of vaporization
T	°C	Temperature
ΔH_o	= 2.50 MJ/kg	Latent heat of vaporization at 0°C
Cp_w	= 4.20 kJ/kgK	Average specific heat of water
Cp_v	= 1.87 kJ/kgK	Average specific heat of water vapor

Equation 2

$$\Delta H = \Delta H_o \left(\frac{T_c - T}{T_c} \right)^{1/3}$$

$T_t < T < T_c$		Range of application
ΔH	MJ/kg	Latent heat of vaporization
T	°C	Temperature
ΔH_o	= 2.50 MJ/kg	Latent heat of vaporization at 0°C
T_t	= 0.01 °C	Triple point temperature
T_c	= 374.14 °C	Critical temperature

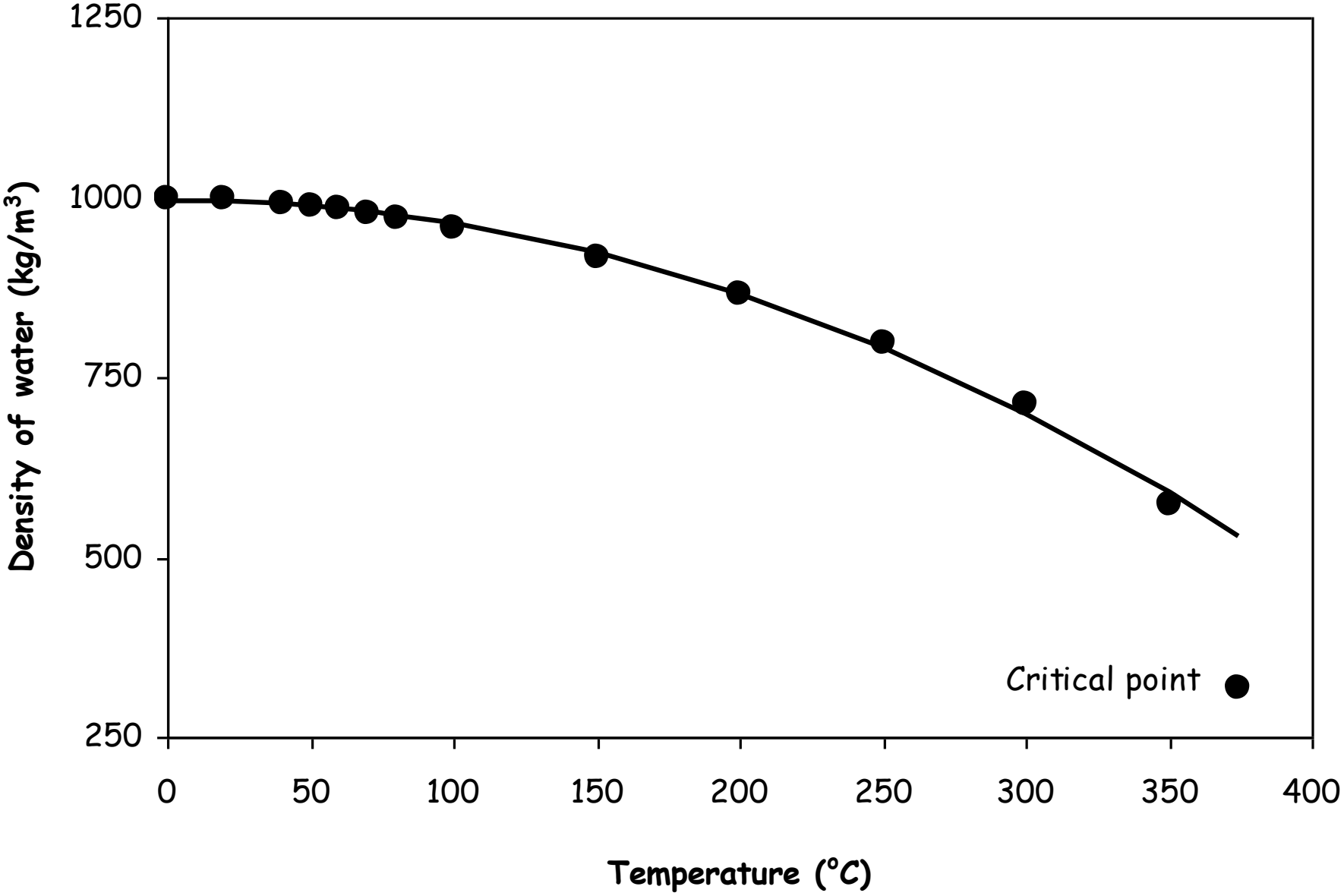

Latent heat of vaporization of water (MJ/kg)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Triple point
$\Delta H = \Delta H_o - (Cp_w - Cp_v)T$
$\Delta H = \Delta H_o \left(\frac{T_c - T}{T_c} \right)^{1/3}$
Critical point
0
50
100
150
200
250
300
350
400
Temperature (°C)

3. Density of Water

Table A.3 Density of Water

$$\rho = a_0 + a_1 T + a_2 T^2$$

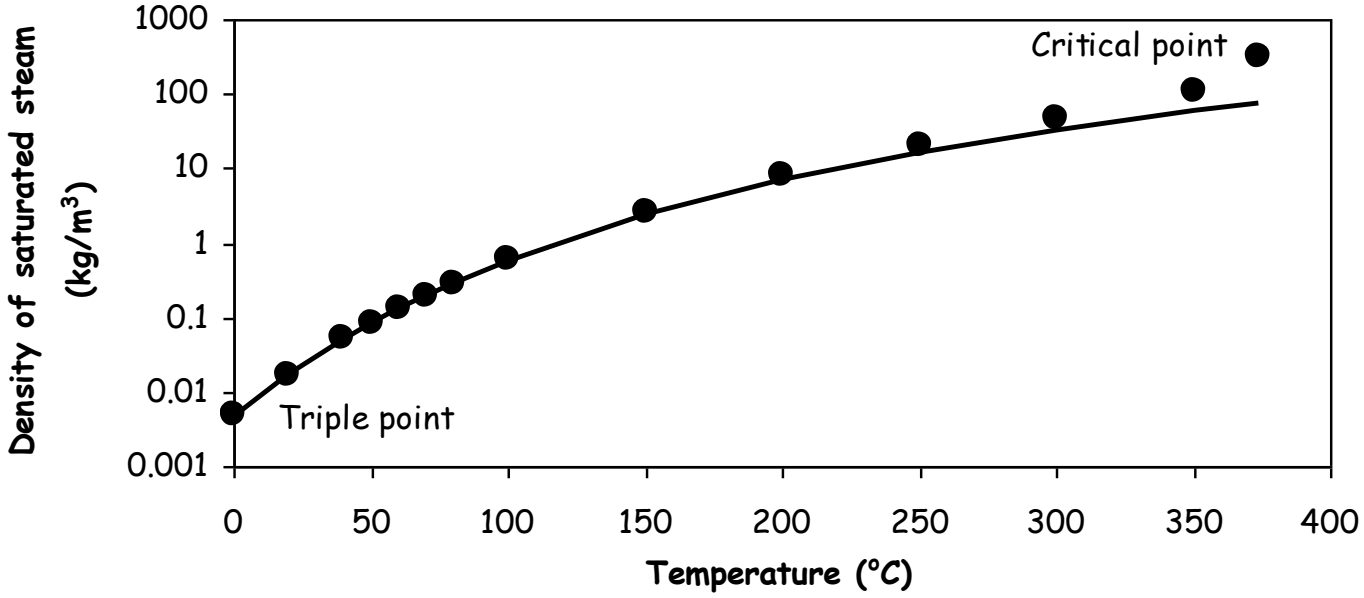
ρ	kg/m^3	Density
T	^{o}C	Temperature
a_0	= 9.97 10^2	Constants in the range 0–150^{o}C
a_1	= 3.14 10^{-3}	
a_2	= –3.76 10^{-3}	
a_0	= 9.95 10^2	Constants in the range 0–350^{o}C
a_1	= 2.91 10^{-2}	
a_2	= –3.40 10^{-3}	


1250
1000
750
500
250
Density of water (kg/m3)
0
50
100
150
200
250
300
350
400
Temperature (°C)
Critical point

4. Density of Saturated Steam

Table A.4 Density of Saturated Steam

$\rho = \frac{M P_s}{R T_a}$		Ideal gas equation
where	$P_s = a_1 - \frac{a_2}{a_3 + T}$	Antoine equation
and	$T_a = T + 273.15$	Absolute temperature
0–250°C		Range of application
ρ	kg/m^3	Density
P_s	bar	Saturated pressure of water
T	°C	Temperature
T_a	K	Absolute temperature
R	= 0.083143 m^{3}bar/kmol K	Ideal gas constant
M	= 18.015 kg/kmol	Molecular weight
a_1	= 1.19 10^1	Antoine constants
a_2	= 3.95 10^3	
a_3	= 2.32 10^2	


Density of saturated steam (kg/m3)
1000
100
10
1
0.1
0.01
0.001
Critical point
Triple point
0
50
100
150
200
250
300
350
400
Temperature (°C)

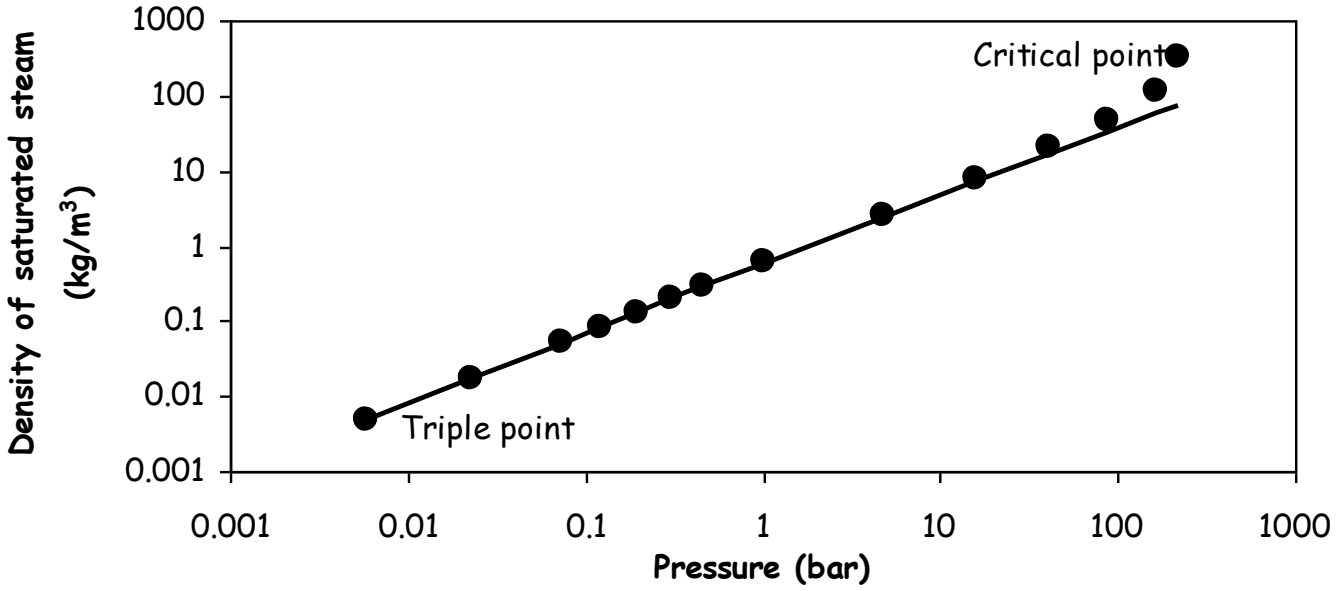

Density of saturated steam (kg/m3)
1000
100
10
1
0.1
0.01
0.001
Critical point
Triple point
0.001
0.01
0.1
1
10
100
1000
Pressure (bar)

Table A.5 Clapeyron Equation for Ice Fusion

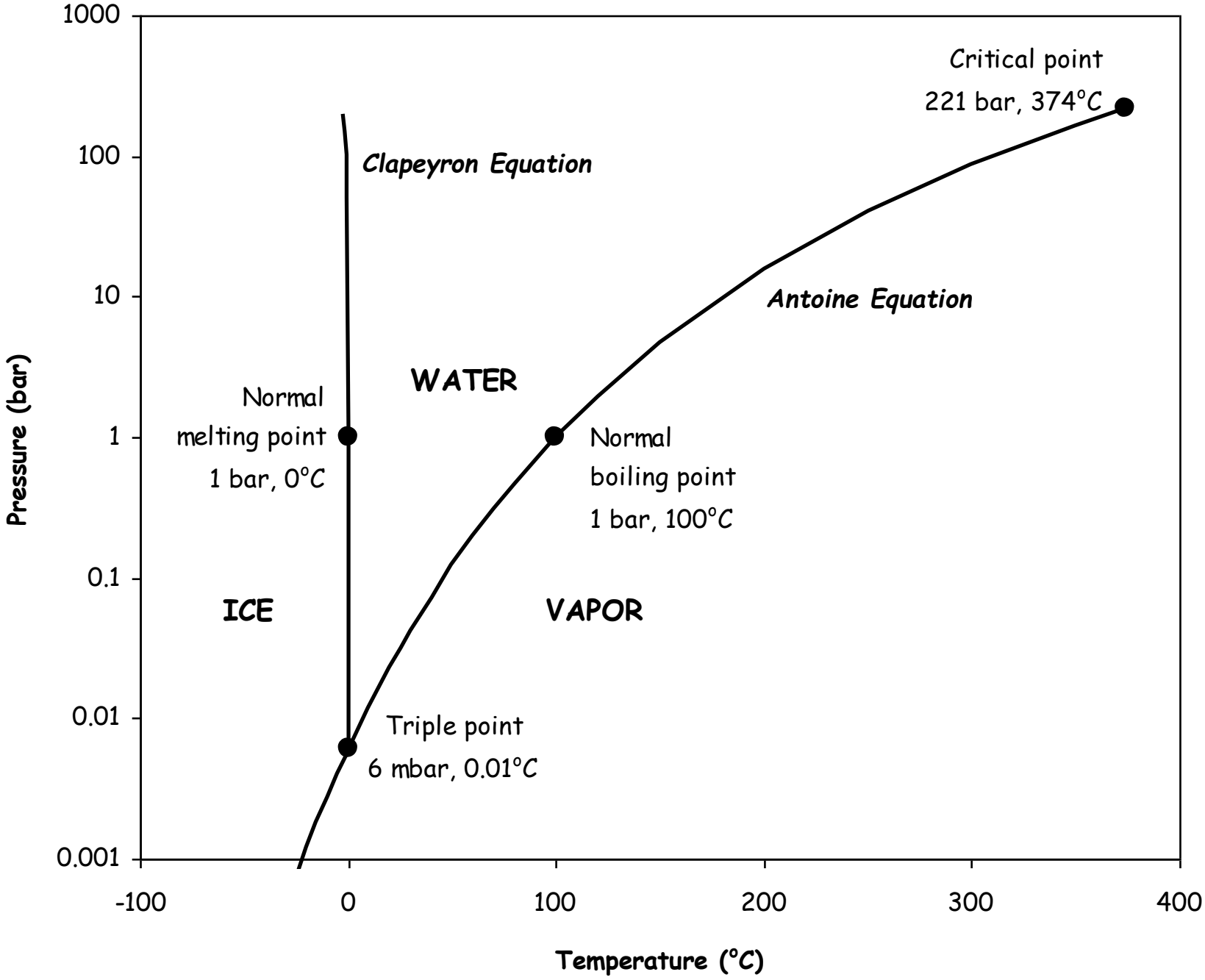
$$P = P_o + \frac{\Delta H_f}{\Delta V_f} \ln\left(\frac{273.15 + T}{273.15 + T_o}\right)$$

where

P	bar	Pressure
T	^{o}C	Temperature
P_o	= 1 bar	Normal pressure
T_o	= 0 ^{o}C	Normal melting temperature

and

$$\frac{\Delta H_f}{\Delta V_f} = -2.71516 \times 10^6 \text{ bar}$$


1000
100
10
1
0.1
0.01
0.001
Pressure (bar)
-100
0
100
200
300
400
Temperature (°C)
Critical point
221 bar, 374°C
Clapeyron Equation
Antoine Equation
WATER
Normal
melting point
1 bar, 0°C
Normal
boiling point
1 bar, 100°C
ICE
VAPOR
Triple point
6 mbar, 0.01°C

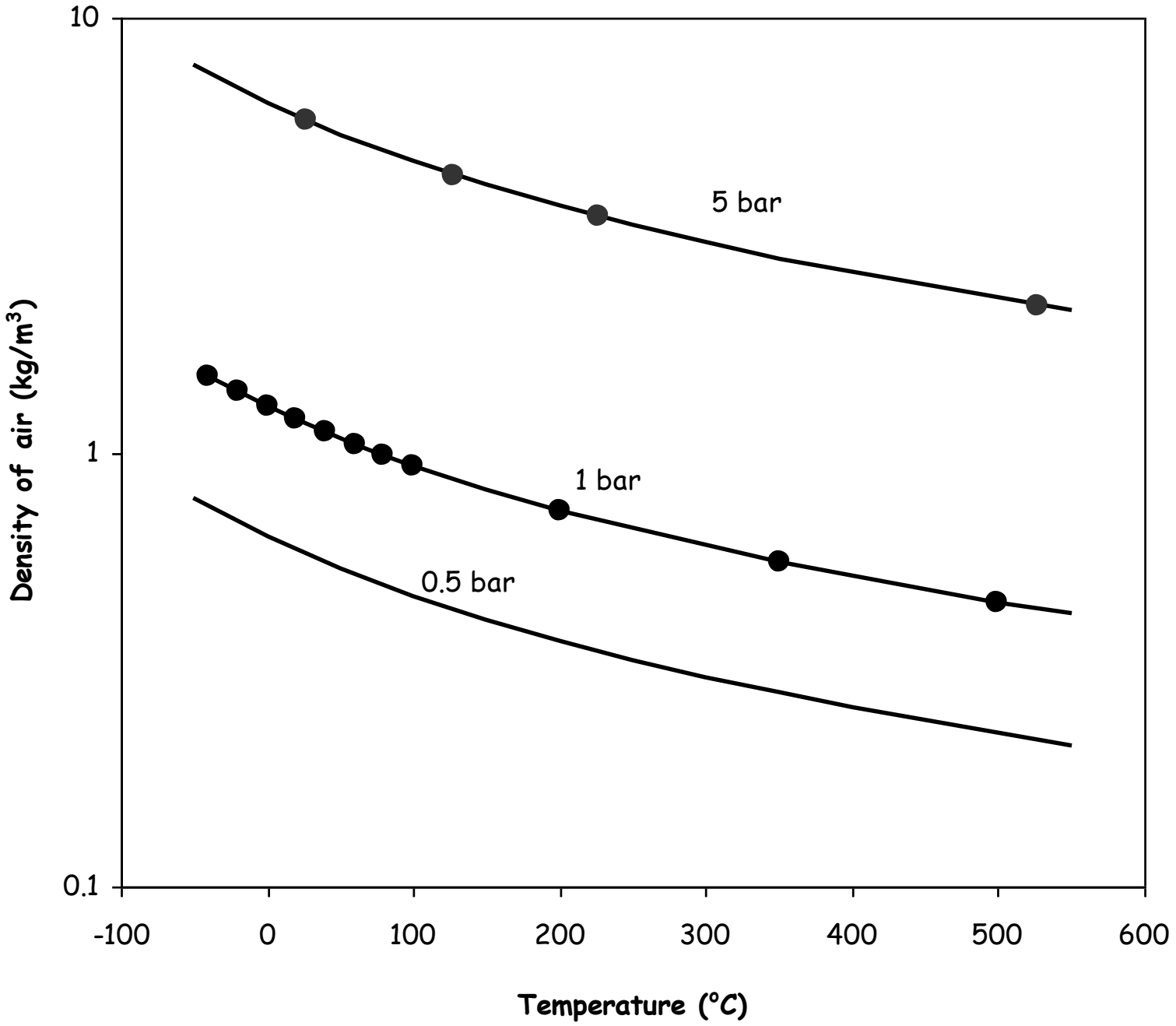
6. Density of Air

Table A.6 Density of Air

$$\rho = \frac{M\,P}{R\,T_a}$$ Ideal gas equation

where $T_a = T + 273.15$ Absolute temperature

ρ	kg/m^3	Density
P	bar	Pressure
T	^{o}C	Temperature
T_a	K	Absolute temperature
R	= 0.083143 m^{3}bar/kmol K	Ideal gas constant
M	= 28.965 kg/kmol	Molecular weight

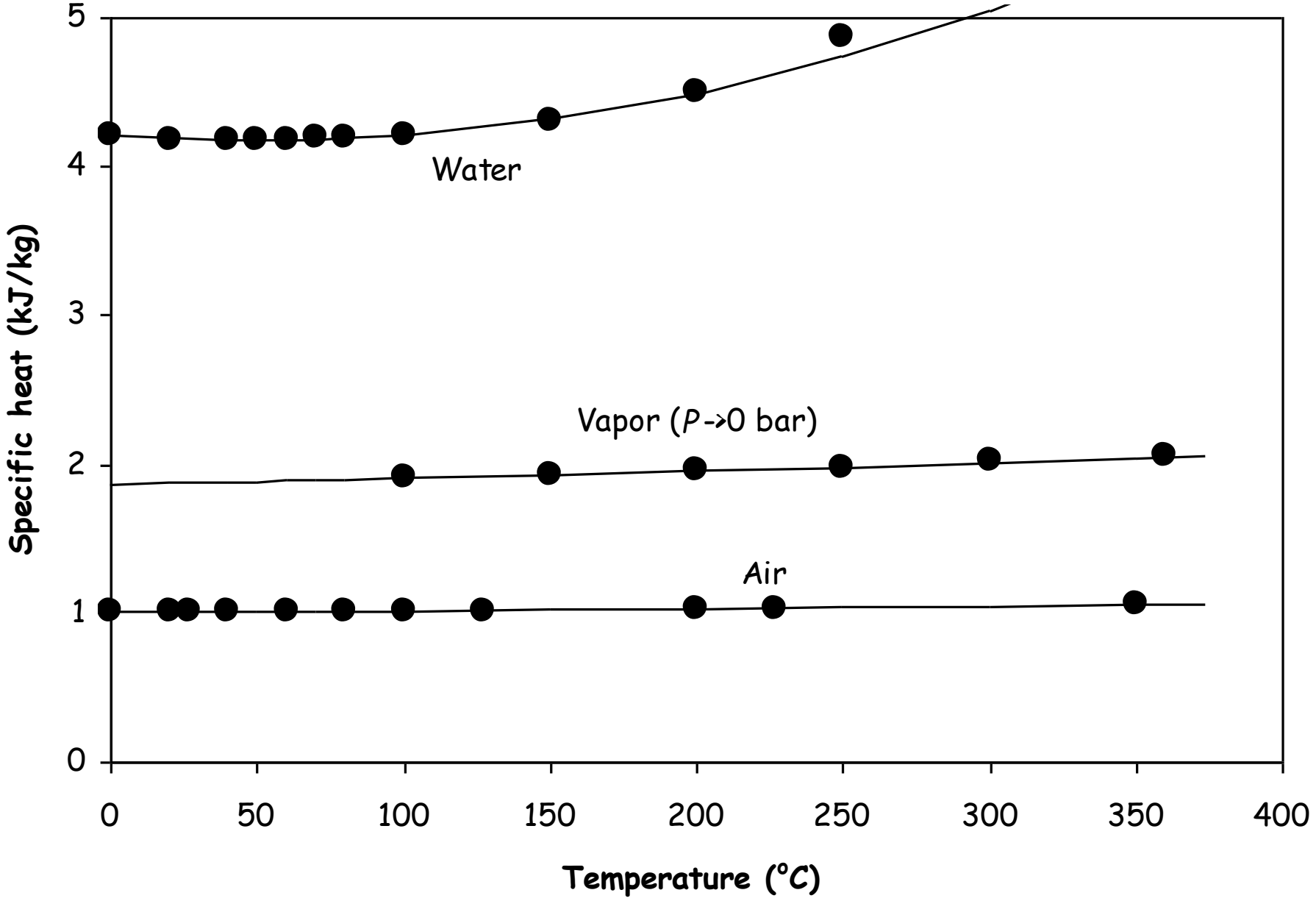

10
1
0.1
Density of air (kg/m3)
5 bar
1 bar
0.5 bar
-100
0
100
200
300
400
500
600
Temperature (°C)

7. Specific Heat of Water, Steam and Air

Table A.7 Specific Heat of Water, Steam and Air

$$C_p = a_0 + a_1 T + a_2 T^2$$

C_p	kJ/kgK	Specific heat
T	°C	Temperature
a_0	= 4.21	Constants for water
a_1	= –1.35 10^{-3}	
a_2	= 1.38 10^{-5}	
a_0	= 1.87	Constants for steam
a_1	= 3.07 10^{-4}	
a_2	= 5.66 10^{-7}	
a_0	= 1.01	Constants for air
a_1	= 3.16 10^{-5}	
a_2	= 3.28 10^{-7}	


Specific heat (kJ/kg)
5
4
3
2
1
0
Water
Vapor (P->0 bar)
Air
0
50
100
150
200
250
300
350
400
Temperature (°C)

8. Viscosity of Water, Steam and Air

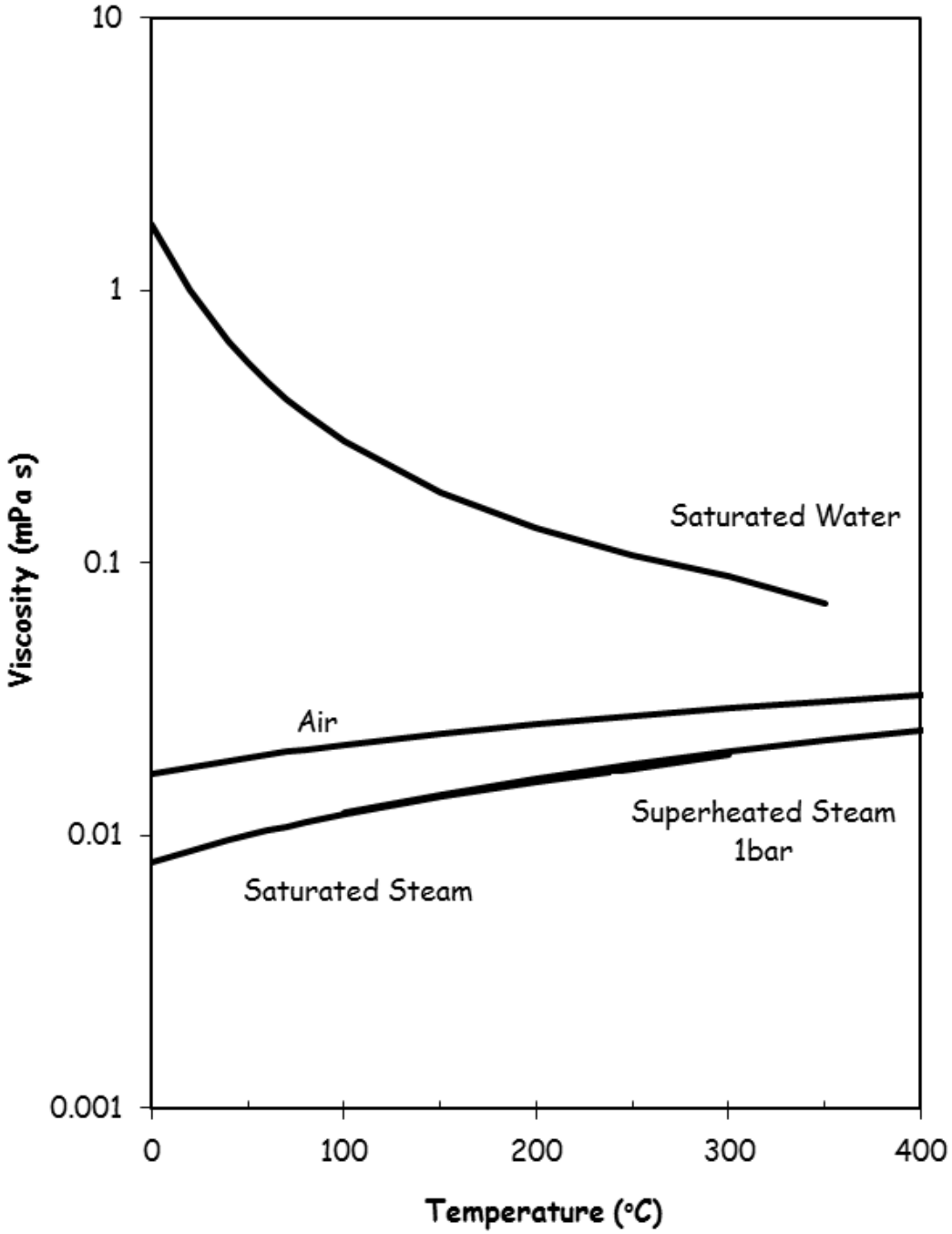
Table A.8 Viscosity of Water, Steam and Air

$$\eta = a_0 + a_1 T + a_2 T^2 + a_3 T^3$$

η	mPa s	Specific heat
T	°C	Temperature
a_0	$= 7.59\ 10^{-3}$	Constants for saturated vapor in the range 0–300°C
a_1	$= 4.49\ 10^{-5}$	
a_2	$= -6.13\ 10^{-8}$	
a_3	$= 1.44\ 10^{-10}$	
a_0	$= 8.07\ 10^{-3}$	Constants for superheated vapor in the range 100–700°C
a_1	$= 4.04\ 10^{-5}$	
a_2	$= 1.24\ 10^{-9}$	
a_3	$= -1.21\ 10^{-12}$	
a_0	$= 1.69\ 10^{-2}$	Constants for air in the range 0–1000°C
a_1	$= 4.98\ 10^{-5}$	
a_2	$= -3.19\ 10^{-8}$	
a_3	$= 1.32\ 10^{-11}$	

$$\eta = a_0 + a_1 T + a_2 T^2 + a_3 T^{-1}$$

a_0	$= -1.07\ 10^{1}$	Constants for saturated water in the range 0–350°C
a_1	$= 1.97\ 10^{-2}$	
a_2	$= -1.47\ 10^{-5}$	
a_3	$= 1.82\ 10^{3}$	

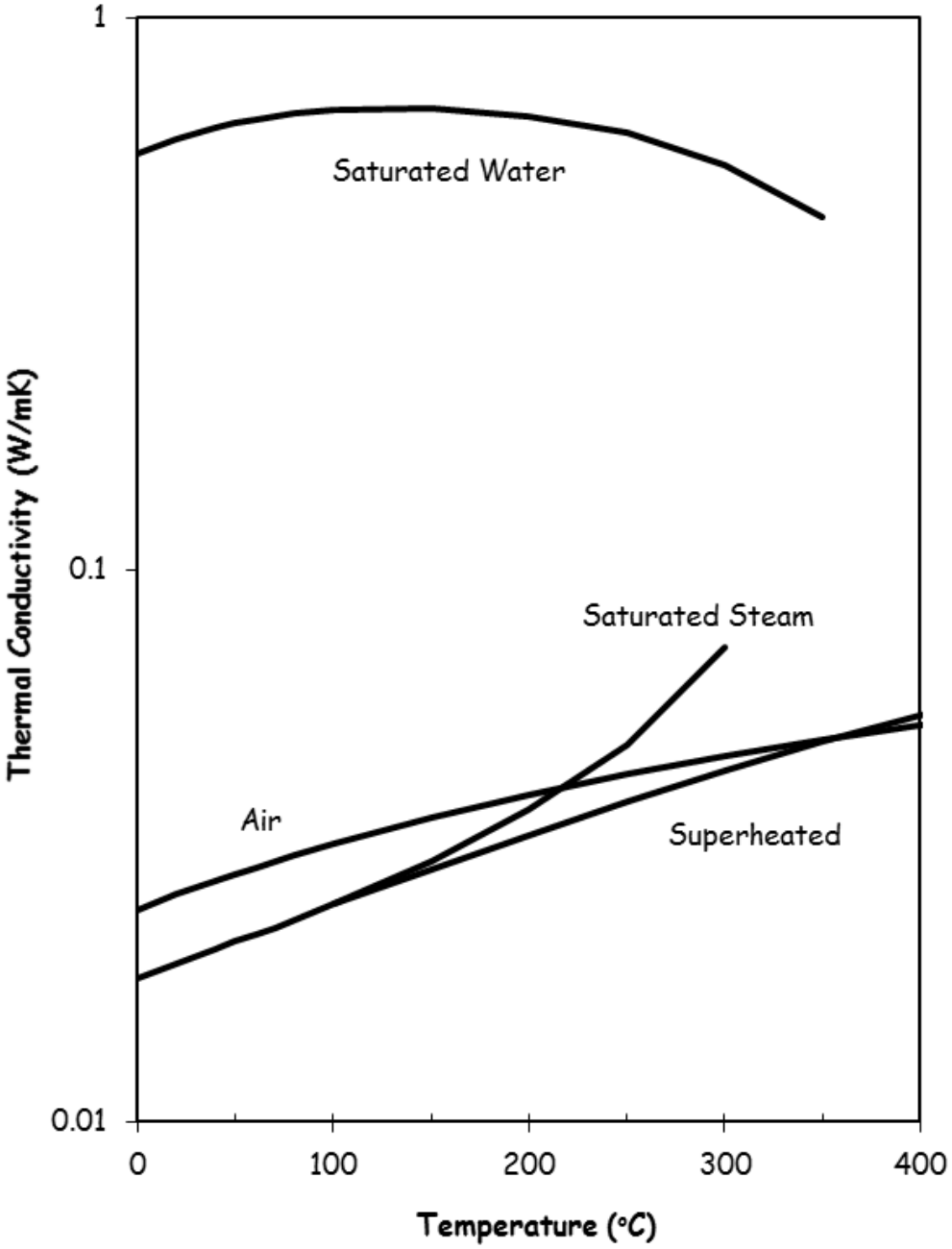

10
1
0.1
0.01
0.001
Viscosity (mPa s)
Saturated Water
Air
Superheated Steam
1bar
Saturated Steam
0
100
200
300
400
Temperature (°C)

9. Thermal Conductivity of Water, Steam and Air

Table A.9 Thermal Conductivity of Water, Steam and Air

$$\lambda = a_0 + a_1 T + a_2 T^2 + a_3 T^3$$

λ	W/m K	Specific heat
T	°C	Temperature
a_0	$= 5.70\ 10^{-1}$	Constants for saturated water in the range 0–350°C
a_1	$= 1.78\ 10^{-3}$	
a_2	$= -6.94\ 10^{-6}$	
a_3	$= 2.20\ 10^{-9}$	
a_0	$= 1.76\ 10^{-2}$	Constants for saturated vapor in the range 0–300°C
a_1	$= 1.05\ 10^{-4}$	
a_2	$= -6.71\ 10^{-7}$	
a_3	$= 3.07\ 10^{-9}$	
a_0	$= 1.77\ 10^{-2}$	Constants for superheated vapor in the range 100–700°C
a_1	$= 6.01\ 10^{-5}$	
a_2	$= 9.51\ 10^{-8}$	
a_3	$= -3.99\ 10^{-11}$	
a_0	$= 2.43\ 10^{-2}$	Constants for air in the range 0–1000°C
a_1	$= 7.89\ 10^{-5}$	
a_2	$= -1.79\ 10^{-8}$	
a_3	$= -8.5710^{-12}$	

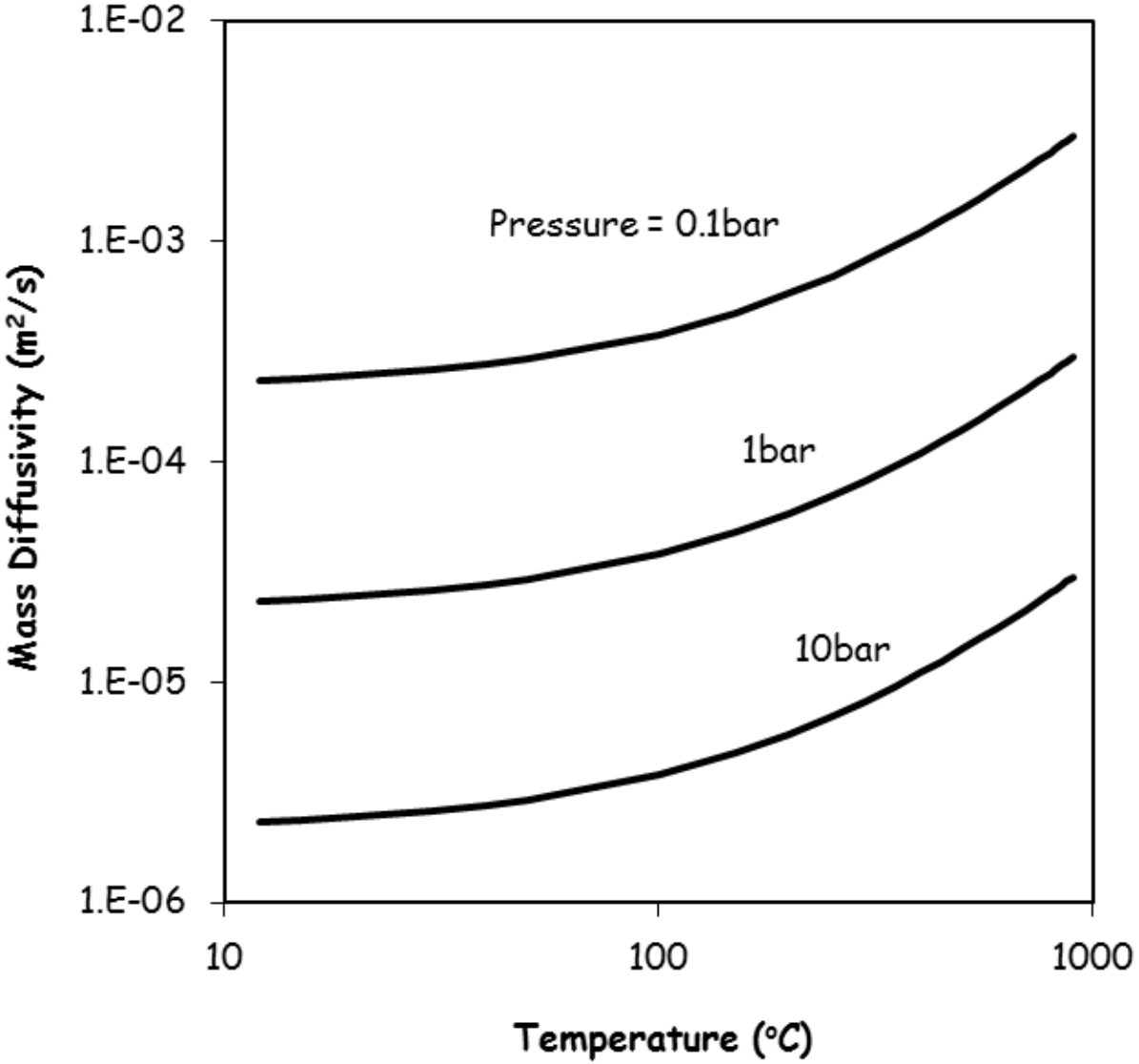

1
0.1
0.01
Thermal Conductivity (W/mK)
Saturated Water
Saturated Steam
Air
Superheated
0
100
200
300
400
Temperature (°C)

10. Mass Diffusivity of Water Vapor in Air

Table A.10 Mass Diffusivity of Water Vapor in Air

$$D = a_0 \left(\frac{T + 273}{273} \right)^{a_1} P^{a_2}$$

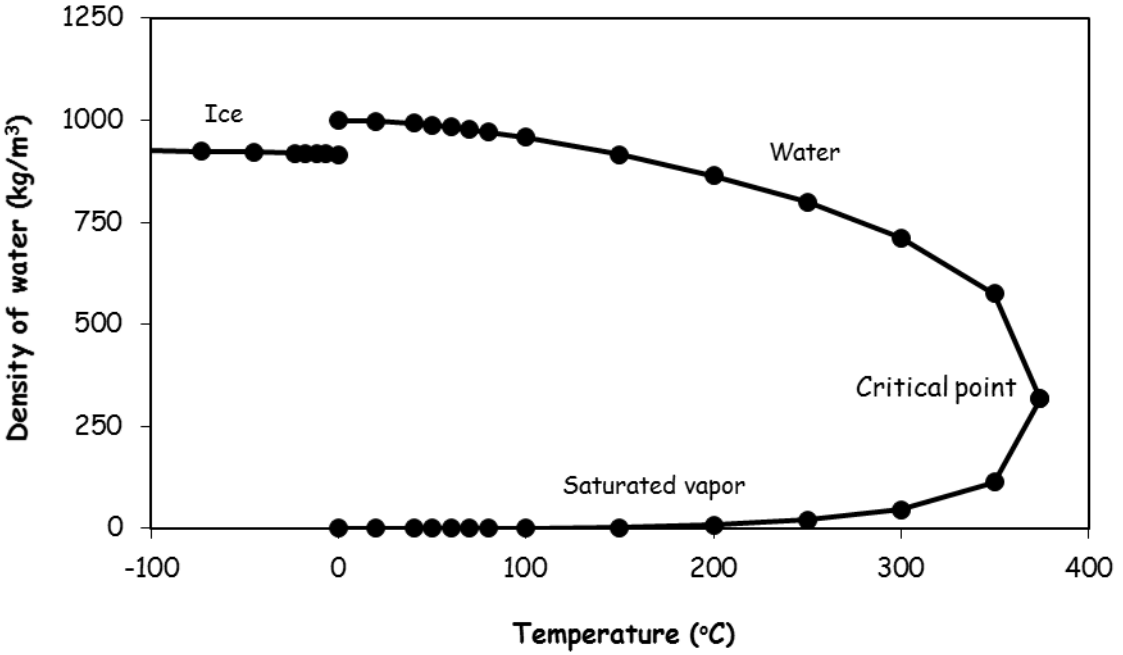
D	m^2/s	Mass diffusivity
T	^oC	Temperature
P	bar	Pressure
a_0	$= 2.16\ 10^{-5}$	Constants for saturated vapor in the range 0–1200^oC
a_1	$= 1.80$	
a_2	$=-1.00$	

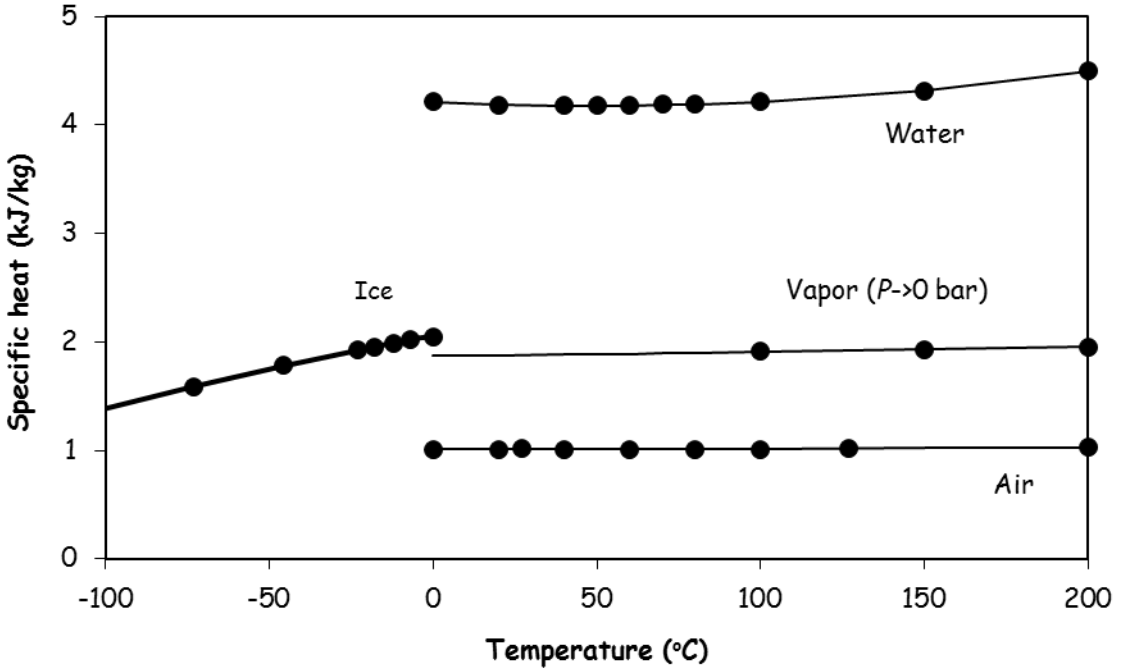

1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
Mass Diffusivity (m²/s)
Pressure = 0.1bar
1bar
10bar
10
100
1000
Temperature (°C)

Και τώρα ας παίξουμε λίγο.

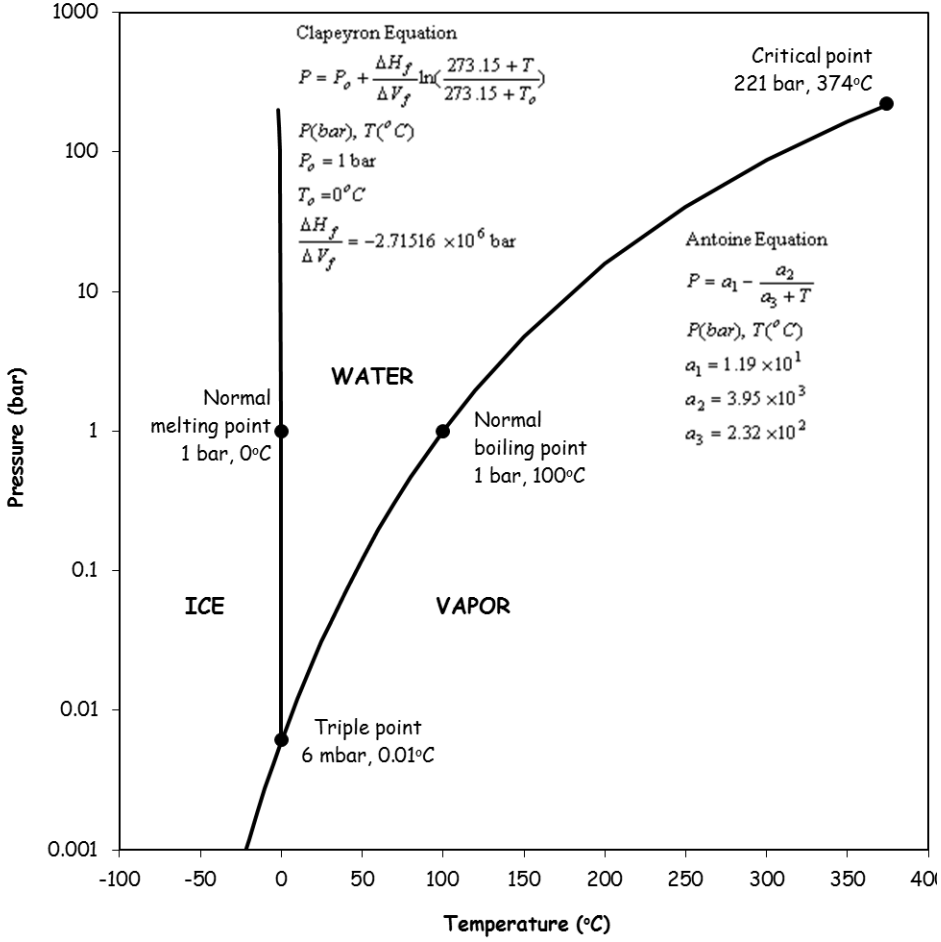
Ας ζωγραφίσουμε
μερικά διαγράμματα
στο Excel
και μετά να ψάξουμε
να τα βρούμε
στη βιβλιογραφία.

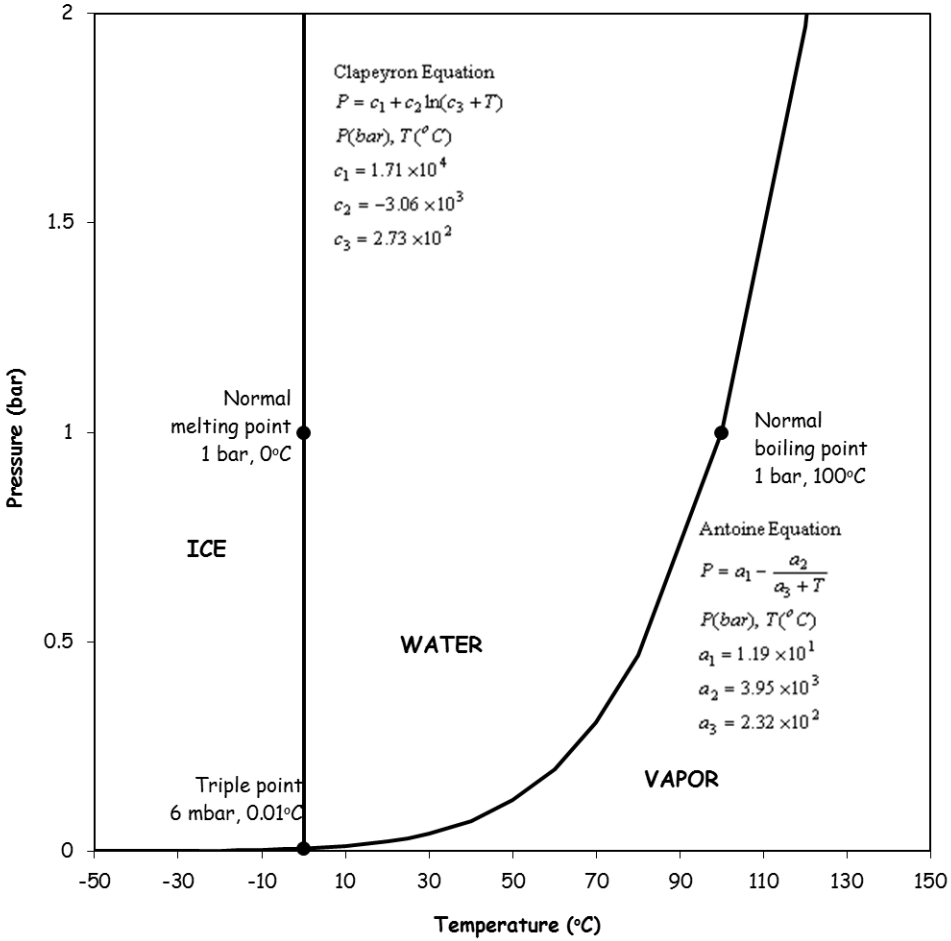
Αυτά δίπλα τι είναι?





και αυτά?


Clapeyron Equation
$P = P_o + \frac{\Delta H_f}{\Delta V_f} \ln\left(\frac{273.15 + T}{273.15 + T_o}\right)$
$P(bar), T(^oC)$
$P_o = 1$ bar
$T_o = 0^oC$
$\frac{\Delta H_f}{\Delta V_f} = -2.71516 \times 10^6$ bar
Critical point
221 bar, 374°C
Antoine Equation
$P = a_1 - \frac{a_2}{a_3 + T}$
$P(bar), T(^oC)$
$a_1 = 1.19 \times 10^1$
$a_2 = 3.95 \times 10^3$
$a_3 = 2.32 \times 10^2$
WATER
Normal melting point 1 bar, 0°C
Normal boiling point 1 bar, 100°C
ICE
VAPOR
Triple point 6 mbar, 0.01°C
Pressure (bar)
Temperature (°C)
1000
100
10
1
0.1
0.01
0.001
-100
-50
0
50
100
150
200
250
300
350


Clapeyron Equation
$P = c_1 + c_2 \ln(c_3 + T)$
$P(bar), T(^oC)$
$c_1 = 1.71 \times 10^4$
$c_2 = -3.06 \times 10^3$
$c_3 = 2.73 \times 10^2$
Antoine Equation
$P = a_1 - \frac{a_2}{a_3 + T}$
$P(bar), T(^oC)$
$a_1 = 1.19 \times 10^1$
$a_2 = 3.95 \times 10^3$
$a_3 = 2.32 \times 10^2$
Normal melting point 1 bar, 0°C
Normal boiling point 1 bar, 100°C
ICE
WATER
VAPOR
Triple point 6 mbar, 0.01°C
Pressure (bar)
Temperature (°C)
2
1.5
1
0.5
0
-50
-30
-10
10
30
50
70
90
110
130
150