ABE 201
Biological Thermodynamics 1

Module 14

Psychrometrics

Overview

- Psychrometric charts illustrate graphically the relationship between thermodynamic properties of air-water vapor mixtures.

- Much like steam tables, compressibility charts, and the Antoine equation, these charts can be used to solve mass/energy balances where water/air are involved.

Psychrometry

- The measurement (μέτρον) of cold (ψυχρόν) gas-vapor mixtures.
- Most commonly, the gas is air and the vapor is water.
- In practice, psychrometry relates measurable properties of air/water mixtures to thermodynamic state properties

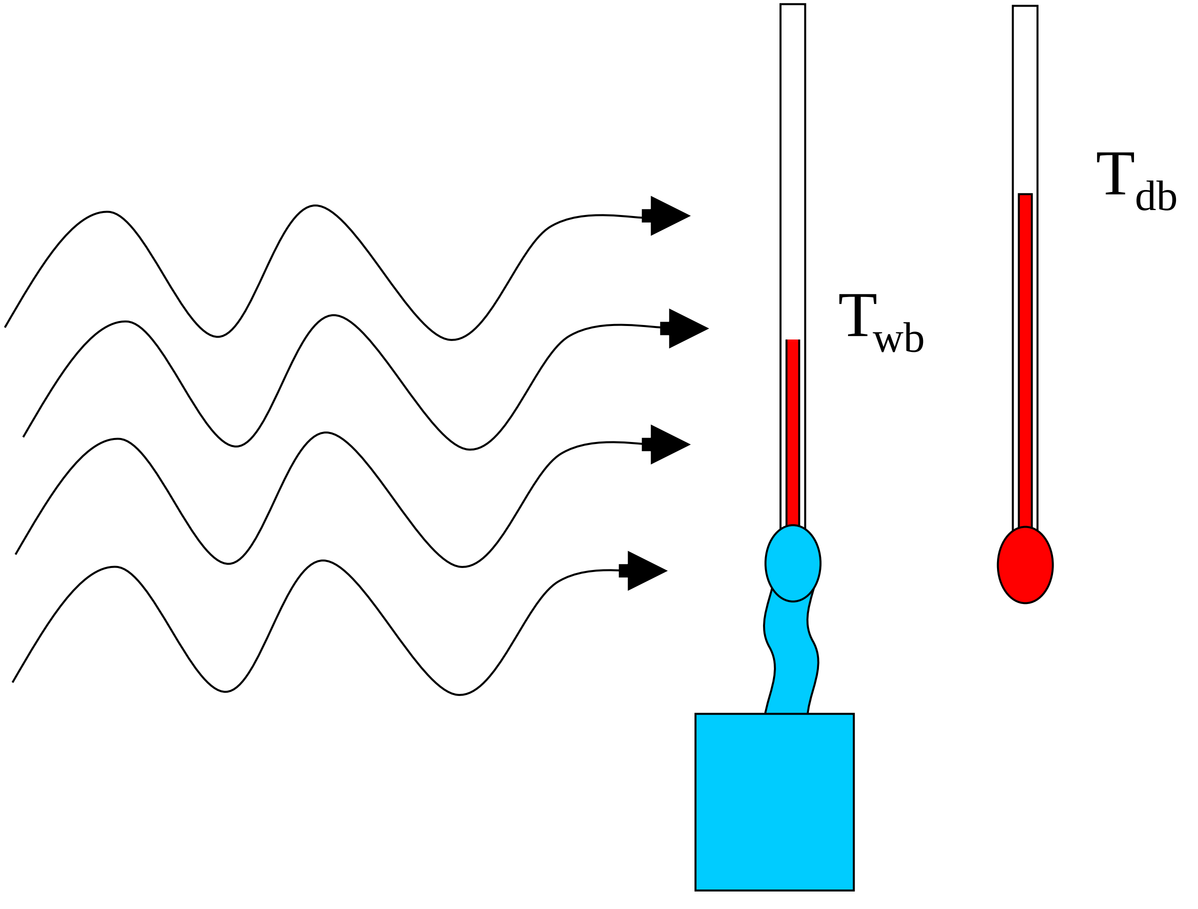
Psychrometric Measurements

- Dry-Bulb Temperature, T or T_{db} = air temperature as measured by thermometer (or equivalent)
- Wet-Bulb Temperature, T_{wb} = temperature of air after undergoing evaporative cooling
- Dew Point, T_{dp} = temperature at which humid air becomes saturated (constant pressure)

State Properties

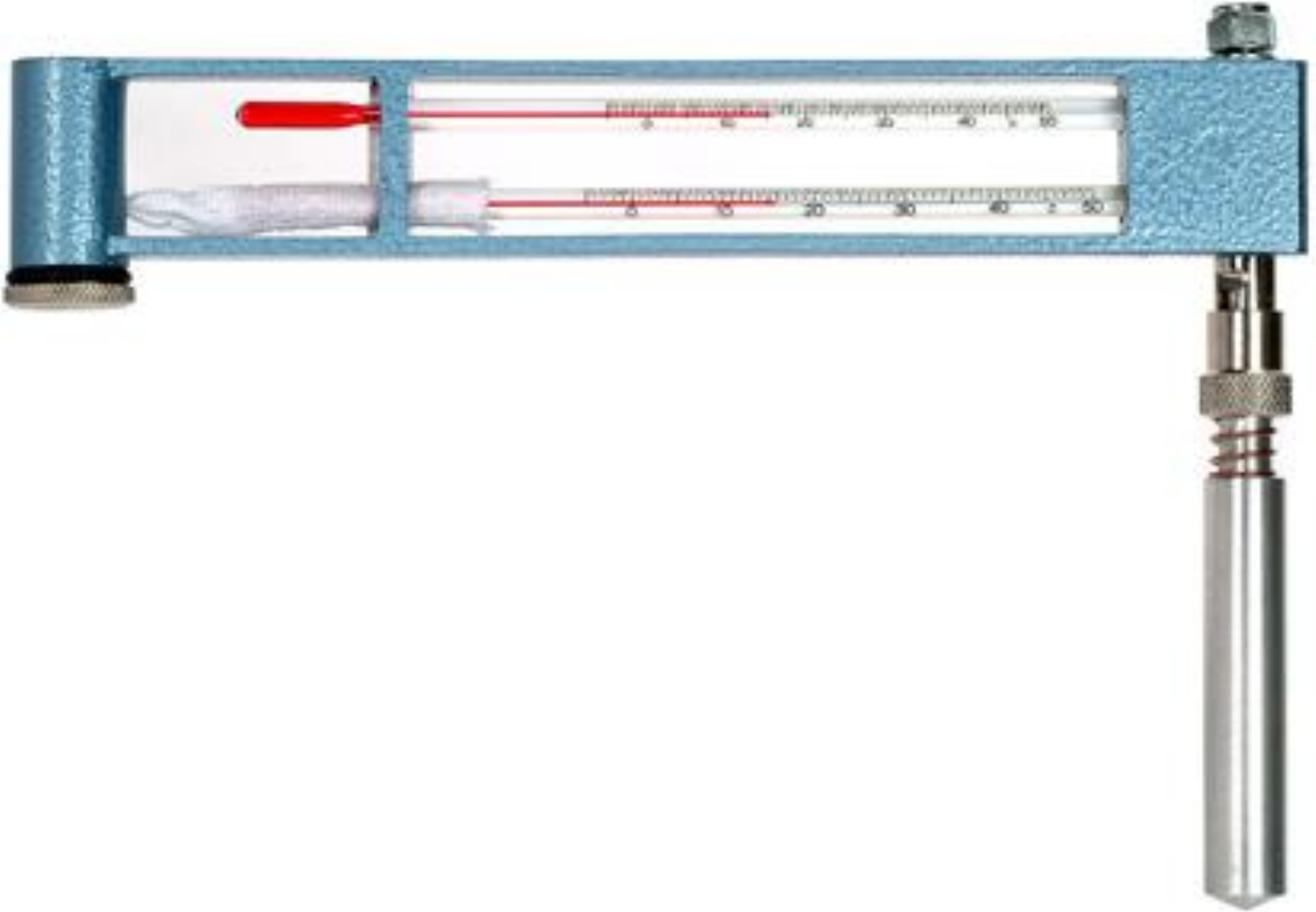
- Specific Volume, $\hat{V}$ = the specific volume of DA (minus volume of water vapor)
- Specific Enthalpy, $\hat{H}$ = the enthalpy of the dry air
- Absolute Humidity, h_a = the ratio of water vapor to dry air (DA), aka moisture content
- Relative Humidity, $h_r = 100\% * p_{H2O} / p^*_{H2O}$

Wet-Bulb Temperature, T_{wb}

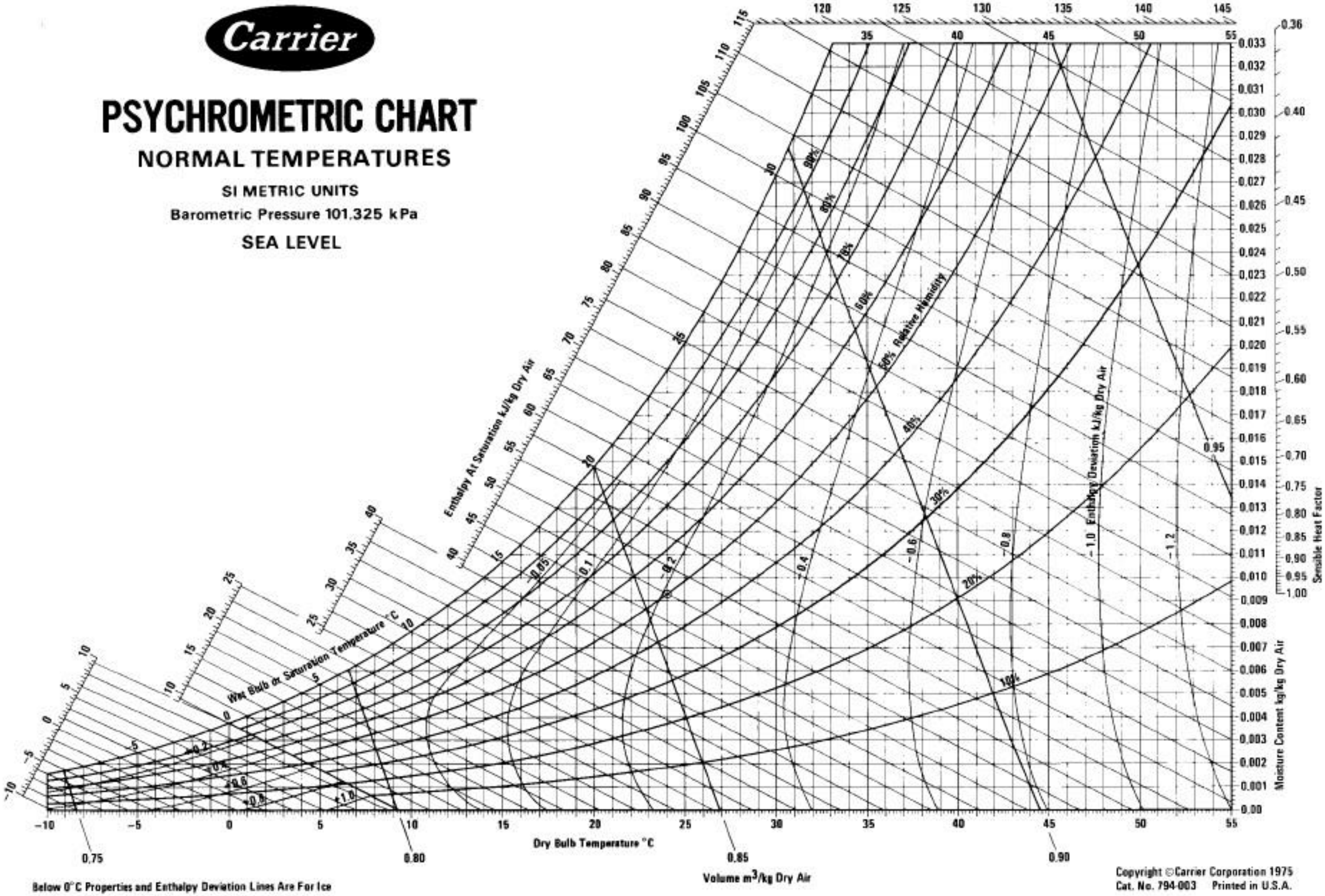


Wet-Bulb Temperature, T_{wb}

- Evaporation of the water from the wick cools the thermometer bulb
- Wet-bulb temperature is a function of:
  - Dry-bulb temperature
  - Moisture content of air
- If the air is saturated (100% rel. hum.), no water evaporates and $T_{wb} = T_{db}$




INSTRUCTIONS
PSYCHRO-DYNE
PSYCHROMETRIC CHART


Carrier
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Enthalpy At Saturation kJ/kg Dry Air
Wet Bulb or Saturation Temperature °C
Relative Humidity
Enthalpy Deviation kJ/kg Dry Air
Dry Bulb Temperature °C
Volume m³/kg Dry Air
Moisture Content kg/kg Dry Air
Sensible Heat Factor
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
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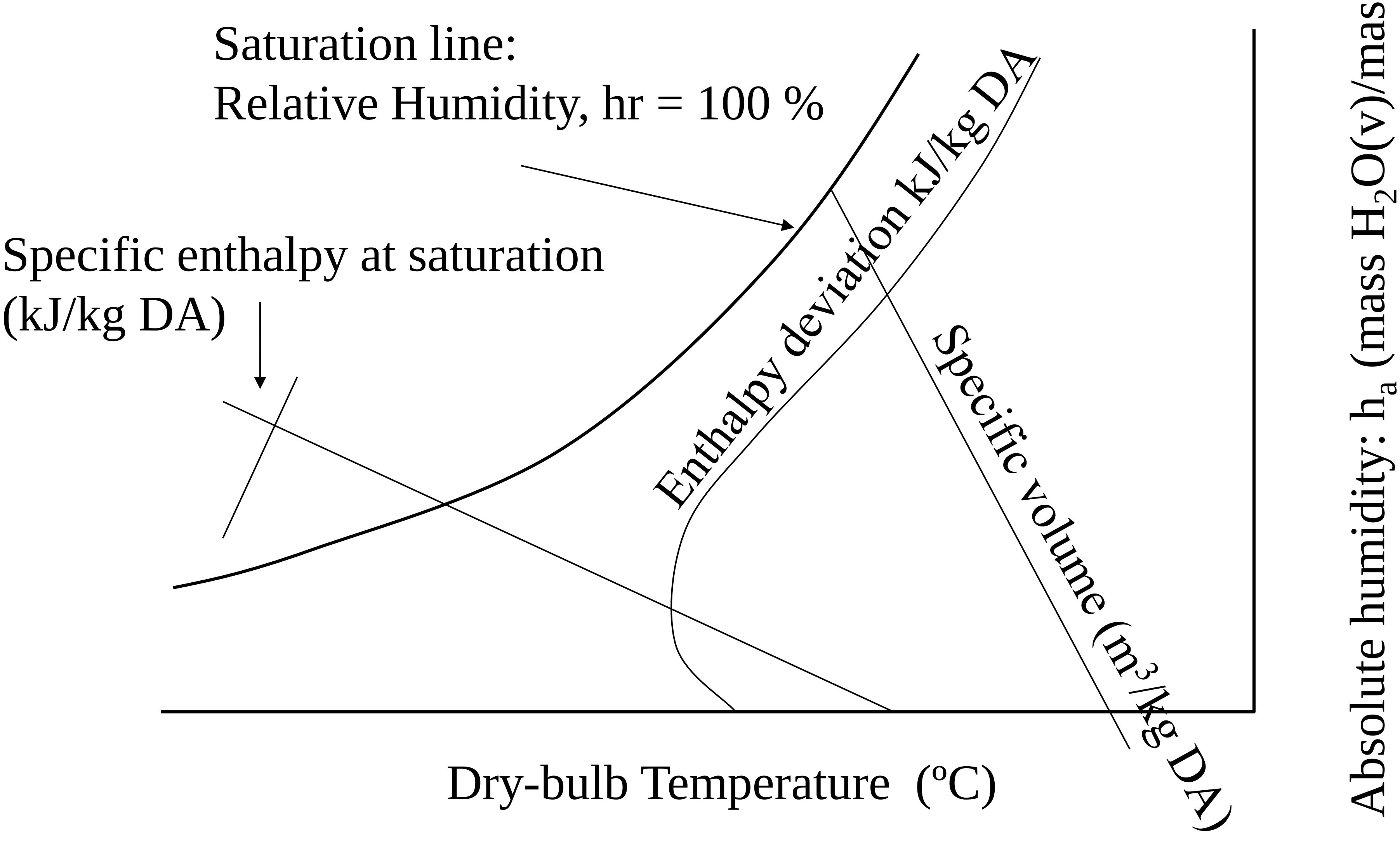
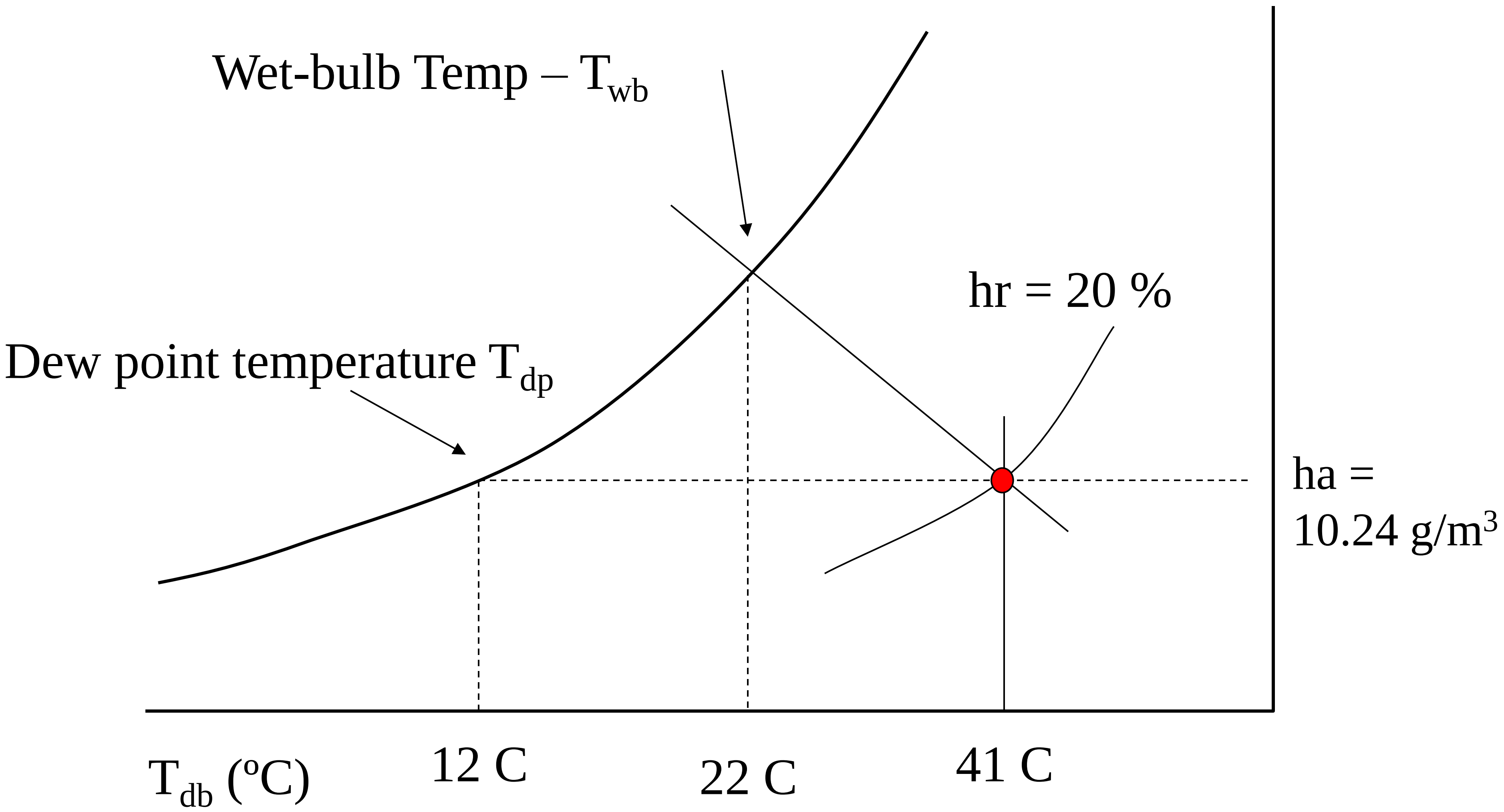
Basic Components of the chart



More information on the chart!



Using the Psychrometric Chart

- T_{db} = 36 C and ha = 0.015 kg/kg DA
- Convert ha=0.015 kg/kg DA into mass fraction.
- What is the Relative Humidity?
- What is the volume of 1 kg Dry air?
- What is the specific enthalpy ?
- What is the wet-bulb temperature?
- What is the dew point?

Carrier

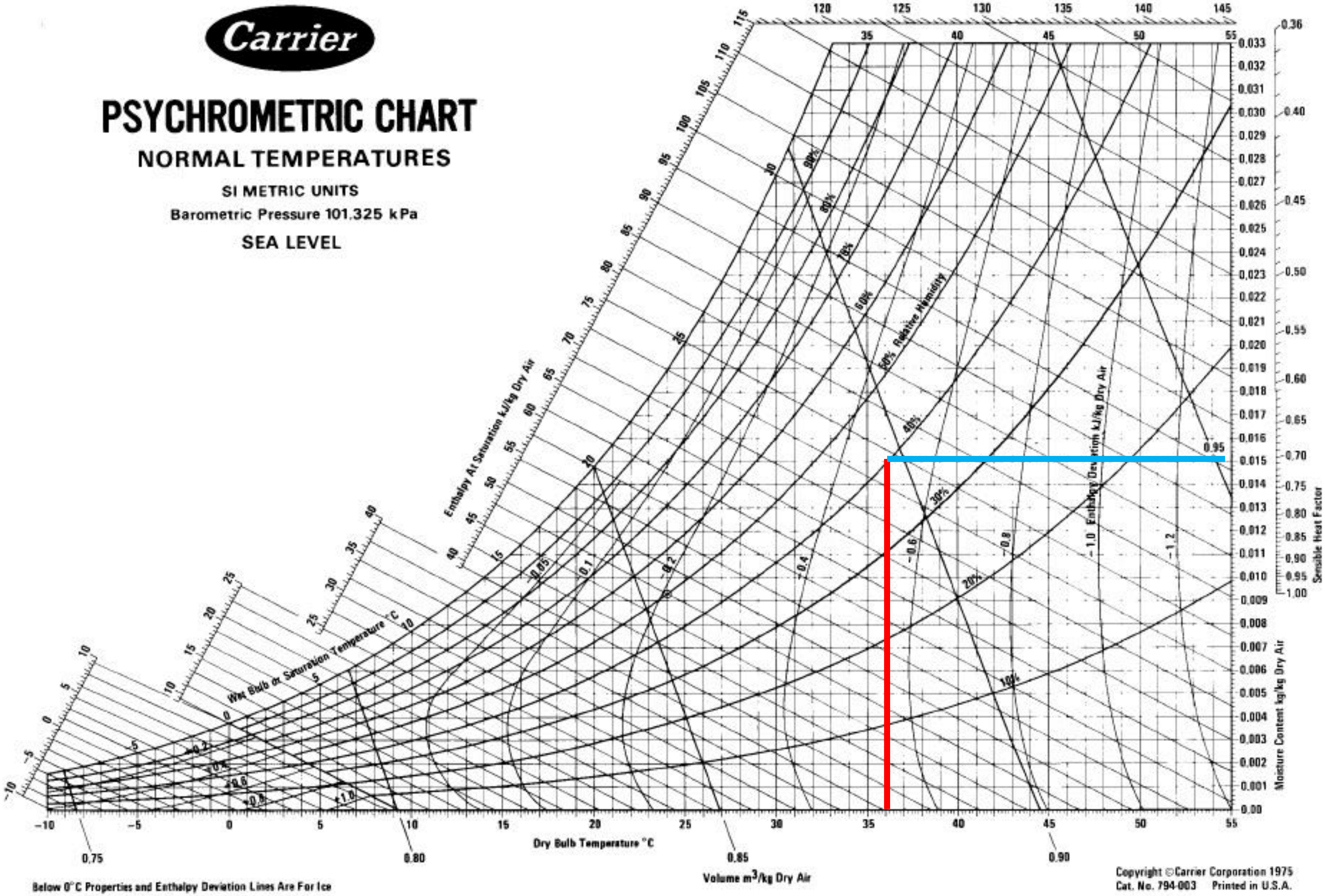
PSYCHROMETRIC CHART

NORMAL TEMPERATURES

SI METRIC UNITS

Barometric Pressure 101.325 kPa

SEA LEVEL



1 kg of DA has 0.015 kg of water.

$x_{water} = 0.015/(1+0.015) = .0148$

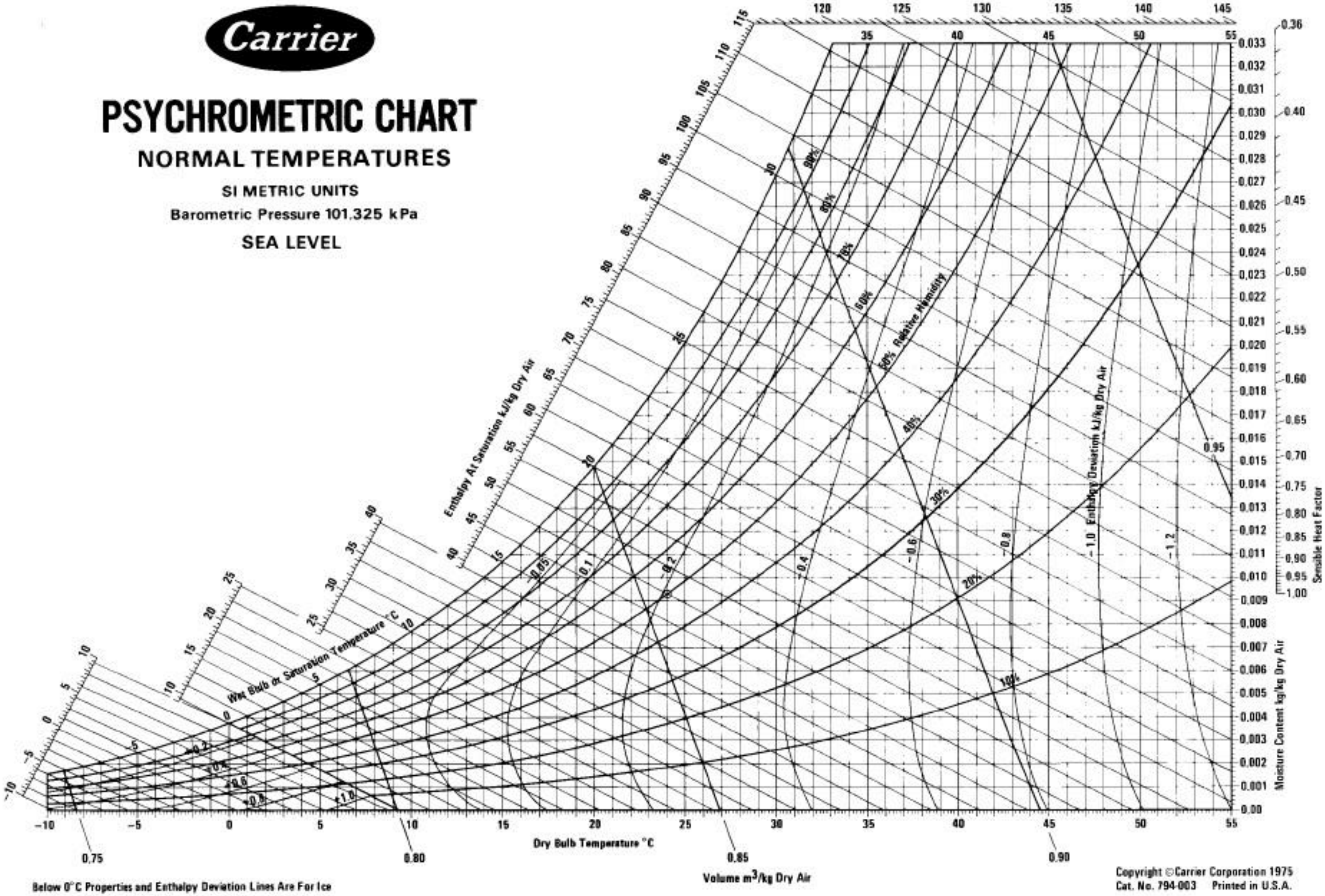
RH = 40 %

Vh = 0.895 m^3/kg

Hhat = (76 – 0.5) kJ/kg dry air

T(wb) = 24.6 C

T(dp) = 20.3 C



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PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Enthalpy At Saturation kJ/kg Dry Air
Wet Bulb or Saturation Temperature °C
Relative Humidity
90%
80%
70%
60%
50%
40%
30%
20%
10%
Enthalpy Deviation kJ/kg Dry Air
Dry Bulb Temperature °C
Volume m³/kg Dry Air
0.75
0.80
0.85
0.90
0.95
Moisture Content kg/kg Dry Air
Sensible Heat Factor
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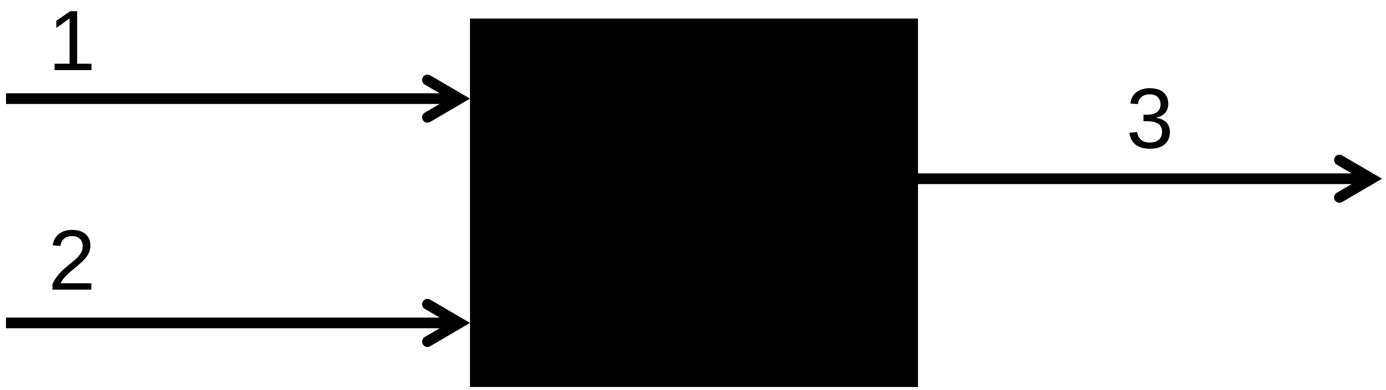
Mixing Air Streams

2 kg DA/min of air from an AC (22C, 54% RH) is mixed with 3 kg DA/min of warm air (41C, 40% RH), what are the psychrometric properties of the mixed air?



Stream 1

m1 = 2 kg DA/min

T(db) = 22 C

RH = 54%

ha = 8.92 g/kg

H = 44.72 kJ/kg DA

T(wb) = 16 C

T(dp) = 12.3 C

Stream 2

m2 = 3 kg DA/min

T(db) = 41 C

RH = 40%

ha = 19.81 g/kg

H = 92.18 kJ/kg DA

T(wb) = 28.6 C

T(dp) = 24.7 C

Mass Balance around Dry Air

m1 + m2 = m3

2 + 3 = 5

Mass Balance around Water

m1 * ha1 + m2 * ha2 = m3 * ha3

ha1 = 8.92 g/kg , ha2 = 19.81

ha3 = 15.45 g w/kg DA

Energy Balance

H1 * m1 + H2 * m2 = H3 * m3

H1 = 44.72 kJ/kg DA,

H2 = 92.18 kJ/kg DA

H3 = 73.20 kJ/kg

ha = 15.45 g/kg

H = 73.2 kJ/kg

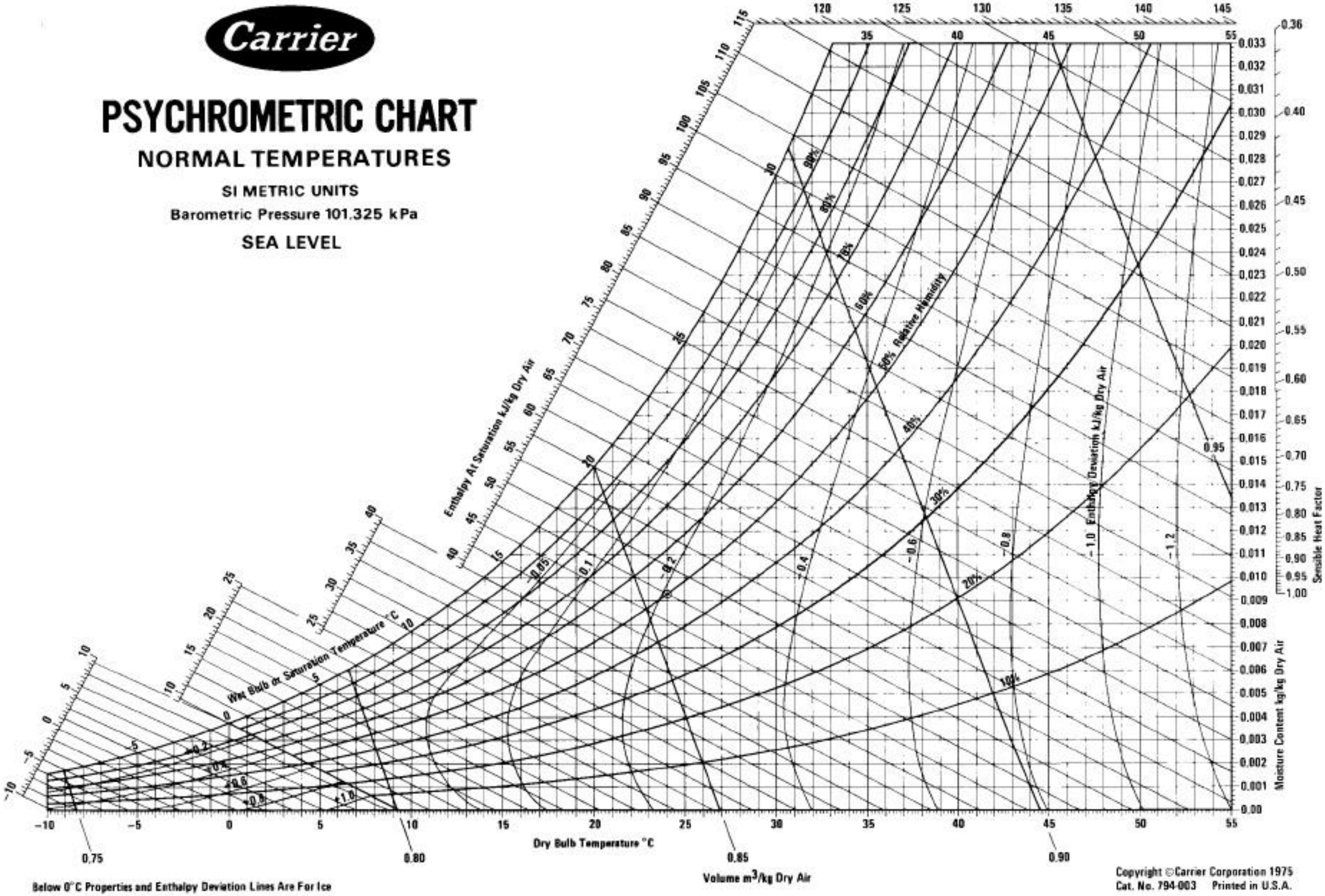
T(db) = 33.5 C

T(wb) = 24.3

T(dp) = 20.7

RH = 47%

V = 0.8903 m3/kg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Drying Processes

- Drying converts water in the material from liquid to vapor.
- If no heat is added, the process remains at a <u>constant enthalpy</u>
  - The air temperature will drop
  - Sensible heat is traded for latent heat
- This process follows a constant enthalpy line on the psychrometric chart

Drying Problem

A counter-current of 200 kg/min of dry air at 49.5 C and 20% RH is used to dry 5 kg/min of dough starting at 20C and 80% MC(wb) to 70% MC(wb). Assume that the dough has a constant

Cp = 1.90 kJ/kg-K

and the dry air is constant enthalpy.

At steady-state, what is the temperature and relative humidity of the exit air and the temperature of the dough?


Air, out
Air, in
Dough, in
Dough, out

Find 49.5 C and 20% RH on chart:

h = 0.015 kg/kg, H = 89 kJ/kg

Mass Balances

Air

$$m_{DA,in} = m_{DA,\text{out}} = 200 kg / \min$$

Dough solids

$$x_{s,in} m_{dough,in} = x_{s,\text{out}} m_{dough,\text{out}}$$

$$(1-0.8)(5) = (1-0.7) m_{dough,\text{out}}$$

$$m_{dough,\text{out}} = 3.33 kg / \min$$

Water

$$h_{a,in} m_{DA,in} + x_{w,in} m_{dough,in} = h_{a,\text{out}} m_{DA,\text{out}} + x_{w,\text{out}} m_{dough,\text{out}}$$

$$(0.015)(200) + (0.8)(5) = h_{a,\text{out}} (200) + (0.7)(3.33)$$

$$h_{a,\text{out}} = 0.023$$

1st Law Energy Balance

$$\Delta H = 0$$

$$H_{a,in} m_{DA,in} + C_p m_{dough,in}(20-0) = H_{a,\mathrm{out}} m_{DA,\mathrm{out}} + C_p m_{dough,\mathrm{out}}(X-0)$$

$$(89)(200) + (1.90)(5)(20-0) = 89(200) + (1.90)(3.33)(X-0)$$

h = 0.023 kg/kg, H = 89 kJ/kg

T(db) =30 C

T(wb)= 28 C

T(dp) = 27 C

RH = 84%

T (dough) = 30 C

Mixing Air Streams

Cool, wet air (T_{db} = 10 C, RH = 80%) is mixed with warm, dry air (T_{db} = 50 C, RH = 10%). If the cool air is mixed with the warm air in a 3:1 ratio (cool:warm), what is the temperature and relative humidity of the final mixture?

T(db) = 10 C, RH = 80%,

H = 25 kJ/kg, h = 0.006 kg/kg

T(db) = 50 C, RH = 10%,

H = 71.5 kJ/kg, h = 0.0078 kg/kg

Air Balance

1 + 3 = 4

Moisture out, ha = [3*(0.006) + 1*(0.0078)] / [4 kg] = 0.00645 kg/kg

Enthalpy out, H = [3*(25) + 1*(71.5)]/[4 kg] = 36.625 kJ/kg

These two points intersect: T(db) = 20 C; RH = 44%

T(wb) = 13.1, T(dp) = 7.5