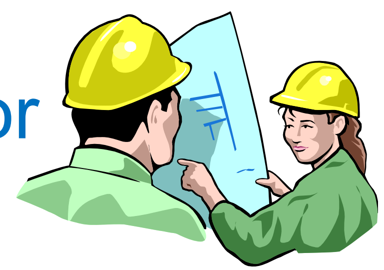
Business

- Professional application due Nov 17
  - Need to estimate what elective courses you will take
  - Mark how you fulfilled Math & Chemistry
  - Major and Total GPA
  - Fill out forms and spreadsheet
  - Then meet with your faculty advisor



- Case Study is Chapter 14
  - 20 problems, all connected
- Please report Dean's lecture attendance

Class 29

Heat and Humidity

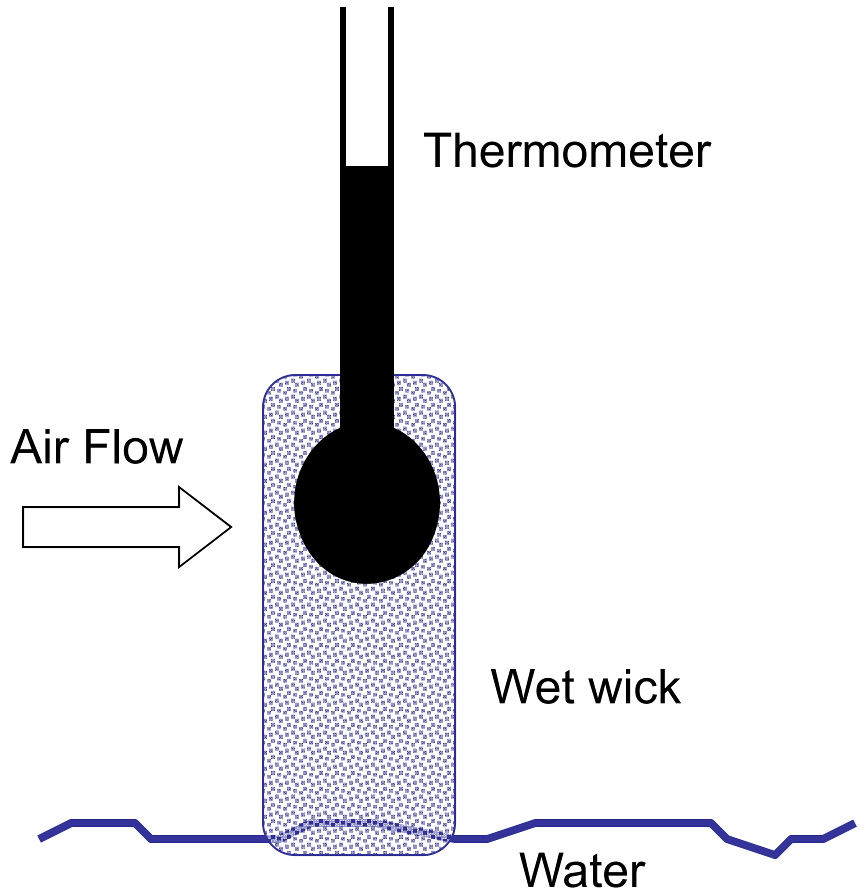
How Do You Measure Humidity?

- Cool the air and weigh the moisture
- Chemically absorb the moisture
- Correlate some other property, such as thermal conductivity
  - show **Kestrel instrument**
- Use IR spectra

How can I use something that I cannot pronounce?

- **Sling psychrometer**

Wet Bulb Temperature

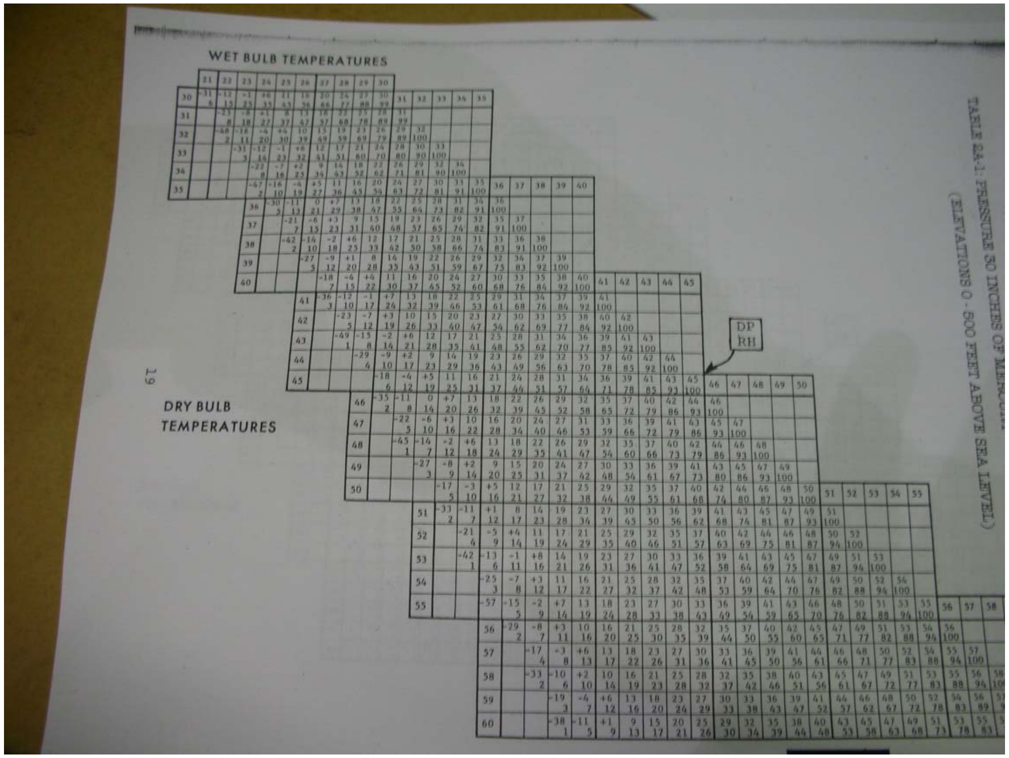


- Thermometer has a wet cloth around bulb
- Air blows past cloth
- As water evaporates, the bulb is cooled
  - Like when you get cold when you get out of a swimming pool
- The difference between dry and wet bulb temperatures is related to relative humidity (RH)
  - No water will evaporate at 100% RH, so $T_{dry} = T_{wet\ bulb}$
  - Biggest ΔT with driest air

Sling Psychrometer

- Two thermometers
  - One dry
  - One kept in wet cloth
- Twirl the wet thermometer
  - High velocity air through cloth
- Measures:
  - Dry bulb T
  - Wet bulb T

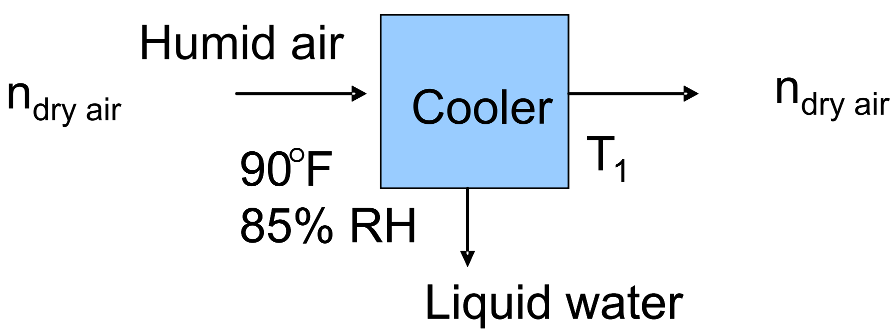
Other Psychrometers



- Wind speed
- $T_{dry\ bulb}$, $T_{wet\ bulb}$
- Relative humidity
- $T_{dew\ point}$

Air-Water Systems

- Extremely common
- Chart developed for ease of use
- LOTS of data on chart!
- Based on “dry air” balance
  – Like on the HW and practice exam!!



Psychrometric Chart

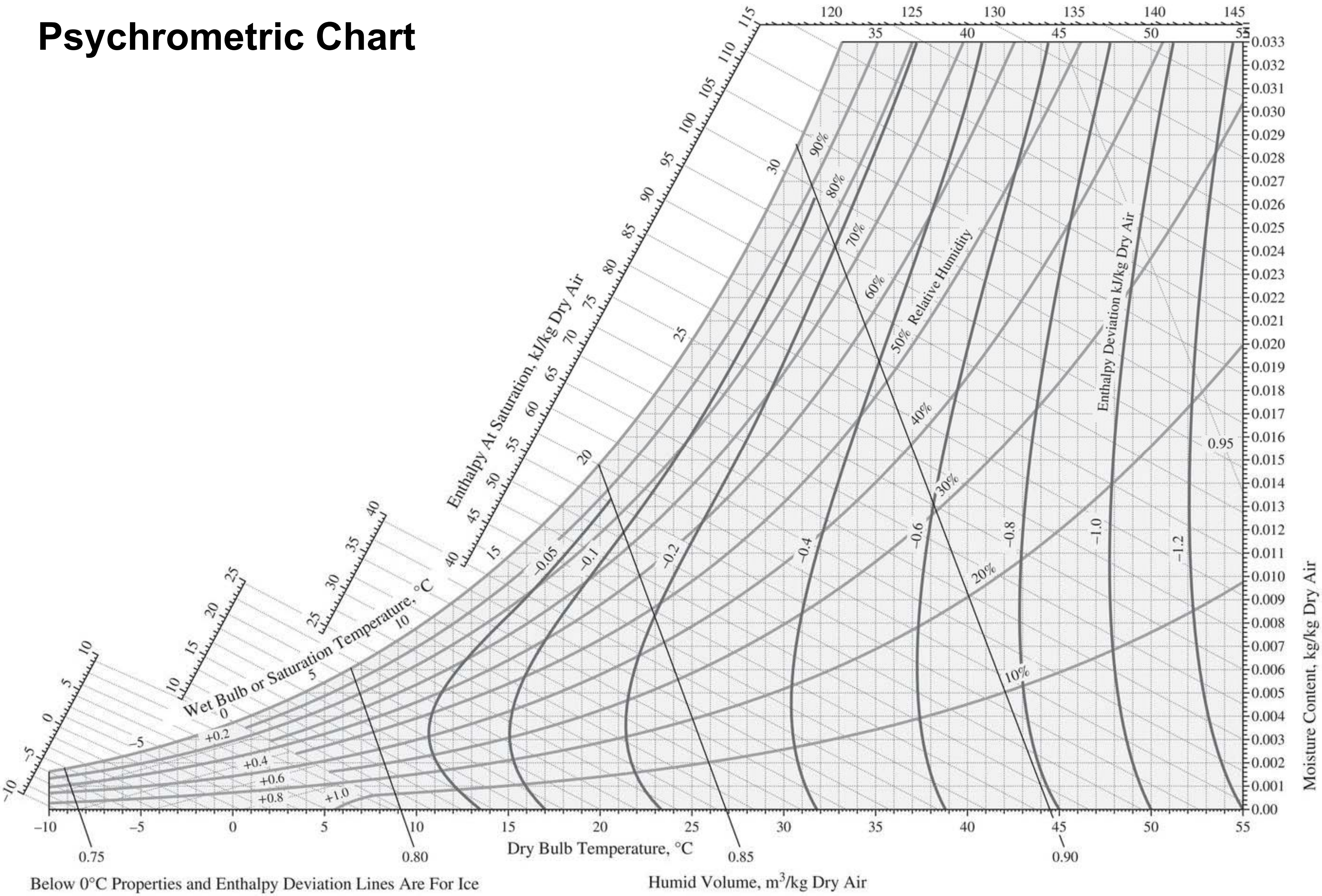


Figure 8.4-1 (p. 433)

Psychrometric chart—SI units. Reference states: H_2O (liquid, 0°C, 1 atm), dry air (0°C, 1 atm). (Data obtained from Carrier Corporation.)

American Units

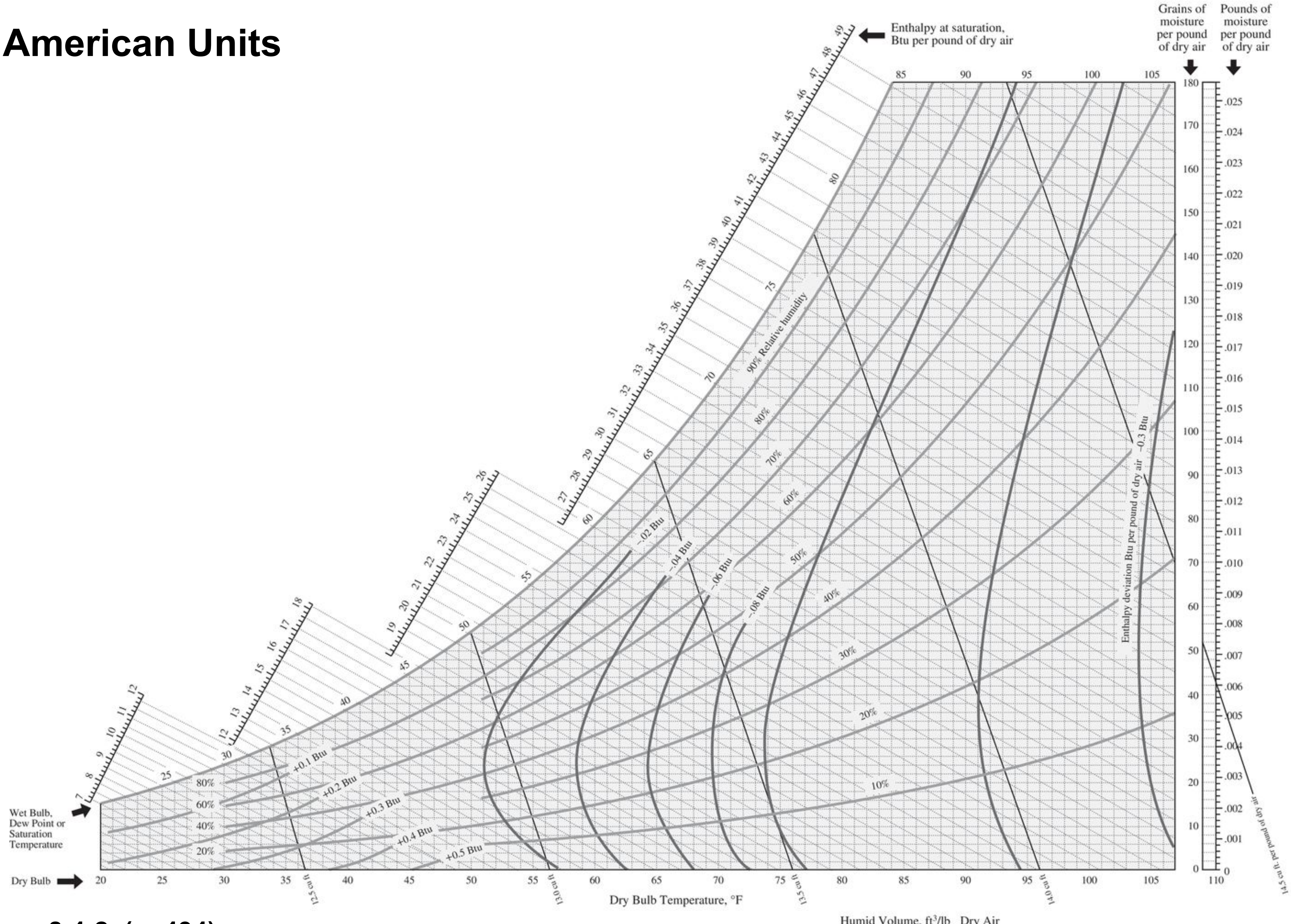


Figure 8.4-2 (p. 434)

Psychrometric chart—U.S. customary units. Reference states: H_2O (liquid, 32°F, 1 atm), dry air (0°F, 1 atm). (Data obtained from Carrier Corporation.)

Psychrometric Chart

(yes, I know the obvious nickname)

Air-Water systems at 1 atm

$$\hat{H}_{H_2O, L\,at\,0^\circ C, 1\,atm} = 0$$

$$\hat{H}_{air, gas\,at\,0^\circ C, 1\,atm} = 0$$

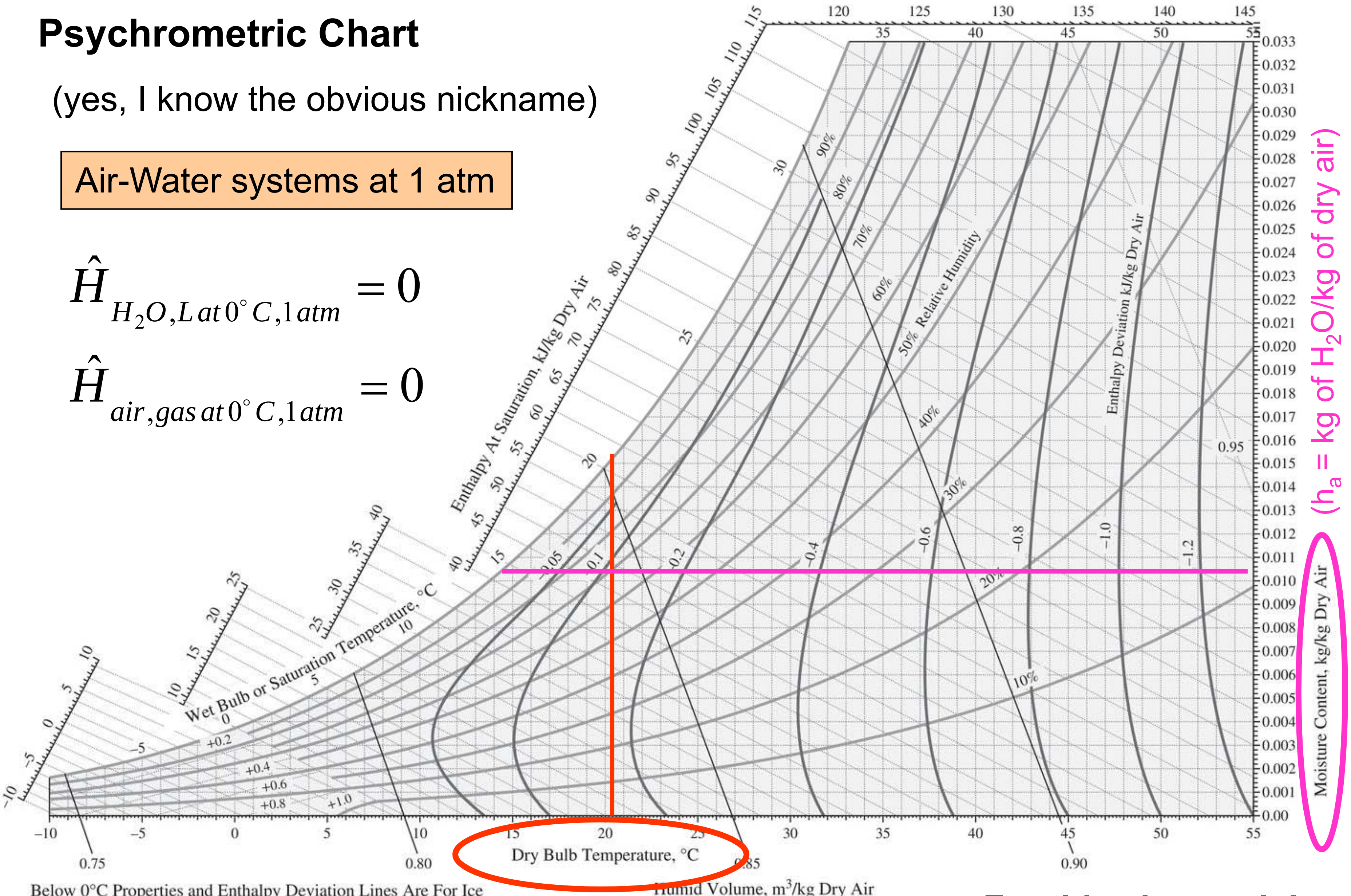


Figure 8.4-1 (p. 433)
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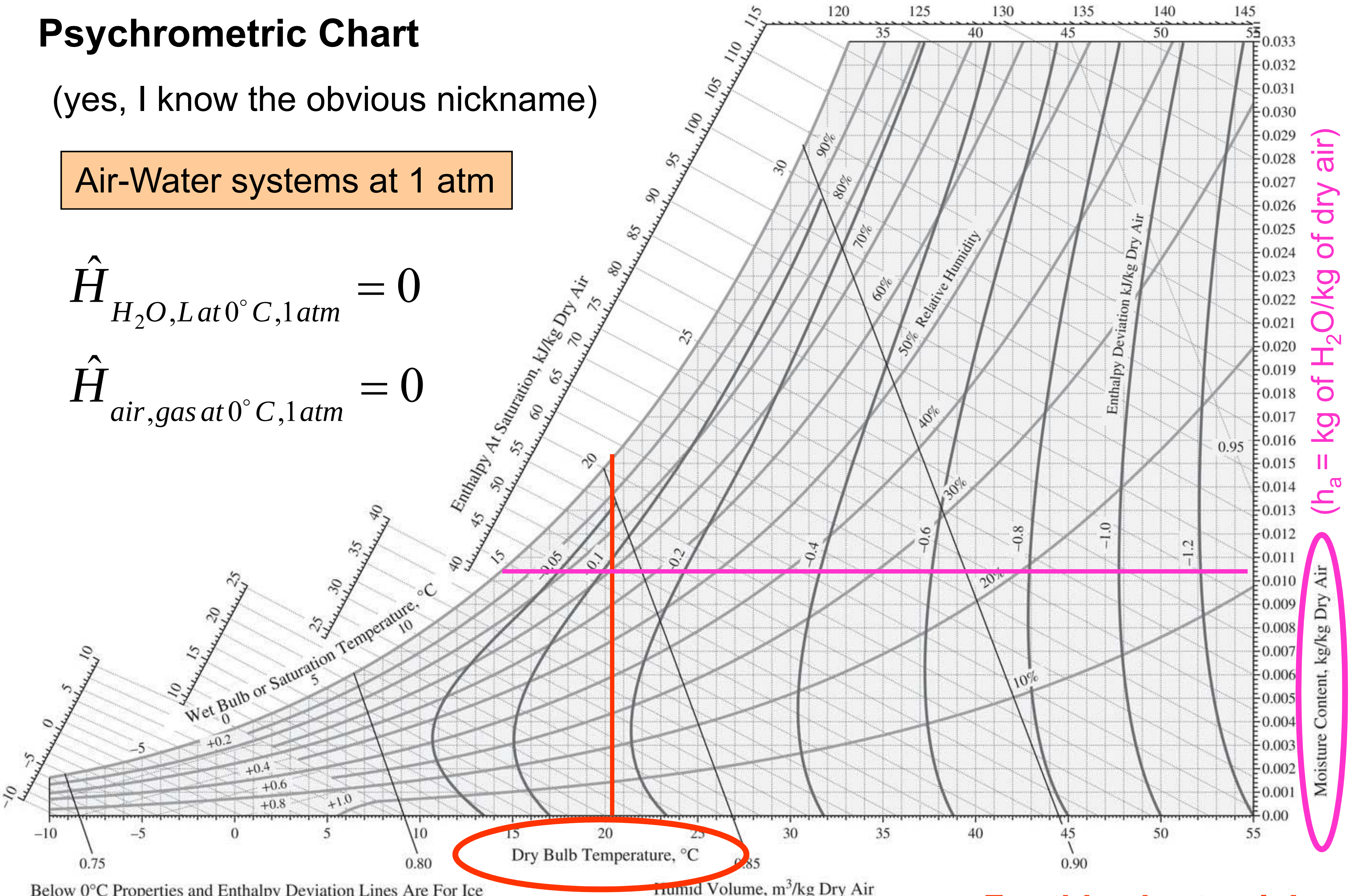


For this chart only!

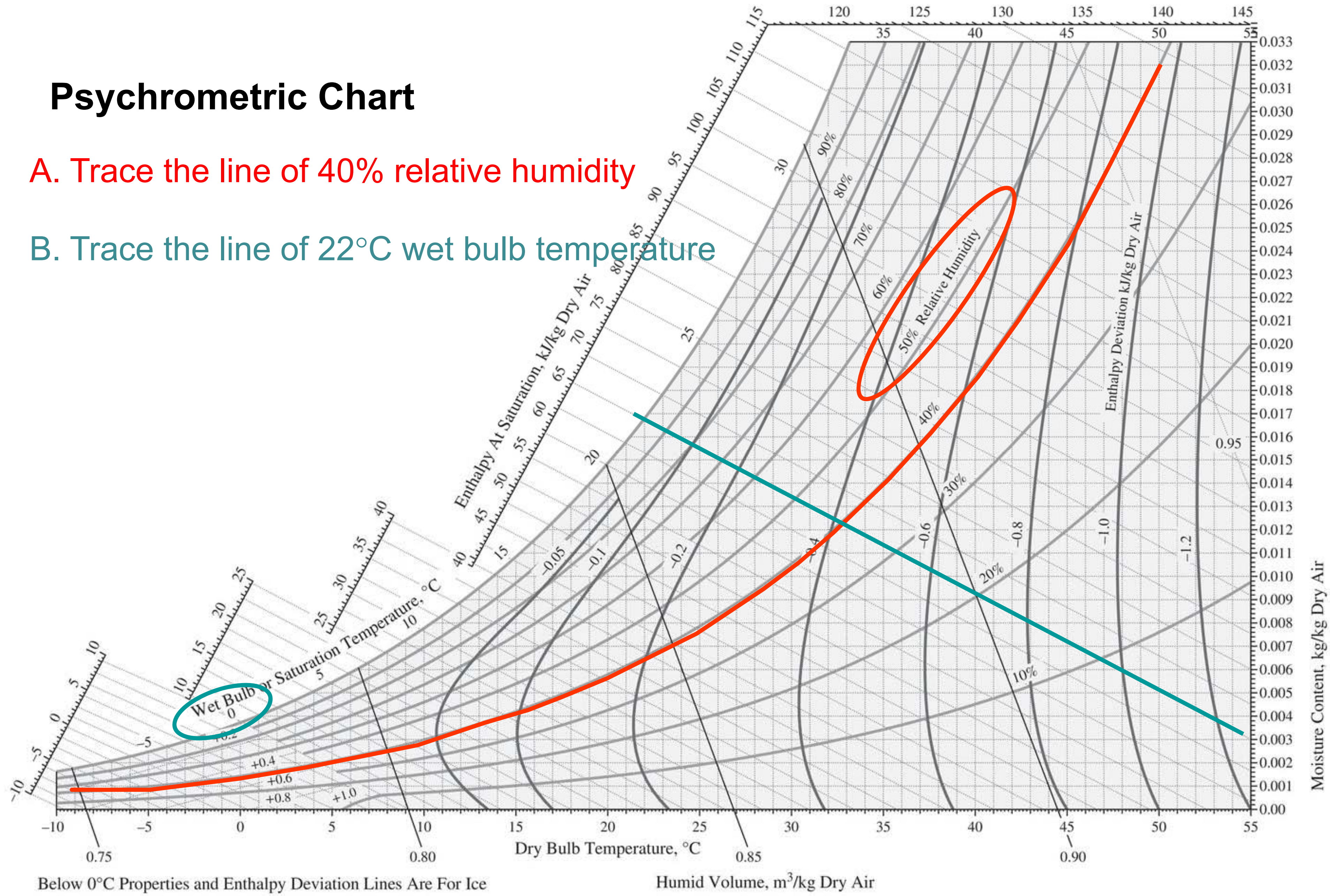
Figure 8.4-1 (p. 433)

Psychrometric chart—SI units. Reference states: H_2O (liquid, 0°C, 1 atm), dry air (0°C, 1 atm). (Data obtained from Carrier Corporation.)

Psychrometric Chart

A. Trace the line of 40% relative humidity

B. Trace the line of 22°C wet bulb temperature

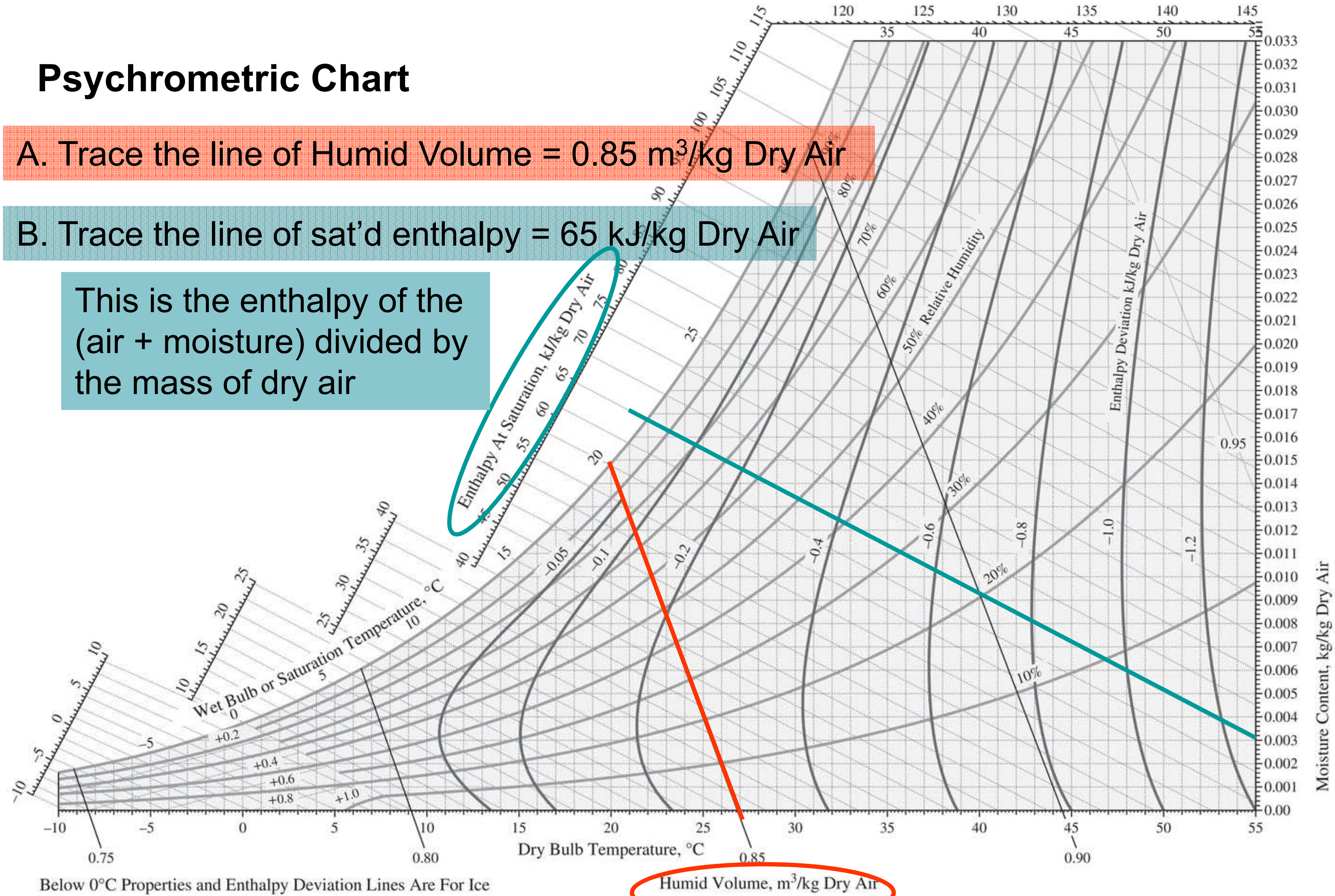


Psychrometric Chart

A. Trace the line of Humid Volume = 0.85 m^3/kg Dry Air

B. Trace the line of sat'd enthalpy = 65 kJ/kg Dry Air

This is the enthalpy of the (air + moisture) divided by the mass of dry air



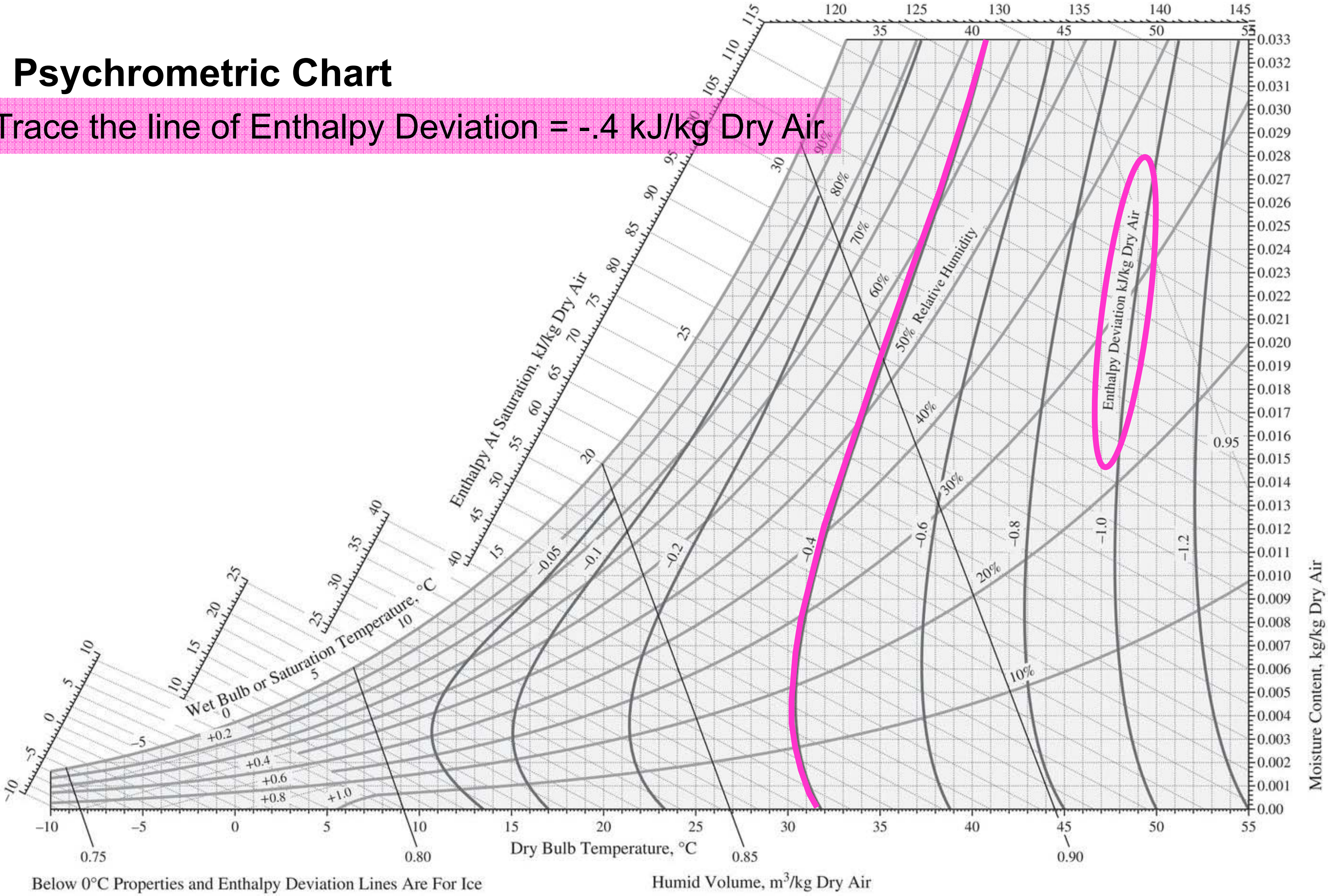
(m³ of air + water vapor)/(kg of dry air)

What if I want an enthalpy that is not saturated? (e.g., at 50% RH?)

- ΔH_{dev} given on chart
- $H_{true} = H_{sat'd} + \Delta H_{dev}$

Psychrometric Chart

Trace the line of Enthalpy Deviation = -.4 kJ/kg Dry Air



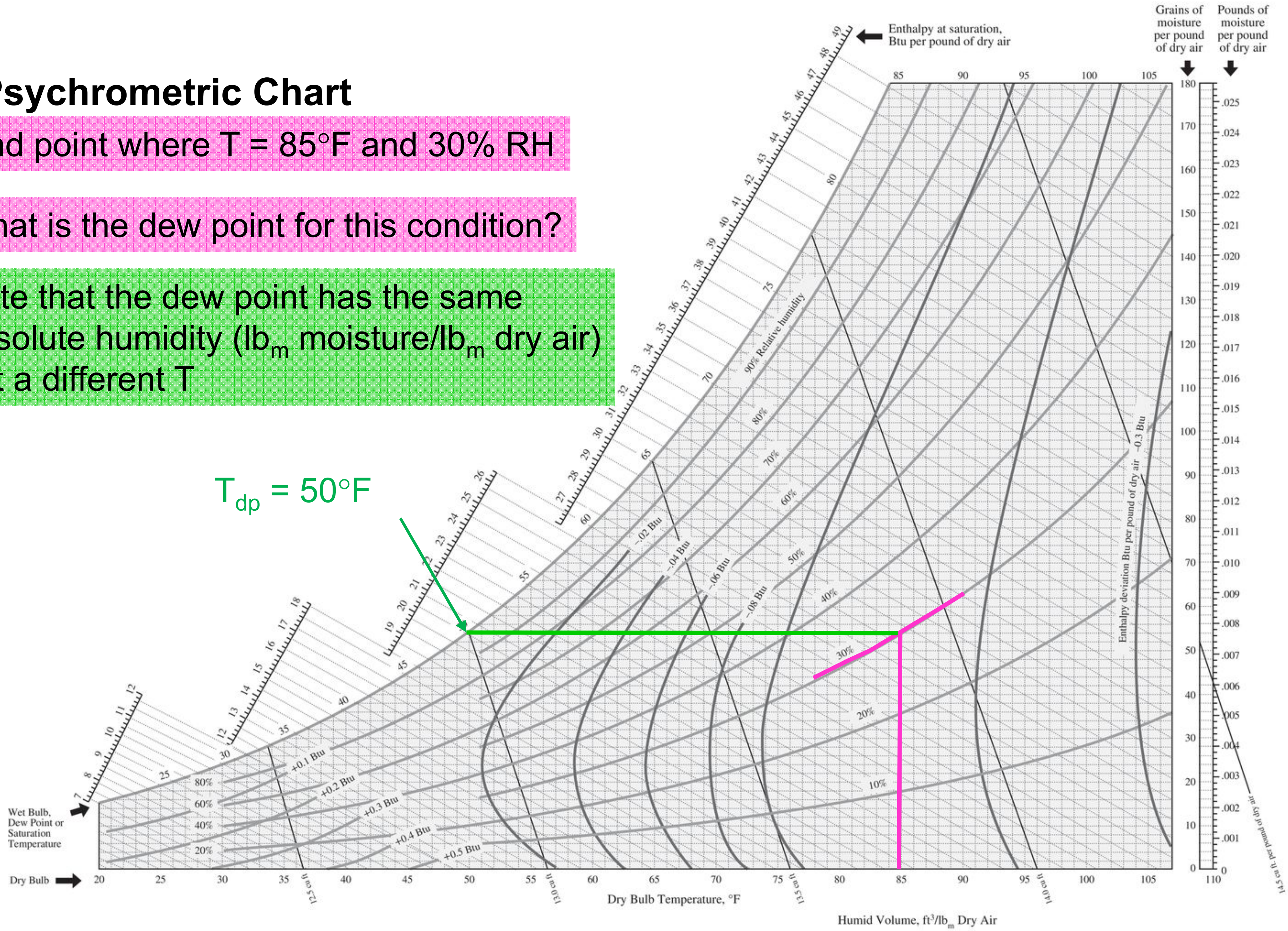
Psychrometric Chart

Find point where T = 85°F and 30% RH

What is the dew point for this condition?

Note that the dew point has the same absolute humidity (lb_m moisture/lb_m dry air) but a different T

T_{dp} = 50°F



When working with these charts, what is the enthalpy of liquid water?

- Reference enthalpy is liquid water at 0°C or 32°F

$$\hat{H}_{H_2O,L\,at\,T,1atm} = \hat{H}_{H_2O,L\,at\,0^\circ C,1atm} + \int_{0^\circ C}^{T} C_{p,H_2O,L}\,dT = C_{p,H_2O,L}\left(T - T_{ref}\right)$$

- $C_{p,H2O,L}$ = 1 Btu/lb$_m$·°F = 4.184 J/g ·°C

- Example: $\hat{H}_{H_2O,L\,at\,45^o F,1atm} = C_{p,H_2O,L}\left(45-32\right) = 13\,Btu/lb_m$

In-Class Assignment

Psychrometric Chart
Chemical Engineering 273, Class 29
In-Class Assignment

The psychrometric chart for air and moisture (i.e., H_2O) at 1 atm total pressure is shown on the next page. Please complete the following:

A. Air at 1 atm, 28°C, 70% relative humidity. Label this point A. Find the following from the psychrometric chart (and show your work on the graph, and don't forget units):
   1. absolute humidity (h_a) ___________
   2. Wet bulb temperature (T_{wb}) ___________
   3. Dew point temperature (T_{dp}) ___________
   4. Saturated enthalpy ($\hat{H}_{sat}$) ___________
   5. Specific enthalpy ($\hat{H}$) ___________
   6. Humid volume (V_h) ___________

B. Air at 1 atm, 80°F, T_{wb} = 70°F. Label this point B. Find the following from the psychrometric chart (and show your work on the graph, and don't forget units):
   1. absolute humidity (h_a) ___________
   2. Relative humidity (h_r or RH) ___________
   3. Dew point temperature (T_{dp}) ___________
   4. Saturated enthalpy ($\hat{H}_{sat}$) ___________
   5. Specific enthalpy ($\hat{H}$) ___________
   6. Humid volume (V_h) ___________

C. Air at 90°F, 80% RH, 100 ft^3/min is cooled to 60°F, 20% RH. Assume that the liquid water leaves at 60°F as well. Find the following:
   1. The mass flow rate of condensed water (lb_m H_2O (liq)/min)
   2. Cooling requirement (in tons of cooling, where 1 ton = 12,000 Btu/hr).

	Air stream in	Air stream out	Condensed water out
h_a (lb_m H_2O/lb_m dry air)			Not applicable
V_h (ft^3/lb_m dry air)			Not applicable
$\hat{H}$ (Btu/lb_m dry air)			

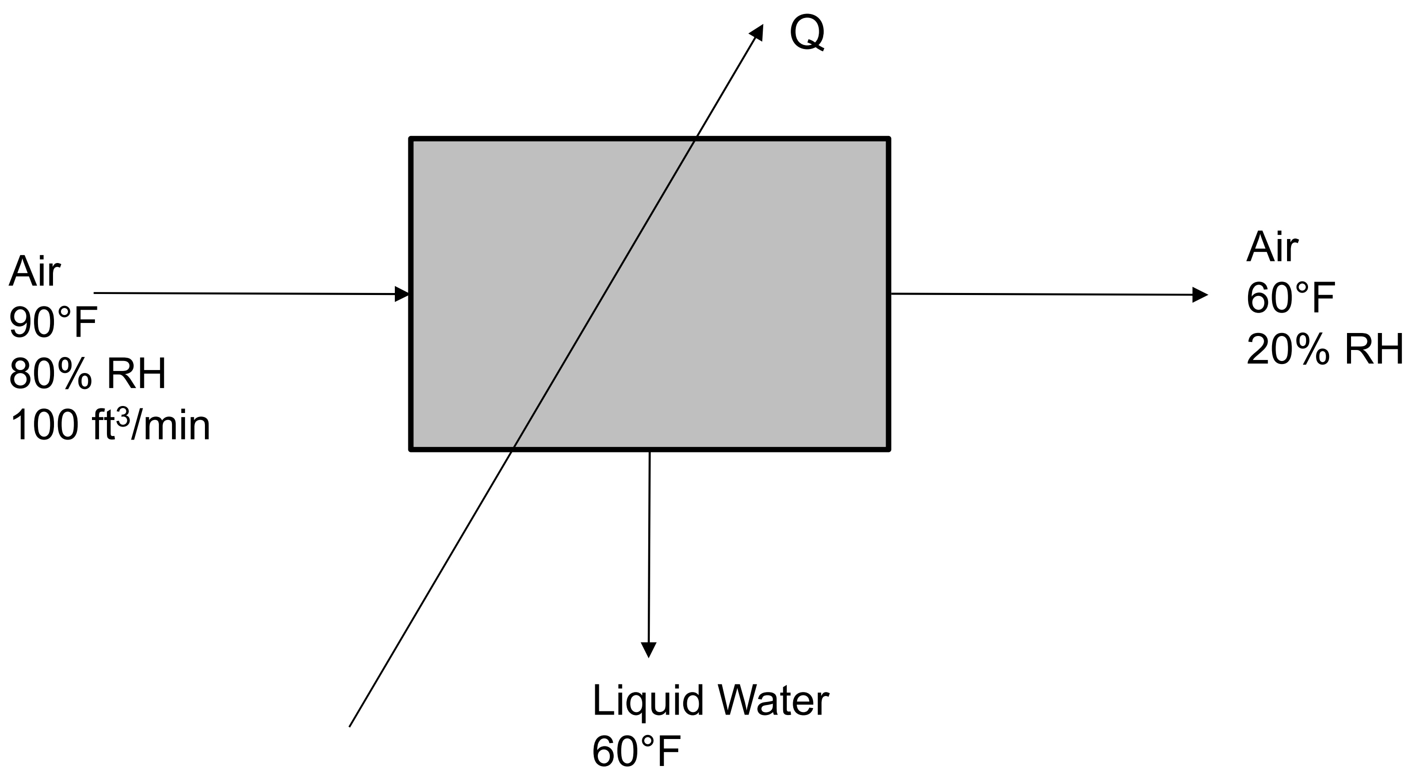
$\dot{m}_{dry\ air} =$

$\dot{m}_{H2O,in} =$

$\dot{m}_{H2O,vapor\ out} =$

$\dot{m}_{H2O,liquid\ out} =$

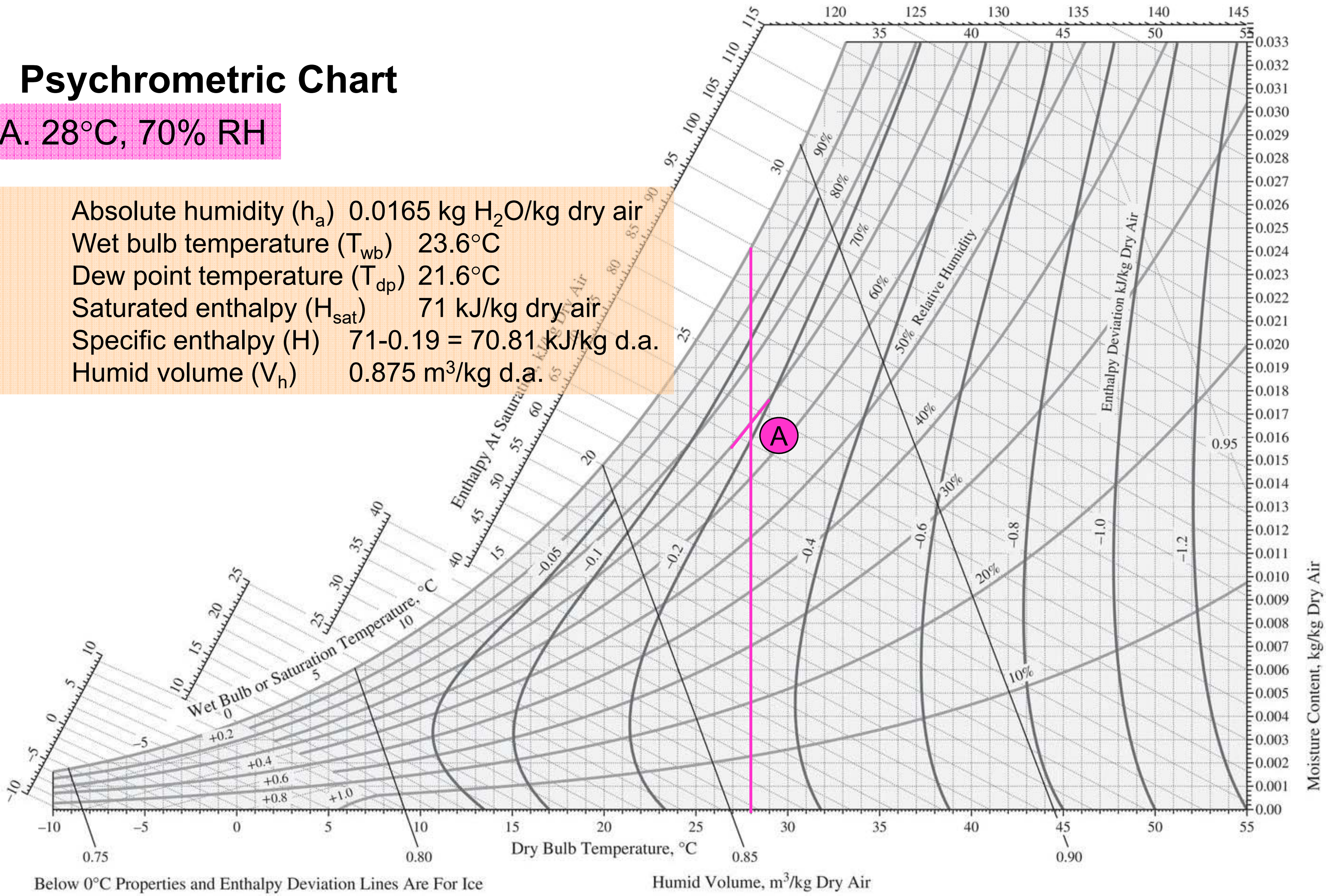
$\dot{Q} =$


Q
Air
90°F
80% RH
100 ft³/min
Air
60°F
20% RH
Liquid Water
60°F

Psychrometric Chart

A. 28°C, 70% RH

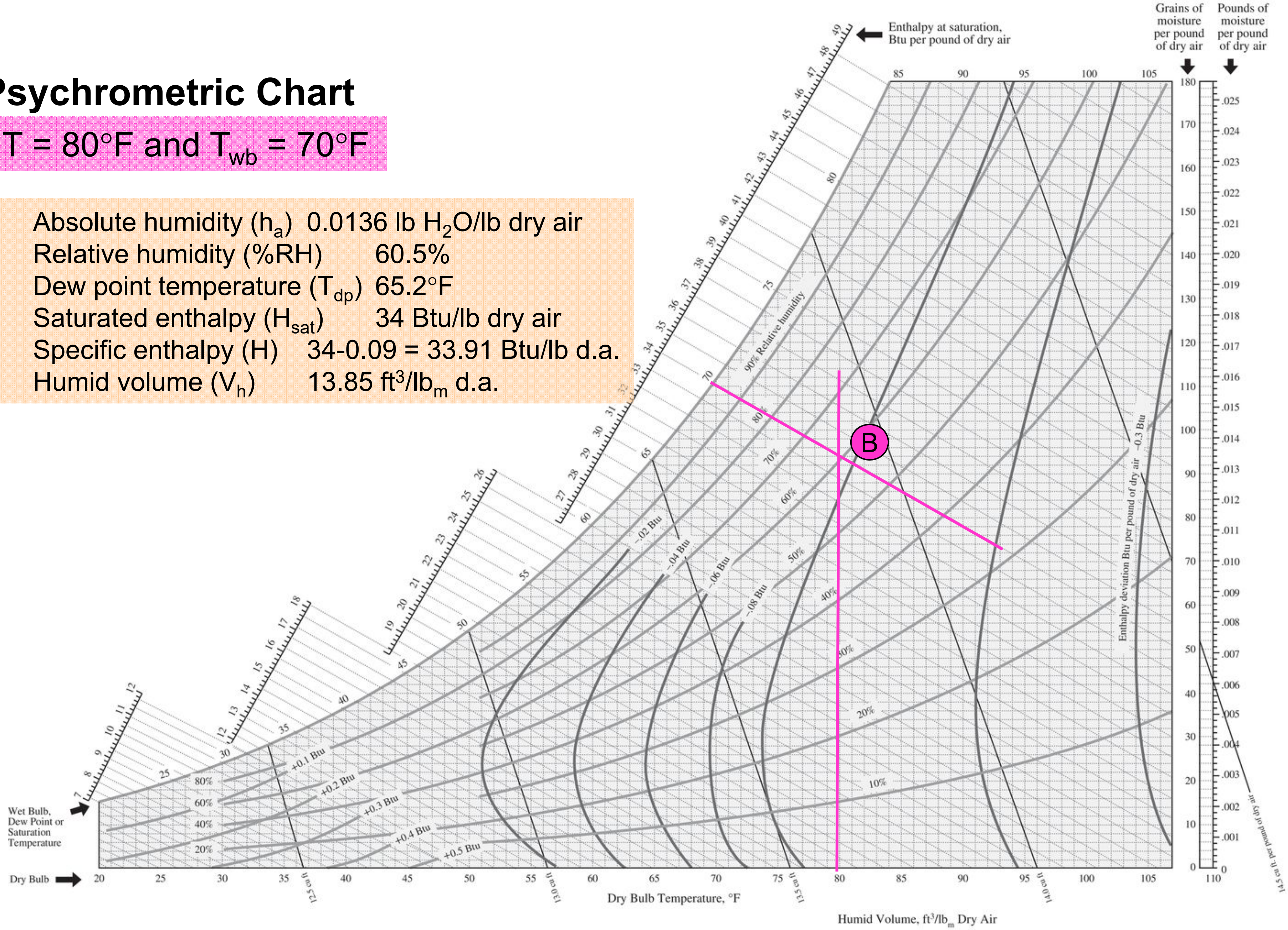
Absolute humidity (h_a) 0.0165 kg H_2O/kg dry air
Wet bulb temperature (T_{wb}) 23.6°C
Dew point temperature (T_{dp}) 21.6°C
Saturated enthalpy (H_{sat}) 71 kJ/kg dry air
Specific enthalpy (H) 71-0.19 = 70.81 kJ/kg d.a.
Humid volume (V_h) 0.875 m^3/kg d.a.



Psychrometric Chart

B. T = 80°F and T_{wb} = 70°F

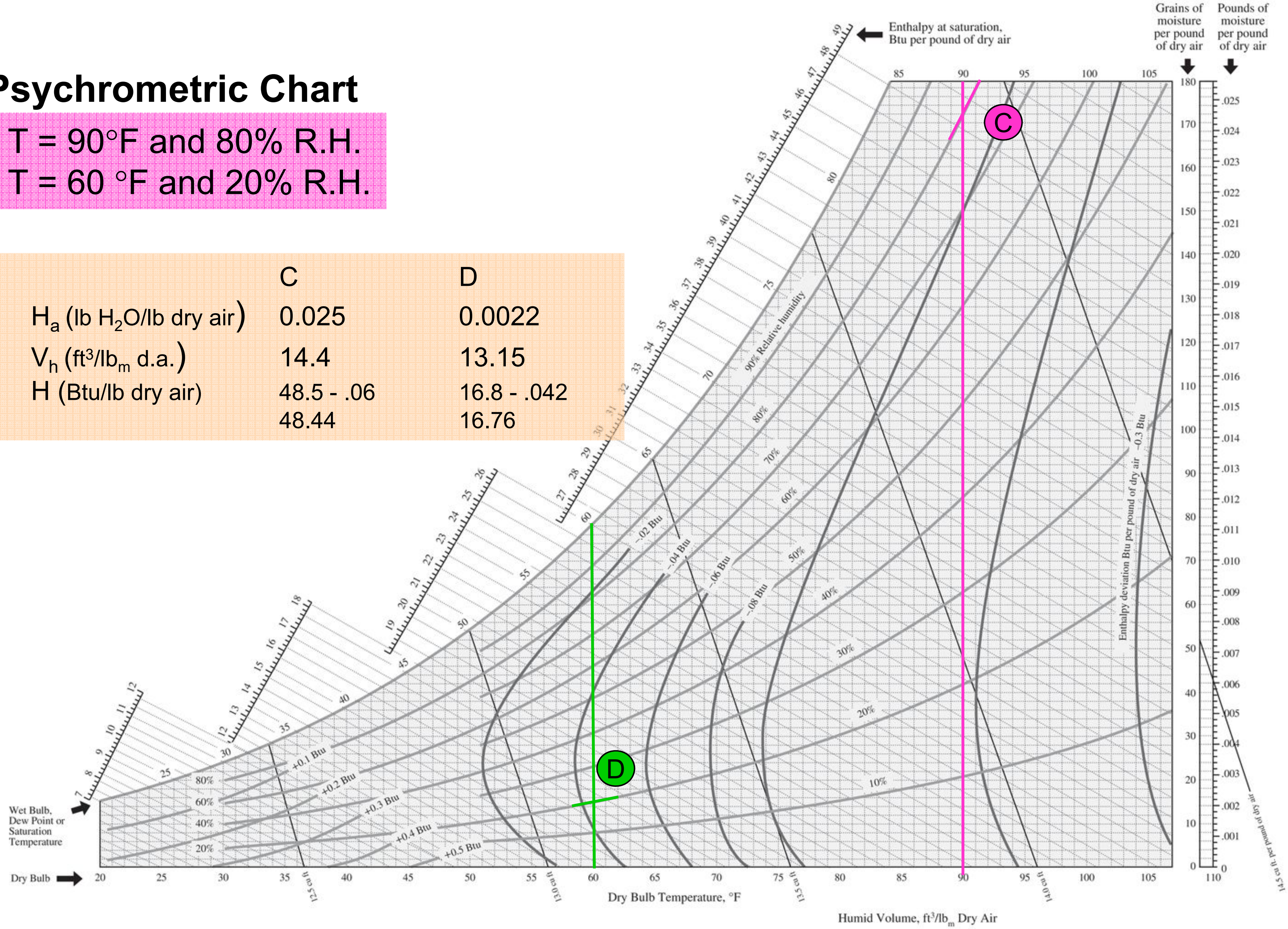
Absolute humidity (h_a) 0.0136 lb H_2O/lb dry air
Relative humidity (%RH) 60.5%
Dew point temperature (T_{dp}) 65.2°F
Saturated enthalpy (H_{sat}) 34 Btu/lb dry air
Specific enthalpy (H) 34-0.09 = 33.91 Btu/lb d.a.
Humid volume (V_h) 13.85 ft^3/lb_m d.a.



Psychrometric Chart

C. T = 90°F and 80% R.H.
D. T = 60 °F and 20% R.H.

	C	D
H_a (lb H_2O/lb dry air)	0.025	0.0022
V_h (ft^3/lb_m d.a.)	14.4	13.15
H (Btu/lb dry air)	48.5 - .06 48.44	16.8 - .042 16.76



Enthalpy of liquid water out?

$H = H_{ref} + c_p\Delta T$

$= 0 + (1\ Btu/lb_m\text{-}°F)(60 - 32°F)$

$= 28\ Btu/lb_m(liq)$

$$\dot{m}_{dry\ air} = \left(100\ \ ft^3/\min\right)\left(\frac{1}{14.4\ \ ft^3/lb\,dry\,air}\right) = 6.94\,lb_m dry\,air/\min$$

$$\dot{m}_{H2O,in} = \left(6.94\,lb_m\frac{dry\,air}{\min}\right)\left(0.025\frac{lb_m\,H_2O}{lb_m\,dry\,air}\right) = 0.1736\frac{lb_m\,H_2O_{in}}{\min}$$

$$\dot{m}_{H2O,vapor\ \ out} = \left(6.94\,lb_m\frac{dry\,air}{\min}\right)\left(0.0022\frac{lb_m\,H_2O}{lb_m\,dry\,air}\right) = 0.0153\frac{lb_m\,H_2O_{out}}{\min}$$

$$\dot{m}_{H2O,liquid\ \ out} = 0.1736\frac{lb_m\,H_2O_{in}}{\min} - 0.0153\frac{lb_m\,H_2O_{out}}{\min} = 0.1583\frac{lb_m\,H_2O_{liquid,out}}{\min}$$

$$\dot{Q} = \left(\sum \dot{m}\hat{H}\right)_{out} - \left(\sum \dot{m}\hat{H}\right)_{in}$$

$$= \left(0.1583\frac{lb_m\,H_2O_{liq,out}}{\min}\right)\left(28\frac{Btu}{lb_m(liq)}\right) + \left(6.94\frac{lb_m\,dry\,air_{out}}{\min}\right)\left(16.76\frac{Btu}{lb_m dry\,air}\right)$$

$$-\left(6.94\frac{lb_m\,dry\,air_{out}}{\min}\right)\left(48.44\frac{Btu}{lb_m dry\,air}\right)$$

$$= -215\frac{Btu}{\min} = -12{,}925\frac{Btu}{hr} = 1.08\ ton\ \ cooling$$