



BRIEF INSTRUCTION
OF
HEMMI BAMBOO SLIDE RULE
FOR
CHEMICAL ENGINEERING

No. 257

BRIAN CUNNINGHAM

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HEMMI
Bamboo Slide Rule

We wish to mention that in designing this slide rule we are deeply indebted to Professor Kazuo SATO of the Tokyo Institute of Technology for his kind and generous instructions and herewith express our profound appreciation and gratitude in this matter.

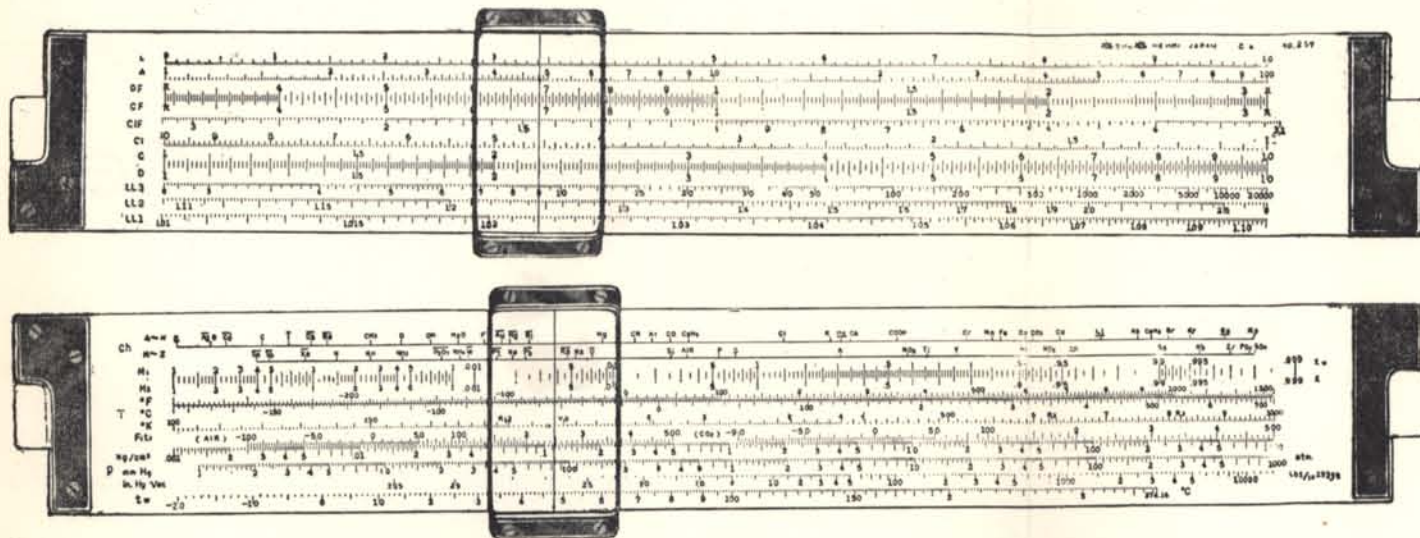
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BRIEF INSTRUCTION OF THE CHEMICAL ENGINEERING SLIDE RULE

(HEMMI NO. 257)



Hemmi Bamboo Chemical Engineering Slide Rule No. 257

I. General Description.

CHARACTERISTICS:

This slide rule is specially designed with the scales arranged to meet the requirements of modern chemical engineers, aiming chiefly rapid and easy treatment of problems in chemical systems where pressure, temperature and concentration play principal role.

Furthermore, this slide rule is provided with scales for the calculation of adiabatic expansion and compression of gases, the liquid-vapor equilibrium relation, atomic and molecular weights, and with several other useful gauge marks.

This slide rule is of duplex type, and the above mentioned scales and gauge marks are arranged on its rear face. Scales on its front face are those mostly for the use in multiplication and division, squares, logarithms and exponential computations.

ARRANGEMENT AND USAGE OF SCALES:

Front Face

- L.....Common logarithm
- ASquare and square root
- DF, CF, CIF (π -fold).....Multiplication, division and proportion
- D, C, CI
- LL3, LL2, LL1..... Exponent

Rear Face

- Ch Atomic and molecular weight
- M_1, M_2, X_W, X Conversion of concentration units, liquid-vapor equilibrium relation of two-component ideal system
- T { °F (Fahrenheit)
°C (Centigrade)Temperature
°K (Kelvin)
- F(t) Adiabatic expansion and compression
- P { Kg/cm²
mmHg, atm
in Hg vac, Lbs/in² gage } Pressure
- t_W Saturated temperature of steam

Inasmuch as scales on the front face are all popular ones, general calculation such as multiplication, division, proportion and others can be performed with them in exactly the same manner as with other standard slide rules.

In this pamphlet, brief explanation to the use of special scales for chemical engineering shall be given in the following chapters.

2. Use of the "Ch" Scale.

This scale consists of gauge marks for 52 elements and 18 atomic groups, and by projecting these marks

on D scale their atomic and formula weights can promptly be found.

Proper places of values are identified by method as given below:

- Mark with line under1 place
- Mark with no line.....2 places
- Mark with line above3 places

Example 1. Find the atomic weights of Li, Al and Hg, respectively.

By setting the indicator line successively at the marks Li, Al and Hg, the required values, 6.94, 27.0 and 200.6, respectively, are obtained.

3. Conversion of Units in Temperature and Pressure.

The temperature scale T is classified into three systems according to its unit, °F, °C and °K. These scales are so arranged on the slide as to correspond with each other, and the scale °K is nothing but the D scale, a 1-unit logarithmic scale ranging from 100 to 1000. Therefore, calculation in absolute temperature T (°K) can be done by using °C or °F scale with °K scale. (see Chapter 7).

The pressure scale P is classified into five systems according to its unit, Kg/cm², atm, mmHg, all of absolute measure, and Lbs/in², in. Hg of vacuum, of gage measure. These scales are arranged on the lower stock, each corresponding to the other, whereas the scale Kg/cm² is composed of 6-unit logarithmic scale ranging from 0.001 to 1000.

To convert a certain temperature or pressure unit into the other systems, it can easily be done by corresponding these scales with each other with aid of the indicator line.

Example 2. Convert 120°C into the other units.

Ans. 120°C = 248°F = 393°K = 708°R.



Set the slide to correspond the left index of C scale to 1.8 of D scale on the opposite side, and the indicator line at 120 on $^{\circ}C$ scale. Then, under the indicator line the answers are obtained as 248 on $^{\circ}F$ scale, 393 on $^{\circ}K$ scale, and 708 on D scale respectively.

Example 3. Indicate the pressure of 120 Lbs/in² gage by the other units.

Ans. 120 Lbs/in²=11.2 atm=11.5 Kg/cm².

Set the indicator line at 120 on the scale Lbs/in² gage, and read the corresponding values on scales atm and Kg/cm², respectively.

4. Saturated Steam Temperature.

The scale t_w represents the condensing temperature of saturated steam or the boiling temperature of water, corresponding to the pressure of any scales on P . Now, 374.16 $^{\circ}C$ on this scale means the critical temperature of water, and values below zero show temperature of undercooled ice.

This temperature scale, t_w , can also be utilized as a temperature axis of the Cox chart or the Othmer's plot.

Example 4. Find the pressure of saturated steam at 150 $^{\circ}C$.

Ans. 4.85 Kg/cm²=4.7 atm=54.5 Lbs/in² gage.

Set the indicator line at 150 $^{\circ}C$ on the t_w scale, and read the saturated pressure of any desired unit on pressure scales.

Example 5. Compute the boiling point of water under the pressure of 30 mmHg.

Ans. 29 $^{\circ}C$.

Set the indicator line at 30 on mmHg scale, and read the required boiling temperature 29 $^{\circ}C$ on scale t_w .

5. Conversion of Concentration Units.

The scales X_w and X are graduated with the values $\log \frac{X}{1-X}$ as the function of X . Then, by cooperating these scales with M_1 and M_2 scales which are two sections of a 8-unit logarithmic scale, problems to convert a certain concentration unit of two-component chemical system into other unit are solved, and any other similar computations as following type can be made.

$$\frac{X}{1-X} \cdot \frac{M_1}{M_2} = \frac{X_w}{1-X_w} \quad (1)$$

where, X , X_w =mol fraction and weight fraction of the first component, respectively.

M_1 , M_2 =molecular weight of the first and the second components, respectively.

Example 6. Convert 20 wt-% of ammonium sulphate solution to mol-%.

Here, $M_1=132.1$ and $M_2=18.0$ are given.

As in Fig. 1, set 132 on M_1 scale at 18 on M_2 scale and read 0.033 in mol fraction or 3.3 mol-% on X scale against 0.20 on X_w scale.

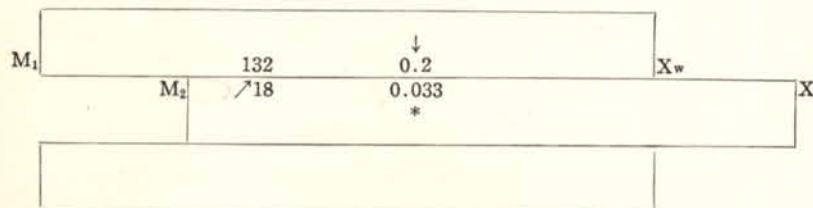


Fig. 1

Example 7. Convert 20, 50 and 80 wt-% of ethyl alcohol aqueous solution to vol-% at 15.56 $^{\circ}C$. Here, the densities of pure ethyl alcohol and water are 0.794 and 0.999, respectively at 15.56 $^{\circ}C$.

Ans. 24.0, 55.8 and 83.5 vol-%.

In this case, the basic equation is as follows:

$$\frac{X_v \cdot \rho_1}{1-X_v} = \frac{X_w}{1-X_w} \quad (2)$$

where, X_v , X_w =volume fraction and weight fraction of the first component, respectively.
 ρ_1 , ρ_2 =densities of the first and the second pure components, respectively.

As in Fig. 2, set 0.794 (ρ_1) on M_1 scale at 1 (ρ_2) on M_2 scale and read 0.240, 0.558 and 0.835 in volume fraction on X scale against 0.20, 0.50 and 0.80, respectively, on X_w scale.

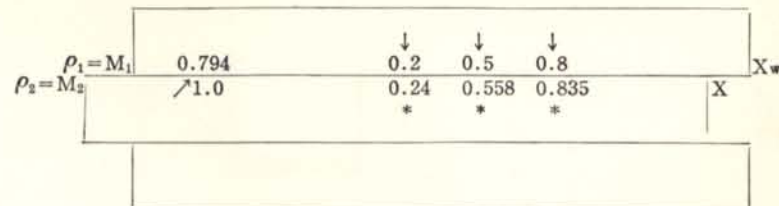


Fig. 2

6. Liquid-Vapor Equilibrium Relation.

In the ideal solution composed of two volatile liquids where the Raoult's law holds, there are certain equilibrium relations between liquid and vapor compositions at a given condition, as follows:

$$\frac{x}{1-x} \cdot \frac{P_1}{P_2} = \frac{y}{1-y} \quad (3)$$

where, x , y =mol fractions of more volatile component in liquid phase and vapor phase, respectively, at the equilibrium condition.

P_1 , P_2 =vapor pressures of more volatile and less volatile pure components, respectively, at the temperature of equilibrium condition.

Since Eq. (3) is the same type of Eq. (1), the liquid-vapor equilibrium relations (x - y relations) of ideal two-component liquid systems can be computed with aid of (M_1 , M_2), (X_w , X) scales.

Example 8. Find x - y relations of benzene-toluene system under 1 atm.

A boiling point of mixture under a certain pressure varies with composition, but ratio of vapor pressures of pure components at the boiling point of mixture retains approximately constant. Vapor pressures of pure components, therefore, are adopted as geometric means of vapor pressures of pure components at their boiling points, as shown in Table 1.

Table 1

	Vapor pressure of pure component (mmHg)	
	Benzene	Toluene
at the boiling point of benzene (80.2 $^{\circ}C$)	760	292
at the boiling point of toluene (110.8 $^{\circ}C$)	1770	760
geometric mean $P_1=1160$		$P_2=470.5$

As in Fig. 3, set 470 (P_2) on M_2 scale at 1160 (P_1) on M_1 scale and read values (y) on X_w scale against any desired values of liquid composition (x) on X scale. The obtained results are listed in Table 2 and plotted in Fig. 4.

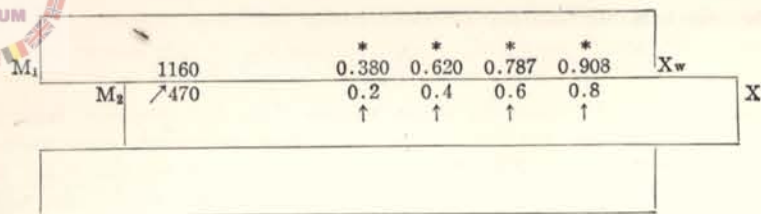


Fig. 3

Table 2

x	y
0.2	0.380
0.4	0.620
0.6	0.787
0.8	0.908

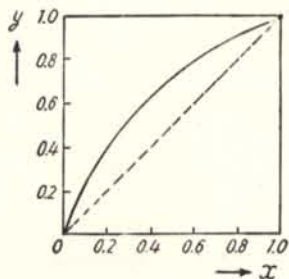


Fig. 4

7. Calculation containing a Factor of Absolute Temperature.

Calculations containing a factor of absolute temperature T ($^{\circ}\text{K}$) frequently appear in problems of physical chemistry and chemical engineering which are very troublesome because actual data are usually given in terms $^{\circ}\text{C}$ or $^{\circ}\text{F}$.

Since all temperature scales on this slide rule corresponds each other and the scale $^{\circ}\text{K}$ is a standard 1-unit logarithmic scale, these calculations can be very easily treated.

Example 9. Compute $580/T$ when the temperature is given as 50°C .

Set 50 on $^{\circ}\text{C}$ scale at 580 on D scale, and get 1.794 on D scale against the left index of C scale.

Example 10. Find $\log T$ for the given temperature 85°F .

Insert the slide correctly into the stock, set the indicator line at 85 on $^{\circ}\text{F}$ scale, and read the value of mantissa of $\log T$ as 0.481 on L scale under the indicator line. By adding the characteristics 2, $\log T = 2.481$ is obtained.

Example 11. What is the reduced temperature of 60°F referred to the critical temperature of methane (-82.1°C)? *Ans.* 1.51

Set the indicator line at 1 at the center of DF scale on the front face and the slide so as to come -82.1 on $^{\circ}\text{C}$ scale under the indicator line on the rear face. Move the indicator line to 60°F and read the value of DF scale, 1.51, on the front face again.

8. Adiabatic Expansion and Compression of Gases.

The relation between temperature and pressure in adiabatic expansion or compression of ideal gas is represented by the following thermodynamic equation:

$$R \ln \frac{P_2}{P_1} = \int_1^2 C_p d \ln T \quad (4)$$

where, P_1, P_2 = initial and final pressures, respectively.

R = molecular gas constant.

$C_p = a + bT + cT^2$ = molecular heat at constant pressure.

a, b and c = constants depending on type of gas.

On this slide rule two systems for this equation had been adopted. One is air as representative of two-atomic gases and the other, CO_2 as that of three-atomic gases.

Example 12. What will be the theoretical temperature ascent of air at 20°C , when it is compressed adiabatically from 1 atm up to 60 Lbs/in 2 gage of pressure?

Set 20°C on $F(t)$ scale for air at 1 on atm scale, and get the temperature 192°C on $F(t)$ scale corresponding to 60 on Lbs/in 2 gage scale, as represented in Fig. 5.

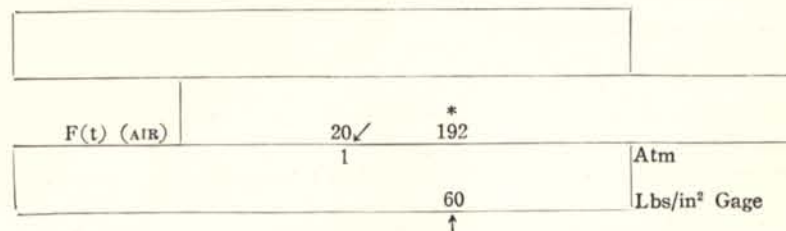


Fig. 5

Example 13. What will be the theoretical temperature descent of 12°C CO_2 gas when it is expanded from 1.5 to 0.4 Kg/cm 2 in pressure?

Set 12°C on $F(t)$ scale for CO_2 at 1.5 on Kg/cm 2 scale, and get the temperature -62°C on $F(t)$ scale corresponding to 0.4 on Kg/cm 2 scale.

9. Logarithmic Mean.

The logarithmic mean temperature difference, Δ_{tm} , between outside and inside fluid temperature as in tubular heat exchanger, is represented by the following equation:

$$\Delta_{tm} = \frac{\Delta_1 - \Delta_2}{\ln \frac{\Delta_1}{\Delta_2}}$$

where, Δ_1, Δ_2 = temperature differences between two fluids at inlet and outlet, respectively, of the equipment.

This calculation can be performed with this slide rule by cooperation of C and LL scales.

Example 14. Calculate the logarithmic mean temperature difference, where $\Delta_1 = 100^{\circ}\text{C}$, $\Delta_2 = 70^{\circ}\text{C}$ are given, *Ans.* 83.9°C .

Firstly, get the ratio $\Delta_1/\Delta_2 = 100/70 = 1.43$ using C and D scales as ordinarily. Then, set the indicator line at 1.43 on $LL2$ scale, and set $100 - 70 = 30$ on C scale under the indicator line, then against the right index on D , 83.9 is read on C scale.

10. Gauge Marks.

This slide rule has the essential gauge marks on $^{\circ}\text{K}$ scale which are frequently used in chemical engineering, that is:

- $R_1 = 1.986$ (cal. $\text{degr}^{-1} \cdot \text{mol}^{-1}$)
- $R_2 = 62.360$ (L. mmHg. $\text{degr}^{-1} \cdot \text{mol}^{-1}$)
- $R_3 = 0.08205$ (L. atm. $\text{degr}^{-1} \cdot \text{mol}^{-1}$)
- $V_0 = 22.414$ (L. mol^{-1}) Standard molecular volume of ideal gases
- $F = 26.8$ (amp. hr. g-equiv $^{-1}$) Faraday constant
- $k = 273.16/760 = 0.3594$ ($^{\circ}\text{K} \cdot \text{mmHg}^{-1}$) Correction factor for volume of ideal gases
- $J = 4.185$ (joule. cal $^{-1}$) Mechanical equivalent of heat