P00 eLEAPS Problem Session Script

Problem Name: P00 Ideal Gas Law
Problem Description: Simplest Equation of State

Date: ________________ **Your Name:** ______________________________________

Problem Session Objectives

- To review the concept of temperature with its absolute and relative units.
- To review the concept of pressure with its absolute and relative units.
- To review the concept of a mole with its three kinds of units.

- To review the concept of the ideal gas law applied to a stationary substance.
- To examine the concept of the ideal gas law applied to a flowing substance.
- To view some measurement devices for temperature and pressure.

Reference Readings

- Felder and Rousseau, 3rd Edition, Section 3.1, Mass and Volume.
- Felder and Rousseau, 3rd Edition, Section 3.2, Flow Rate.
- Felder and Rousseau, 3rd Edition, Section 3.3, Chemical Composition.

- Felder and Rousseau, 3rd Edition, Section 3.4, Pressure.
- Felder and Rousseau, 3rd Edition, Section 3.5, Temperature.
- Felder and Rousseau, 3rd Edition, Section 5.2, Ideal Gases.

- Michael Hanyak, white CinChE Manual, Latest Edition, Chapter 3.

Review Materials

- A good reference on measuring devices and their principles of operation is http://www.omega.com. Check out the **Technical Reference** section under Omega's *Temperature, Pressure, and Flow Handbooks*, particularly as you prepare for and conduct laboratory experiments.

- Another good reference on measuring devices is the *Visual Encyclopedia of Chemical Engineering Equipment* on the CD-ROM that comes with the Felder and Rousseau textbook. Check out the **Process Parameters** section in this encyclopedia, particularly as you prepare for and conduct laboratory experiments.

Interaction 1:

Topic: Ideal Gas

Background: Welcome to the eLEAPS problem session about an ideal gas. Save this script document to the desktop. Click here to open and save the solution template also to the desktop. Close all internet browser windows. Open the two saved documents with **Adobe Reader**.

In the solution template document, right click and select **Print**, choose "**Document and Markups**" under **Comments and Forms**, and print it to get a PAPER COPY. Print to a color printer for the best effect. You will fill-in this paper copy as you do the problem session. Close the template document and then delete it, since it is no longer needed.

P00 eLEAPS Problem Solution Template

Coaching Script and Solution Template

This coaching script contains two kinds of pages—script and template. They are arranged similar to the left and right pages in a book. The left page is an interaction in the coaching script. The right page is the current focus in the solution template that is associated with the left coaching script page.

How you navigate through the coaching script depends up the type of computer that you are using—a personal computer with a mouse or an Apple iPad with a stylus pen. In either case, you have opened this coaching script using the Acrobat Reader program that is installed on your computer and not the Acrobat Reader plug-in found in a web browser.

Please complete the first interaction in the first coaching script page. Then, proceed to navigate through the coaching script based upon your computer type, as describe below.

Personal Computer with a Mouse

The Acrobat Reader program should have displayed this coaching script in its two-page view mode. If not, then select the **View/Page Display/Two Page Scrolling** option from the menu bar.

In the two-page view mode, the left column of pages will be the coaching script, while the right column of pages will be the current focus in the solution template. You can magnify the view (i.e., zoom in) so that the coaching script page is readable. Then, you can use the horizontal scroll bar to move between the left page (the coaching script) and its right page (the template solution).

After you manually complete a portion of your PAPER COPY of the problem solution template (as directed by its associated coaching script interaction), you can then delete the boxes in the right page to view the correct answers. You can also view the popup notes found in the right page.

You proceed to the next script **Interaction** by scrolling down to the next set of two pages in the Acrobat Reader program.

Apple iPad with a Rubber-Domed Stylus Pen

The Acrobat Reader app for the iPad (downloaded from the App Store) does not support the two-page view mode. To simulate this viewing mode, select the **Single Page** option under **Document Modes** in the menu bar.

In the **Single Page** mode, you will be able to horizontally swipe between the left page (the coaching script) and its right page (the template solution).

After you manually complete a portion of your PAPER COPY of the problem solution template (as directed by its associated coaching script interaction), you can then delete the boxes in the right page to view the correct answers. You can also view the popup notes found in the right page.

You proceed to the next script **Interaction** by swiping pass the current right page in the Acrobat Reader app.

If you quickly tap the **Home** button on the iPad twice, you can conveniently switch between the Adobe Reader and any other apps.

Interaction 2:	
Topic:	Temperature Scales
Background:	We begin our review of quantities appearing in the ideal gas law by first examining the concept of temperature. Please examine Page 1 of your PAPER COPY of the template document. As indicated by the SEVEN yellow rectangles, you are to complete the scale diagram, conversion factors, and conversion equations for temperature.
Temperature Question:	The relative scales for temperature are ºF and ºC. Which Centigrade <u>value or values</u> below that are divisible by ten would convert to Fahrenheit values that are also divisible by ten?
Option 1:	□ -40ºC
Option 2:	□ 0ºC
Option 3:	□ 10ºC
Option 4:	□ 110ºC
Feedback 1:	Select the text of your first option and then highlight it. If necessary, select the text of additional options and highlight them. After selecting your option(s), click this yellow rectangle and then delete it to see the feedback for each option.
Feedback 2:	
Feedback 3:	
Feedback 4:	

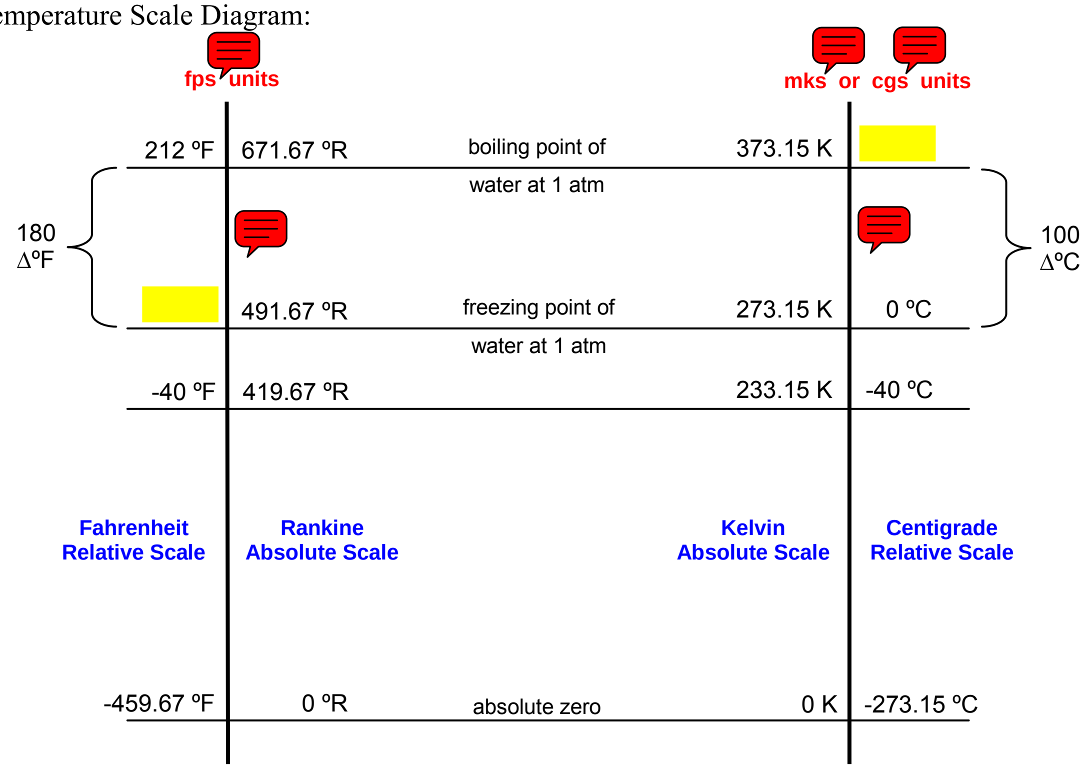
Simplest Equation of State

An equation of state (**EOS**) predicts the relationship between the temperature, pressure, moles, and volume of a single-phase substance, that is, either all-liquid or all-gas mixture of chemical compounds.

Temperature

A. Temperature is a measure of the thermal energy of the random motion of the molecules of a chemical substance at thermal equilibrium. A substance can be pure or a mixture of chemical compounds.

B. Temperature Scale Diagram:



C. Conversion Factors:

$\Delta^\circ F \equiv \Delta R$	$\Delta^\circ C \equiv \quad \Delta^\circ F$	$\Delta^\circ C$ is sometimes expressed as C° or just $^\circ C$.
$\Delta^\circ C \equiv \Delta K$	$\Delta K \equiv \quad \Delta R$	$\Delta^\circ F$ is sometimes expressed as F° or just $^\circ F$.

D. Conversion Equations:

$\left[T_{^\circ F} - 32^\circ F\right]\Delta^\circ F = \left[T_{^\circ C} - 0^\circ C\right]\Delta^\circ C \cdot \left\langle \frac{1.8\,\Delta^\circ F}{\Delta^\circ C} \right\rangle$	$\left[T_{^\circ C} - \left(-273.15^\circ C\right)\right]\Delta^\circ C = \left[T_K - 0\,K\right]\Delta K \cdot \left\langle \frac{\Delta^\circ C}{\Delta K} \right\rangle$
$T_{^\circ F} - 32 = \qquad$ *or* $\quad T_{^\circ F} - 32 = \frac{9}{5} \qquad$	$T_K = T_{^\circ C} + 273.15$
$\left[T_{^\circ R} - 0^\circ R\right]\Delta R = \left[T_K - 0\,K\right]\Delta K \cdot \left\langle \frac{1.8\,\Delta R}{\Delta K} \right\rangle$	$\left[T_{^\circ F} - \left(-459.67^\circ F\right)\right]\Delta^\circ F = \left[T_{^\circ R} - 0^\circ R\right]\Delta R \cdot \left\langle \frac{\Delta^\circ F}{\Delta R} \right\rangle$
$T_{^\circ R} = \qquad T_K$	$T_{^\circ R} = T_{^\circ F} + 459.67$

E. In any equation of state, absolute temperature must be used, either K or $^\circ R$, but not $^\circ C$ or $^\circ F$.

Interaction 3:	
Topic:	Absolute Pressure
Background:	We continue our review of quantities appearing in the ideal gas law by next examining the concept of absolute pressure. Please examine Page 2 of your PAPER COPY of the template document. As indicated by the three yellow rectangles, you are to complete the pressure drop (ΔP) equation and finish the conversion example for a column of water.
Pressure Question:	A barometer is a device used to measure atmospheric pressure. Click here to see an electronic barometer and a mercury barometer and note their prices. A barometer measure atmospheric pressure relative to
Option 1:	○ the pressure at sea level.
Option 2:	○ a perfect vacuum.
Feedback 1:	Select the text of only ONE option and then highlight it. After selecting your option, click this yellow rectangle and then delete it to see the feedback for each option.
Feedback 2:	

Before continuing, close ALL browser and other windows that you opened during this interaction.

Simplest Equation of State

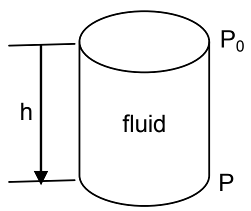
Pressure

A. Pressure is defined as force per unit of area acting in a direction perpendicular to a surface. Some examples of its absolute units are:

$P = F / A$

cgs units	mks units	fps units
dynes / cm^2	N / m^2 (Pa)	lb$_f$ / in^2
mm Hg	kPa	psi or psia
atm	bar	atm

B. Column of a non-reacting fluid (gas or liquid) at rest.



Assuming fluid density (ρ) and gravity's pull (g) are constant

$$P = \frac{F}{A} = \frac{W}{A} = \frac{m \cdot g}{A}$$

but $m = \rho \cdot V = \rho \cdot L \cdot A$

$$\int_{P_0}^{P} dP = \int_0^h \rho \cdot g \cdot dL$$

$$\Delta P = P - P_0 =$$

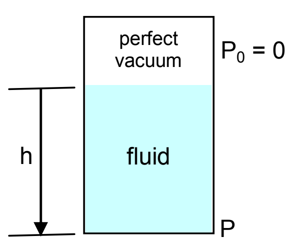
For example, a one-foot column of water with $\rho = 62.4\ lb_m/ft^3$ and $g = 32.1\ ft/s^2$.

$$P - P_0 = \left(\frac{62.4\ lb_m}{ft^3}\right)\left(\quad\right)(1\ ft)\left\langle \quad \bullet \frac{1\ ft^2}{144\ in^2}\right\rangle$$

$$P - P_0 = 0.432 \frac{lb_f}{in^2} = 0.432\ psi$$

C. Absolute Pressure

1. Reference is a perfect vacuum; that is, $P_0 = 0$.



$$P = \rho \cdot g \cdot h$$

where P is absolute pressure, since it is reference to a perfect vacuum.

An example device for the diagram is called a **barometer**. It measures P_b, the absolute (or barometric) pressure of the earth's atmosphere.

2. In any equation of state, absolute pressure must be used; that is, it must be referenced to zero.

Interaction 4:	
Topic:	Relative Pressure
Background:	We continue our review of quantities appearing in the ideal gas law by examining the concept of relative pressure. Please examine Page 3 of your PAPER COPY of the template document. As indicated under Item 2, two cases of relative pressure exits. You are to complete Item 3 by calculating the absolute pressure for two examples.
Pressure Question:	One example of a device to measure relative pressure is a Bourdon gauge. Click here to see two examples of this type of gauge and note the price of the gauge. Compared to a Bourdon gauge, a barometer costs
Option 1:	○ at least one-tenth of the price.
Option 2:	○ about the same price.
Option 3:	○ at least ten times the price.
Feedback 1:	Select the text of only ONE option and then highlight it. After selecting your option, click this yellow rectangle and then delete it to see the feedback for each option.
Feedback 2:	
Feedback 3:	

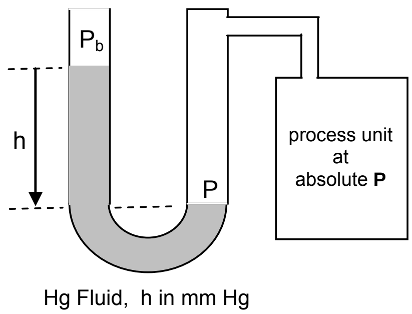
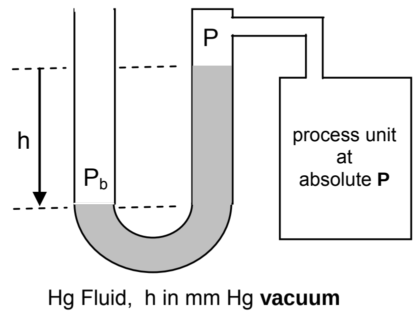
Before continuing, close ALL browser and other windows that you opened during this interaction.

Simplest Equation of State

D. Relative Pressure

1. Reference is atmospheric pressure, which is measured by a barometer, P_b. Typical devices that measure relative pressure are manometers (U-tube filled with a liquid), Bourdon gauges, or differential pressure transducers.

2. Two cases exists:

Above Atmospheric, $P \geq P_b$	**Below Atmospheric, $P < P_b$**
	
$P_g = P - P_b = \rho \cdot g \cdot h$	$P_g = P_b - P = \rho \cdot g \cdot h$

where P_g is the gauge pressure, a positive number.
P_b is the barometric (or atmospheric) pressure.
P is the absolute pressure in the process vessel.

Note that gauge pressure is always measured relative to atmospheric pressure.

3. Relative-to-Absolute Pressure Equations:

Above Atmospheric, $P \geq P_b$	**Below Atmospheric, $P < P_b$**
$P = P_b + P_g$ $e.g., \; psia = psia + psig$	$P = P_b - P_g$ $e.g., \; in\ Hg = in\ Hg - in\ Hg\ vac$

$P_g = 20.2\,psig \quad P_b = 764\,mm\,Hg \quad P \text{ in } kPa\,?$

$$P = 764\ mm\ Hg \left\langle \quad \right\rangle \left\langle \quad \right\rangle \left\langle \frac{101.325\ kPa}{14.696\ psi} \right\rangle = 241\ kPa$$

$P_g = 20.6\,in\,Hg\ vac \quad P_b = 1.01\,bar \quad P \text{ in } psia\,?$

$$P = 1.01\,bar \left\langle \frac{14.696\ psi}{1.01325\ bar} \right\rangle \left\langle \quad \right\rangle \left\langle \quad \right\rangle = 4.53\ psia$$

Interaction 5:

Topic:	Ideal Gas Law
Background:	We complete our review of quantities appearing in the ideal gas law by examining the concepts of moles, specific volume, and density. Please examine Page 4 about the ideal gas law in your PAPER COPY of the template document. You are to calculate the gas constant under Item C using conversion factors, and you are to derive an expression for the density under Item D starting with the ideal gas law. You should consult the "gotche" table on Pages 3-3 to 3-6 of the white CinChE manual, or the laminated green "gotche" table given to you as a handout by your instructor.
Pressure Question:	Click here to view, print, and complete a problem involving the ideal gas law using your pocket calculator. Accounting for precision, the correct answer for the number of moles of gas in the tank is
Option 1:	○ 0.3485 kg-mol.
Option 2:	○ 0.583 kg-mol.
Option 3:	○ 7.482 kg-mol.
Option 4:	○ 12.5 kg-mol.
Option 5:	○ not listed.
Feedback 1:	Select the text of only ONE option and then highlight it. After selecting your option, click this yellow rectangle and then delete it to see the feedback for each option.
Feedback 2:	
Feedback 3:	
Feedback 4:	
Feedback 5:	

Before continuing, close ALL browser and other windows that you opened during this interaction.

Simplest Equation of State

Ideal Gas Law

A. The simplest and most widely-used equation of state (EOS) is the **ideal gas law**. As its name implies, it is only applicable in the gas region. Thus, it can not be used to describe liquids.

$$P\,V = n\,R\,T \qquad or \qquad P\,\dot{V} = \dot{n}\,R\,T$$

where	T	is	the absolute temperature of the mixture,
	P	is	the absolute pressure of the mixture,
	V	is	the total volume of the mixture,
	n	is	the total number of moles in the mixture,
	R	is	the universal or ideal gas constant.

For any mixture, $n = n_1 + n_2 + \cdots + n_{nc}$, where n_j is the number of moles of component j; that is, of chemical compound j. For a pure-component mixture, $nc = 1$ and $n = n_1$. Each component in an ideal gaseous mixture also follows the ideal gas law; that is, $P\,V_j = n_j\,R\,T$.

B. A **mole** represents the number of molecules in a substance, a pure compound or a mixture of chemical compounds. A g-mol (or mol) contains Avogadro's number of molecules ($N_A = 6.022 \times 10^{23}$).

	cgs units	mks units	fps units
n	g-mol or mol	kg-mol or kmol	lb-mol
conversion factors	1 kg-mol ≡ 1000 g-mol 1 lb-mol ≡ 453.5924 g-mol		

C. The value of the gas constant R depends upon the units for V, P, n, and T, as follows:

$R = 8.314472 \dfrac{m^3 \cdot Pa}{mol \cdot K}$	$R = 62.3637 \dfrac{L \cdot mm\,Hg}{mol \cdot K}$
$R = 83.14472 \dfrac{L \cdot mbar}{mol \cdot K}$	$R = 0.7302 \dfrac{ft^3 \cdot atm}{lbmol \cdot {}^\circ R}$
$R = 0.0820574587 \dfrac{L \cdot atm}{mol \cdot K}$	$R = \qquad \dfrac{ft^3 \cdot psia}{lbmol \cdot {}^\circ R}$

The inside of the back cover of the Felder and Rousseau textbook tabulates approximate values for R. They are also listed at the web site of *www.wikipedia.org*.

D. Specific volume and density for a mixture of chemical compounds:

Specific volume is $\hat{V} = V/n$ or $\hat{V} = V/m$ Molecular weight is $M = m/n$ and $M = \sum_{j=1}^{nc} x_j M_j$ Since $P \cdot V = n \cdot R \cdot T$, then $P \cdot \hat{V} = R \cdot T$	Density is $\rho = \dfrac{m}{V}$ or $\hat{\rho} = \dfrac{n}{V}$ $P \cdot \quad = \quad \cdot R \cdot T \Rightarrow \rho = $

E. A gas behaves like an ideal gas when $\hat{V}_{ideal} = RT/P > 5\ L/mol\ (\ 80\ ft^3/lbmol)$ for diatomic gas, and for other gases when $\hat{V}_{ideal} = RT/P > 20\ L/mol\ (320\ ft^3/lbmol)$.

P00 eLEAPS Problem Session Script

Interaction 6:

Topic: Ideal Gas

Background: Thank you for completing this problem session. Please place your filled-in PAPER COPY of the template document in your technical journal. Click here for the correct solution to the template document.

If you so desire, you could print this eLEAPS script (two pages per sheet and on both side of a sheet) and place it also in your technical journal.

If you have any questions or concerns about the problem session, please contact your instructor.

Read the Important Observations below and consult the Reference Readings and Review Materials.

Problem Session Observations

- Absolute temperature units must be used in an equation of state.
- Absolute pressure units must be used in an equation of state.

- The ideal gas law relates volume and moles for a mixture of chemical compounds.
- Two forms of the ideal gas law exist—stationary and flow rate forms.

- Specific volume of an ideal gas is not dependent on the mixture composition.
- Density of an ideal gas does dependent on the mixture composition.

Reference Readings

- Felder and Rousseau, 3rd Edition, Section 3.1, Mass and Volume.
- Felder and Rousseau, 3rd Edition, Section 3.2, Flow Rate.
- Felder and Rousseau, 3rd Edition, Section 3.3, Chemical Composition.

- Felder and Rousseau, 3rd Edition, Section 3.4, Pressure.
- Felder and Rousseau, 3rd Edition, Section 3.5, Temperature.
- Felder and Rousseau, 3rd Edition, Section 5.2, Ideal Gases.

- Michael Hanyak, white CinChE Manual, Latest Edition, Chapter 3.

Review Materials

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