RJP Homework Problems

See the web document "ASSIGNMENTS" for problems in the Text.

RJP 0-1

Write a FORTRAN program that computes the function $y=x^2e^{-z}$, where $z = x^2/30$, for values of x ranging from 0 to 20 in steps of 0.10. Write the results to a file with x in the first column and the values of y in the 2nd column. Import the file into EXCEL and plot y as a function of x.

A. Just plot a curve connecting the data points. Do not plot the data points as symbols.
B. Enlarge the graph to full page until there is a margin of about 1 inch on all sides.
C. The title of the graph should be "TP RJP 0-1, y=x2e(-x2/30)."
D. The title should be above the graph not in the plane of the variables.
E. Label the axes and choose the y-axis major unit to be 1.0 and the x-axis major unit to be 2.0.
F. There should be horizontal and vertical lines for the major units.
G. Use an appropriate font size that is easy to read but not overbearing so that the numbers are not crowed.

Submit the program and the graph only, not the data table.

RJP 1-4

A. Compute the mass in kilograms of 500 kilomoles of diatomic nitrogen
B. Compute the number of molecules that comprise 100 kg of diatomic oxygen.

RJP 1-5

A system consists of 3 indistinguishable particles that have a total of 4 units energy, and 4 possible energy levels with g =1. Any particle in the first energy level would have 1 unit of energy; particles in the second level would have 2 units of energy, and so forth. What are the occupation numbers for each possible macrostate of the assembly? Draw a schematic of the system showing each possible macrostate where the energy levels can be represented as horizontal shelves.

RJP 2-3

An automobile tire of volume 5.6×10^3 cm^3 is filled with nitrogen to a gauge pressure of 29 psi at a temperature of 300 K. Note: Gauge pressure = Absolute pressure - atmospheric pressure, and 1 psi = 6.90×10^3 N/m^2.

a. What is the mass of N_2 in the tire?
b. If, during a trip, the temperature of the tire rises to 320K, what will be the gauge pressure? Assume the volume remains constant.

RJP 2-5

N identical balloons are filled with 0.061 Kg-moles of He at 273K to a gauge pressure of 0.50 atm. How many such balloons, N, each having an empty mass of 0.01 Kg, will be required to just float a 12 Kg object at STP? Assume air is 100% N_2. Use Archimedes principle.

RJP 2-7

An open ended U-tube with a uniform cross section equal to 1 cm^2 and height 100 cm on both sides is mounted on a stand in the lab. The tube is filled with mercury to a height of 50 cm on both sides when the barometric pressure in the lab is 750 Torr. The left side of the tube is then sealed and the right side is connected to a vacuum pump and evacuated to a pressure of essentially zero Torr.

(a) What distance in cm does the mercury level fall from its original position on the left side of the tube? Hint: Set up and solve a quadratic equation.
(b) What is the final pressure in Torr of the air trapped in the left side of the tube?

RJP 2-10

Write a FORTRAN program that computes 10 values of P = nRT/V for 1 kmole of an ideal gas that has a constant volume of 2 m^3 and T varies from 250 K to 350 K in steps of 10K. The program must print the results to a two-column table of P and T on a single formatted page with a label, a caption and column headers as shown below:

Table 1
Values of P for various values of T for 1 kmole of an ideal gas at a constant volume of 2 cubic meters.

P(N/m2)	T(K)
35.23	155
45. 67	165
etc.	

RJP 2-20

A tank contains CO_2 at a temperature of 410K. The specific volume of the gas is 0.0700 m3 kmole-1.
(a) Use the ideal gas law to compute the pressure (N m^{-2}) in the tank.
(b) Compute the pressure in the tank using the van der Waal equation with b = 0.04290 and a = 3.66e5.

RJP 2-30

Carbon dioxide is compressed in a tank to a pressure of 100.0 atm. and a temperature of 300K. Find the volume of the gas by iterating the van der Waal equation starting with a value for v_0 found from the ideal gas law. Substitute this value for v into the v^2 term and solve for a new value of v. Then use this new value for v to go back and compute v^2 and get a new value for the linear term in v again, etc. The van der Waal constants for CO_2 are a = 366 x 10^3 J m^3 $kmole^{-2}$ and b = 0.0429 m^3 $kmole^{-1}$. Write a FORTRAN program that does this. How many iterations does it take before the answer does not change in the 5^{th} decimal place. The answer you get should be 0.07976 cubic meters per kilomole. Show this by submitting your program and a table that has in two columns, the iteration number and the value of v found from the van der Waal equation. The table should have a caption and the columns must have headers and this formatting must be done in your program. Iterative solutions for complex equations are a common practice in physics.

RJP 3-15

Find $(\partial V/\partial T)_P$ implicitly from the equation of state for a van der Waal gas. Do not use the relationships between partials, that is, equations 3.4-5 and 3.4-7.

RJP 3-21

Show that the coefficient of volumetric expansion for a van der Waals gas is

$$\beta = Rv^2(v - b) / RTv^3 - 2a(v-b)^2$$

Show each step clearly, line by line with annotation. Use the relationships between partials.

RJP 3-22

Derive an expression for the compressibility of a van der Wall gas. What happens if a = b = 0?

RJP 3-23.

An approximate equation of state of a gas is P(v-b) = RT.
(a) Compute the expansivity of the gas.
(b) Compute the compressibility of the gas.

RJP 3-25

A substance has a value $\beta(T) = aT$ (K^{-1}), where a =1.43 x 10^{-4}. Calculate the final volume for 0.0498 m^3 of the substance, if it undergoes and isobaric process from T_i = 300K to T_f = 400K.

RJP 3-40

Write a program that numerically integrates:

$$V_f - V_o = \Delta V = \int \beta V dT_P - \int \kappa V dP_T,$$

for a block of copper that is heated from 100K and 1 atm to T=300K at 500atm. Assume V_o is 0.30m^3. Do not assume V, β and κ are constant as P or T is varied. Instead, read values of these coefficients from the graphs supplied and form files of these values as functions of T or P for small increments of the latter. These files are to be read by your program as indexed parameters. Do not separate variables, instead you use the new value of V that was found in the previous step for the value of V and the new value of beta or kappa in the next step. Figuring out how to do the numerical integration and program it, is part of this problem.

The order of the two processes is important in order to know the values of P or T that are held constant.

Use the following variable names in your program:

- P = pressure
- V = volume
- T = temperature
- BET(i) = β_i
- KAP(i) = κ_i
- DELT= ΔT
- DELP = ΔP
- DELV = ΔV

Your program is to write the results to formatted tables. At the top of the page there should be a caption saying that it is Table 1 or 2 and what is in the table, including the value of ΔP or ΔT that is used, as well as the initial values of V and the value of what is constant, T or P. Each column of data should have a header. The first column gives the number of the step in T or P. The second column gives the value T or P. The 3rd column lists the value of either β or κ. The 4th column is ΔV_P or ΔV_T and the 5th column gives the new value of V after ΔV is added. The results for the isobaric and isothermal processes are to be on separate pages.

Run the program with pressure increments of 50 atm and temperature increments of 50K. Submit with a cover page with your name, course and date in the upper right corner. The number of the problem and title are to be centered on the page.. This is to be followed by a list of your source program and then the pages of output tables. The latter must have at least 1-inch margins on all sides. Each table is to appear as if were published in a journal.

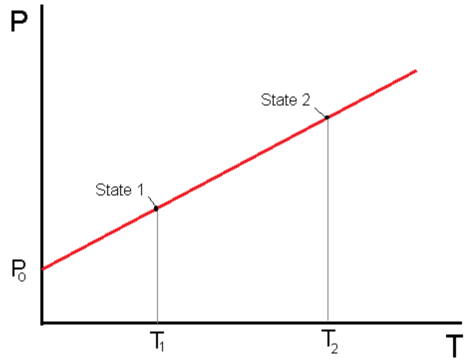
RJP 3-55

One kmole of an ideal gas undergoes an arbitrary process from state 1 with T_1 =300K at 1 atm. to state 3 with T_3 = 400 K at 2atm.

Use my equations 3.3-1 and 3.3-2 to show that the change in volume is independent of the path. Carry out the integrations in detail, step by step, calculating the values of ΔV and the new value of V for each step. Carry out the calculations with a precision of 4 significant figures. Remember not to put any numbers in the equations until the last step when computing ΔV (Pfeiffer's 8th and 9th commandments).

RJP 4-02

The work done by a solid when expanding is given by $đw = \int PdV$, where dV is given by RJP (3.2-4). Assume β and κ are constant and sufficiently small that v does not change significantly during the expansion. Find an expression for the work done in going from state 1 to state 2 as shown in the diagram below. Express the answer in terms of P1, P2, T1, T2, Vo, β and κ.



RJP 4-3

A fictional metal of atomic weight 27 has a density of 3000 kg m^{-3}. The heat of fusion is 4 x 10^5 J kg^{-1} at the melting point (900 K), and at the boiling point (1300 K) the heat of vaporization 1.20 x 10^7 J kg^{-1}. In the solid phase, $c_P = 750 + 0.500T$ in units of J kg^{-1} K^{-1} and as a liquid C_P = 1200 J kg^{-1} K^{-1}, independent of the temperature. Assume the pressure remains constant at 1 atm and that β is very small for the solid phase.

a. Calculate the heat of sublimation of a 10 g. metal sample, assuming that the heats of vaporization and fusion are independent of temperature and pressure.
b. Calculate the change of the internal energy of the sample of the metal sample upon melting.
C. Calculate the change of the internal energy of the metal sample upon vaporizing and justify any approximation that is made.

RJP 4-5.

Two kg of water at 373K is mixed with 1 kg of water at 273 in a container that has a very large specific heat and therefore undergoes no change in temperature in the time the mixed water comes to thermal equilibrium. The value of c_P for water is 4.18 kJ/kg·K. Calculate the final temperature of the mixture.

RJP 4-10.

The specific internal energy of a van der Waal gas is given $u = c_vT - a/v$ + constant. Derive an expression for $C_p - C_v$ in terms of a, b, T, and v, the independent variables.

RJP 4-12

On a beautiful autumn day, while walking across campus, a certain TD student measures the air temperature to be 24C and the dew point (temperature at which condensation occurs) to be 18C, simultaneously while sweet talking a friend (our nameless TD student is a man of many talents). During the night, infrared radiation loss results in a temperature drop of the ground from 30 C to 12 C. Assume the ground eventually cools to the air temperature and then they both continue to drop in tandem with the ground cooling the air. How much total heat is released by 2.0 kilogram of the water vapor as it is cooled from 24C to 12C. Cite references used to obtain the necessary constants.

RJP 4-15

Assume h = h(T, P). If dh =0.0, prove that $(\partial h/\partial P)_T = -c_P(\partial T/\partial P)_h$.

RJP 4-18

A. Show that the specific enthalpy of the gas in problem can be written as h = (a + R)T + constant.
B. Find C_P.

RJP 4-22

A 4 kmoles of a van der Waal gas comprise a system that undergoes an isothermal expansion from 15 m^3 to 55 m^3 at 400 K. Compute the work done by system for this process. The van der Waal constants are a= 5.800 x 10^5 and b = 0.0320. First derive a general expression for the work done in terms of the initial and final volumes and the constants a and b, before inserting any numbers.

RJP 5-18

The specific internal energy of a van der Waals gas is $u = u_0 + c_v T - a/v$, where u_0 is a constant. Now consider the case where one side of the apparatus shown in Fig. 4.1 of S&S contains n_A kmoles of a van der Waals gas and the right side contains n_B kmoles of the same gas, both at the same initial temperature, T_1. The volumes of both chambers are the same: $V_A = V_B$. After a valve in the diaphragm is opened to allow the gases to mix, assume this is a free expansion for both gases, since the gases are just mixing rather doing work by pushing a piston. Find an expression for the change in temperature, $T_2 - T_1$, for the combined system in terms of n_A, n_B, c_v, and $V = V_A = V_B$. Identify u for each gas as u_A and u_B, and that there is an initial internal energy for the combined system, u_i, and a final value u_f. Do not confuse specific volumes with total volumes. Express the answer in terms of n_A, n_B, c_v, a and V. What happens if $n_A = n_B$?

RJP 5-22

In the compression stroke of a Diesel engine, air-fuel mixture is compressed from 1 atm at 300K to 1/15 of its original volume. Assuming this is a reversible adiabatic process, find the final temperature of the mixture. Assume that the value of γ for the mixture is 1.40.

RJP 5-23

A. Calculate the amount of work done on an ideal gas to compress it isothermally to twice its initial pressure of 10^6 N m^{-2} and a volume of 0.50 m^3 $kmole^{-1}$ with $\gamma = 5/3$.
B. Calculate the amount of work done to compress the same gas adiabatically for the same pressure change.

RJP- 5-25

A gas is enclosed in an adiabatic cylinder with a moveable piston. Experimentally it is found that a quasi-static change in volume results in a corresponding change in pressure according to the relation P^3V^5 = a constant. Find the work done by the system, with an initial pressure of 10^5 Pa and initial volume of 10^{-3} m^3, when it expands to a final pressure equal to 10^4 Pa and final volume of 8 x 10^{-3} m^3.

RJP 5-40

Consider a volume of air, initially at T_o = 300K and P_o = 1 atm, that flows from sea level to the top of a 4 km high mountain. Assume the air undergoes an adiabatic process in so doing. As the volume of air rises, the pressure within that volume is always in equilibrium with the surrounding ambient pressure at any height. The latter is given by

$$P=P_0e^{-ah},$$

where h is the height of the air above sea level in meters, P_0 is sea level pressure, and a = 1.45 x 10^{-4} m^{-1}. What is the pressure, P_h, and temperature, T_h, of the air when it gets to the top of the mountain. Find an expression for T_h before inserting any numbers into the equations.

RJP 5-50

An air-conditioner (Carnot refrigerator) is used to maintain a constant temperature of 300 K for the interior of a building. The air-conditioner is powered by a 5 kilowatt electric motor and uses a working substance (coolant that is an ideal gas) that undergoes an adiabatic compression of 3 to 1 and has γ=1.40.

A. What must be the temperature of the hot reservoir? (This is the same as the temperature of the coolant after the compression?
B. How much heat is removed from the building every hour?
C. How much heat is delivered to the hot reservoir every hour?

RJP 5-51 thru 5-57 exist

RJP 5-55

Find the change in entropy for 1 kg of water heated at constant pressure from ice at 200K to a superheated vapor at 400K. Use the following:

c_P (ice) = 2.09 x 10^3 J/kg/K

c_P (liquid) = 4.18 x 10^3 J/kg/K
c_P (vapor) = 2.09 x 10^3 J/kg/K
l_{fusion} = 3.34 x 10^5 J/kg
l_{vapor} = 2.26 x 10^6 J/kg

RJP 5-60

Find the summation, Σ Q/T, for a carnot engine that has a coefficient of efficiency equal to 0.50, operating between reservoirs at 400K and 200K, if the engine absorbs Q = 800J.

RJP 5-62

First derive a general expression for the change in entropy for n kmoles of a van der Waal gas that undergoes and expansion from T_i, V_i, to T_f, V_f in terms of the constants for c_v, n , T, R, V, and b. Then calculate ΔS for 5 kmoles of the gas initially at 300K with V_i = 0.500 m^3 and V_f = 1.5 m^3 at 250K. The gas has b = 0.05m^3/kmole, $u = u_0 + c_vT - a/v$, where $c_v = c_o + cT$, with c_o= 0.5222 kJ/kmole/K and c =0.002120 kJ/kmole/K^2. If you do the problem correctly, you do not need to know the value of the van der Waal constant a. (40pts)

RJP 5-64

A lead bullet of mass 10 gm traveling at 500 m/sec hits a very large volume of water at 25^o C. The initial temperature of the bullet is 150^o C and lead has C_P = 128 J/kg/K. Calculate the change in entropy of the universe after the bullet has come to rest in the water and has reached thermal equilibrium with the water.

RJP 6-15

The internal energy of a gas is $u = u_o + aT^2$, where a = 22.50, and the equation of state is (P+b)V= nRT, where b = 6.600e3. Use the appropriate TdS equation to compute the change in entropy of 5 kmoles of the gas that under goes a compression ratio of 4 with an increase in temperature from 300K to 400K.

RJP 9-90

Calculate the partial pressure P_i for N_2 and O_2 in N/m^2. Assume standard conditions and that the total atmospheric pressure is equal to the sum of the partial pressure of just these 2 gases and is equal to 1 atm. Assume atmospheric abundances of 20% for oxygen and 80% for nitrogen.

RJP 9-94

Calculate the root mean square speed of H_2, O_2, and N_2 at 273K. Compare these with the escape velocity from the surface of the Earth, given by;

$$1/2mv^2_{esc} = GM_Em/R_E.$$

The subscript E identifies the Earth. Use SI units.

RJP 9-95

A system consists totally of N_2 molecules at 300K.

A. Compute the rms speed of the molecules.
B. Compute the number density of the molecules at 1 atm. of pressure.

RJP 9-100

An astronaut on a space-walk carries a tank with volume V, containing N_0 molecules of O_2 at 300K. A meteoroid punctures a hole of area Δa in the tank. Assume no particles re-enter the tank after escaping.

A. Find the expression for the number of molecules remaining in the tank after time t in terms of N_0, V, mean v, and Δa.

B. Assume that the mean speed ($\bar{v}$) of the particles in the tank is 0.88 the rms speed. Calculate the time for the number of molecules in the tank to decrease to N_0 /2. Express your answer in terms of, V, $\bar{v}$ and Δa.

RJP 9-101

A space probe is propelled by a stream of N_2 gas released from a tank, that has a volume of.60 m^3, through an orifice of diameter 0.001m^2. If there are N_o molecules in the tank initially, derive an expression for the pressure in the tank as a function of time. The temperature of the gas is 200K.

RJP 10-5

Plot the functions v^2, Be^{-av2}, and Bv^2e^{-av2} in the same plane. Determine the values of the constants B and a such that the range of the 3 functions along the ordinate is the same for the same range of values of v.

RJP 10-15

Write a program that computes N_v/N for a given value of N and m, but for different values of v and T (Equation 11.28 in AHC and Fig. 11.7). Let N=6.00 x 10^{26} of N_2. Start with T=200K and compute the file for N_v/N for different values of v starting with v = 0 m/sec and incrementing v by 10 m/sec, up to v= 1200 m/sec. Then repeat for T=400K, T= 800K, and T=1600K.

Graph the results of N_v/N versus v for all Temperatures in the same plane. Use appropriate scaling for the y- and x-axes of the graph and identify what is plotted along each axis. Don't put too many numbers along each axis, in order not to crowd them. Identify each curve with the appropriate temperature.

RJP 10-22

Write a FORTRAN program that uses the Maxwell speed distribution function (RJP equation 10-57) to compute the number of diatomic nitrogen molecules, $N_{\Delta v}$, that have speeds between v = 0 to v=1000 m/s, by numerical integration. Use steps Δv = 20 m/s for T=300K, and take the total number of molecules in the system to be N=10000. What is the fraction $N_{\Delta v}/N$?

In the program, as you step the values of v, write these values of v and corresponding computed values for N_v and the running sum of $N_v\Delta v$ to a file. Import the file into EXCEL and plot N_v vs. v in landscape format, with v along the horizontal axis. The v-axis should have values indicated every 100 m/s ranging from 0 to 1000 m/s. The y-axis should range from 0 to an appropriate value that is a bit larger than the maximum value of N_v .

Submit the following:

1. A cover page.
2. The source program.
3. A table, with a centered caption and column headers, listing values of v every 40 m/s, the corresponding values of N_v and the sum of $N_v\Delta v$ up to that v. The last value of the 3rd column should be, $N_{\Delta v}$, the total number of molecules that have speeds in the range from 0 to 1000 m/s. At the end of the table list the value of $N_{\Delta v}/N$, properly identified.
4. The graph, with axes appropriately labeled using a font size that is also appropriate.

RJP 10-112

The velocity distribution for a system of particles is given as:

$dN_v = \{4N / [(\pi)^{1/2}(b)^2] \} [\exp-(v/b)] dv$, where b = kT/m .

A. Calculate the value of dN_v /dv at v=b .
B. Draw a graph of dN_v /dv versus v (x-axis), indicating values of the ordinate for values of v=0 and v=b
C. Find the fraction of particles that have speeds between v=0 and v=b.
D. Calculate the mean speed.

RJP 11-142

Compute the partition function Z = $\sum_i [g_i \exp - (w_i/kT)]$, for the hydrogen atom for the surface (photosphere) temperature of the Sun, neglecting terms higher than i=4. Is the temperature significant for the value of Z?

RJP 11-143

Find the ratio of the number hydrogen atoms in the 1st excited state to the number in the ground state for the temperature in the Sun's photosphere, that is, find N_B/N_A, where A is the ground state.

RJP 11-10

Calculate the energy of the j=3 quantum level in electron volts for an electron confined to a volume of radius 1.0 Bohr radius (look up).

RJP 11-12

What is the energy difference in ev between an electron confined to a volume of 1 Bohr radius and two Bohr radii?

RJP 11-40

A system consists of 3 energy levels and 4 indistinguishable particles.

A. Draw the different possible macrostates for the system using an array of boxes and dots.
B. Write down the occupation numbers for each macrostate.
C. Show the computation of the thermodynamic probability for each macrostate.

Not assigned yet:

RJP 10-104

Find the value of ρ_{max} for the Maxwell velocity distribution function, using RJP Chap. 10, equations (37), (42), and (51). Your answer should be in terms of N, k, T, and m.

RJP 10-110

The velocity distribution for a system of particles is given as:

$dN_v = \{4N / [(b)^3(\pi)^{1/2}] \} v[\exp-(v/b)^2] dv$, where b is kT/m.

A. Find the most probable speed v_m in terms of k, T, and m.
B. Calculate the fraction of particles with speeds between v=0 and v=v_m in terms of k, T, & m.
C. Find the expression for the mean speed if the velocity distribution is from 0 to infinity.

RJP 10-120

Write a fortran program to compute values of dN_v for a system of O_2 particles with the following velocity distribution function:

$$dN_v = 4\,(\pi)^{-0.5}\,N\,(m/2kT)^{3/2}\,v^2\,[\exp(-mv^2/2kT)]\,dv,$$

where dN_v is the number of particles that have speeds between v and v+dv, and v ranges from zero to 1000 m/sec. Take N to be1.00. Export a file of values of dN_v /dv versus v to a grapher and graph the results out to v= 2400m/sec. Explore what happens for different values of T, such as, 200K, 400K and 1000K and show the results in a single diagram. Print out a table of the running sum of dN_v /dv times dv, for each temperature, to see if it converges to 1.00. The 1st column of each table should be v, the second column should be dN_v /dv, the 3rd column is to be dN_v, and the 4th column the running sum of dN_v. Use a fixed value of dv = 20 m/s. Submit the source code, the graph, and a table for each temperature. Everyone's source code should be their own. I do not want to see two or more programs that are clones of one another.