

## Problems and Solutions Chapter 1

1 Determine the efficiency of energy utilization for a pump. Assume the following efficiencies in the energy conversions:

- Crude oil to fuel oil is 90%.
- Fuel to electricity is 40%.
- Electricity transmission and distribution is 90%.
- Conversion of electrical energy into mechanical energy of the fluid being pumped is 40%.

**Hint:** the overall efficiency for the primary energy source is the product of all the individual conversion efficiencies.

**Solution:**

$$\text{Overall efficiency} = (0.90)(0.40)(0.90)(0.40) = 0.13 \times 100 = \boxed{13\%}$$

2 Replacing automobiles that have internal combustion engines with electric-powered vehicles is considered by some as the best solution to urban smog and tropospheric ozone. Write a short paper (1–2 pages double-spaced) on the likely effects of this transition on industrial production of fuels. Assume that the amount of energy required per mile traveled is roughly the same for each kind of vehicle. Consider the environmental impacts of using different kinds of fuel for the electricity generation to satisfy the demand from electric vehicles. This analysis does not need to include the loss of power over the lines/grid.

**Solution:** As student answer.

3 Visit the Office of Solid Waste and Emergency Response on the EPA website ([www.epa.gov](http://www.epa.gov)) and determine how close you live to a designated Superfund site.

**Solution:**

Go to the following website: <http://www.epa.gov/superfund/sites/index.htm>

Here is a list of the sites in Georgia:

SITE/SUMMARY	STATUS	MANAGER/E-MAIL
<a href="#">Alternate Energy Resources</a>	FINAL	<a href="mailto:bennett.giezelle@epa.gov">bennett.giezelle@epa.gov</a>
<a href="#">Armstrong World Industries</a>	FINAL	<a href="mailto:farrier.brian@epa.gov">farrier.brian@epa.gov</a>
<a href="#">Brunswick Wood Preserving</a>	FINAL	<a href="mailto:farrier.brian@epa.gov">farrier.brian@epa.gov</a>
<a href="#">Camilla Wood Treating</a>	FINAL	<a href="mailto:miller.scott@epa.gov">miller.scott@epa.gov</a>
<a href="#">Cedartown Industries</a>	DELETED	<a href="mailto:farrier.brian@epa.gov">farrier.brian@epa.gov</a>
<a href="#">Cedartown Landfill</a>	DELETED	<a href="mailto:farrier.brian@epa.gov">farrier.brian@epa.gov</a>
<a href="#">Diamond Shamrock</a>	FINAL	<a href="mailto:king.charlesl@epa.gov">king.charlesl@epa.gov</a>
<a href="#">Firestone Tire</a>	FINAL	<a href="mailto:king.charlesl@epa.gov">king.charlesl@epa.gov</a>

SITE/SUMMARY	STATUS	MANAGER/E-MAIL
<a href="#">Hercules 009 Landfill</a>	FINAL	<a href="mailto:martin.scott@epa.gov">martin.scott@epa.gov</a>
<a href="#">LCP Chemical</a>	FINAL	<a href="mailto:jackson.galo@epa.gov">jackson.galo@epa.gov</a>
<a href="#">Luminous Processors</a>	DELETED	<a href="mailto:denman.bill@epa.gov">denman.bill@epa.gov</a>
<a href="#">Marine Corps Logistics Base</a>	FINAL	<a href="mailto:koroma-llamas.lila@epa.gov">koroma-llamas.lila@epa.gov</a>
<a href="#">Marzone/Chevron</a>	FINAL	<a href="mailto:joseph.robenson@epa.gov">joseph.robenson@epa.gov</a>
<a href="#">Mathis Bros.</a>	FINAL	<a href="mailto:king.charlesl@epa.gov">king.charlesl@epa.gov</a>
<a href="#">Monsanto/Augusta Plant</a>	DELETED	<a href="mailto:joseph.robenson@epa.gov">joseph.robenson@epa.gov</a>
<a href="#">Peach Orchard Road PCE Ground Water Plume</a>	FINAL	<a href="mailto:bennett.giezelle@epa.gov">bennett.giezelle@epa.gov</a>
<a href="#">Powersville</a>	DELETED	<a href="mailto:farrier.brian@epa.gov">farrier.brian@epa.gov</a>
<a href="#">Robins Air Force Base</a>	FINAL	<a href="mailto:hazen.hugh@epa.gov">hazen.hugh@epa.gov</a>
<a href="#">T.H. Agriculture</a>	FINAL	<a href="mailto:hou.james@epa.gov">hou.james@epa.gov</a>
<a href="#">Terry Creek Dredge Spoil</a>	PROPOSED	<a href="mailto:martin.scott@epa.gov">martin.scott@epa.gov</a>
<a href="#">Woolfolk Chemical</a>	FINAL	<a href="mailto:king.charlesl@epa.gov">king.charlesl@epa.gov</a>

- 4 You have been tasked with determining the volume of a rectangular box.
- a. Using Equation (1.8) as a starting place, derive an equation that describes the minimum uncertainty expected in the box volume, based solely on the uncertainties in the measured dimensions.

**Solution:**

Equation 1.9 provides the general equation that describes the propagation of uncertainty.

$$\Delta y = \pm \sqrt{\sum_{i=1}^n \left( \frac{\partial y}{\partial x_i} \right)^2 (\Delta x_i)^2}$$

In this problem,  $y$  is a function of three variables, each with their own uncertainty,  $\Delta x_i$ .

Let  $x$ ,  $y$ , and  $z$  be the length, width, and height of the box having uncertainties denoted as  $\Delta x$ ,  $\Delta y$ , and  $\Delta z$ .

The box volume is calculated as:

$$V = x \cdot y \cdot z$$

Use Equation 1.9 to determine the uncertainty in the volume,  $(\Delta V)$ .

Expanding Equation 1.9 for the volume function gives:

$$\Delta V = \pm \sqrt{\left(\frac{\partial V}{\partial x}\right)^2 (\Delta x)^2 + \left(\frac{\partial V}{\partial y}\right)^2 (\Delta y)^2 + \left(\frac{\partial V}{\partial z}\right)^2 (\Delta z)^2}$$

Taking the partial derivative with respect to each variable gives:

$$\left(\frac{\partial V}{\partial x}\right) = yz$$

$$\left(\frac{\partial V}{\partial y}\right) = xz$$

$$\left(\frac{\partial V}{\partial z}\right) = xy$$

Substitution yields:

$$\Delta V = \pm \sqrt{(yz)^2 (\Delta x)^2 + (xz)^2 (\Delta y)^2 + (xy)^2 (\Delta z)^2}$$

Divide both sides by  $V$

$$\frac{\Delta V}{V} = \pm \sqrt{\frac{(yz)^2 (\Delta x)^2 + (xz)^2 (\Delta y)^2 + (xy)^2 (\Delta z)^2}{(xyz)^2}}$$

Simplifying gives

$$\frac{\Delta V}{V} = \pm \sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2 + \left(\frac{\Delta z}{z}\right)^2}$$

- b. Assume the box has dimensions of  $x$ ,  $y$ , and  $z$ . A meter stick was used to obtain the following measurements:  $x = (10 \pm 1)$  cm;  $y = (20 \pm 1)$  cm; and  $z = (5 \pm 1)$  cm. Find the uncertainty in the volume of the box.

**Solution:**

$$\Delta V = V \pm \sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2 + \left(\frac{\Delta z}{z}\right)^2}$$

- c. A caliper was used to measure the dimensions of a box having dimensions of  $x$ ,  $y$ , and  $z$ . The following measurements were obtained:  $x = (10 \pm 0.01)$  cm;  $y = (20 \pm 0.01)$  cm; and  $z = (5 \pm 0.01)$  cm. Find the uncertainty in the volume of the box.

**Solution:**

$$\Delta V = (10 \text{ cm})(20 \text{ cm})(5 \text{ cm}) \pm \sqrt{\left(\frac{1}{10}\right)^2 + \left(\frac{1}{20}\right)^2 + \left(\frac{1}{5}\right)^2}$$

$$\Delta V = 1000 \text{ cm}^3 \pm 0.23 \text{ cm}^3$$

$$\Delta V = (1000 \pm 0.23) \text{ cm}^3$$

- 5 The Manning Equation is an empirical relationship that relates open-channel flow velocity with channel characteristics.

[Equation] 
$$V = \frac{1}{n} \left( \frac{A}{P} \right)^{\frac{2}{3}} S^{1/2}$$

where:

- $V$  = mean velocity, m/s
- $n$  = Manning's roughness coefficient, dimensionless
- $S$  = slope of the energy grade line (m/m)
- $A$  = cross-sectional area of the channel,  $\text{m}^2$
- $P$  = wetted perimeter of the flow channel, m.

Assume that the Manning surface roughness, the area, and the wetted perimeter are uncertain. Using the standard rules for error propagation, derive an equation of error for velocity.

**Solution:**

Equation 1.9 provides the general equation that describes the propagation of uncertainty.

$$\Delta y = \pm \sqrt{\sum_{i=1}^n \left( \frac{\partial y}{\partial x_i} \right)^2 (\Delta x_i)^2}$$

Take the partial derivative of the Manning Equation with respect to  $n$ ,  $A$ , and  $P$  and substitute into Equation 1.9.

Taking the partial derivative of  $n$  gives:

$$\begin{aligned}
\frac{\partial V}{\partial n} &= \frac{\partial}{\partial n} \left( \frac{A^{\frac{2}{3}} \cdot \sqrt{S}}{nP^{\frac{2}{3}}} \right) \\
&= \frac{A^{\frac{2}{3}} \cdot \sqrt{S} \cdot \frac{\partial}{\partial n} \left( \frac{1}{n} \right)}{P^{\frac{2}{3}}} \\
&= \frac{A^{\frac{2}{3}} \cdot \sqrt{S} \cdot \left( -\frac{\partial}{\partial n} (n) \right)}{n^2 P^{\frac{2}{3}}} \\
&= \frac{-A^{\frac{2}{3}} \cdot \sqrt{S} \cdot 1}{P^{\frac{2}{3}} \cdot n^2} \\
&= \frac{-A^{\frac{2}{3}} \cdot \sqrt{S}}{n^2 P^{\frac{2}{3}}}
\end{aligned}$$

Determine the partial with respect to A:

$$\begin{aligned}
\frac{\partial V}{\partial A} &= \frac{\partial}{\partial A} \left( \frac{A^{\frac{2}{3}} \cdot \sqrt{S}}{nP^{\frac{2}{3}}} \right) \\
&= \frac{\sqrt{S} \frac{\partial}{\partial A} \left( A^{\frac{2}{3}} \right)}{nP^{\frac{2}{3}}} \\
&= \frac{\sqrt{S} \frac{2}{3} A^{\frac{2}{3}-1}}{nP^{\frac{2}{3}}} \\
&= \frac{2 \cdot \sqrt{S}}{3nP^{\frac{2}{3}} \cdot A^{\frac{1}{3}}} \\
&= \frac{2 \cdot \sqrt{S}}{3A^{\frac{1}{3}} \cdot nP^{\frac{2}{3}}}
\end{aligned}$$

And finally, find the partial with respect to P:

$$\begin{aligned}
\frac{\partial V}{\partial P} &= \frac{\partial}{\partial P} \left( \frac{A^{\frac{2}{3}} \cdot \sqrt{S}}{nP^{\frac{2}{3}}} \right) \\
&= \frac{A^{\frac{2}{3}} \cdot \sqrt{S} \cdot \frac{\partial}{\partial P} \left( \frac{1}{P^{\frac{2}{3}}} \right)}{n} \\
&= \frac{A^{\frac{2}{3}} \cdot \sqrt{S} \cdot \left( -\frac{\partial}{\partial P} \left( P^{\frac{2}{3}} \right) \right)}{n \left( P^{\frac{2}{3}} \right)^2} \\
&= \frac{-A^{\frac{2}{3}} \cdot \sqrt{S} \cdot \frac{2}{3} \cdot P^{\frac{2}{3}-1}}{n P^{\frac{4}{3}}} \\
&= \frac{-2 A^{\frac{2}{3}} \cdot \sqrt{S}}{3 n P^{\frac{5}{3}}}
\end{aligned}$$

The corresponding uncertainty for  $V$  is:

$$\Delta V = \left[ \left( \frac{-A^{\frac{2}{3}} \cdot \sqrt{S}}{n^2 P^{\frac{2}{3}}} \right)^2 (\Delta n)^2 + \left( \frac{2 \cdot \sqrt{S}}{3 A^{\frac{1}{3}} \cdot n P^{\frac{2}{3}}} \right)^2 (\Delta A)^2 + \left( \frac{-2 A^{\frac{2}{3}} \cdot \sqrt{S}}{3 n P^{\frac{5}{3}}} \right)^2 (\Delta P)^2 \right]^{\frac{1}{2}}$$

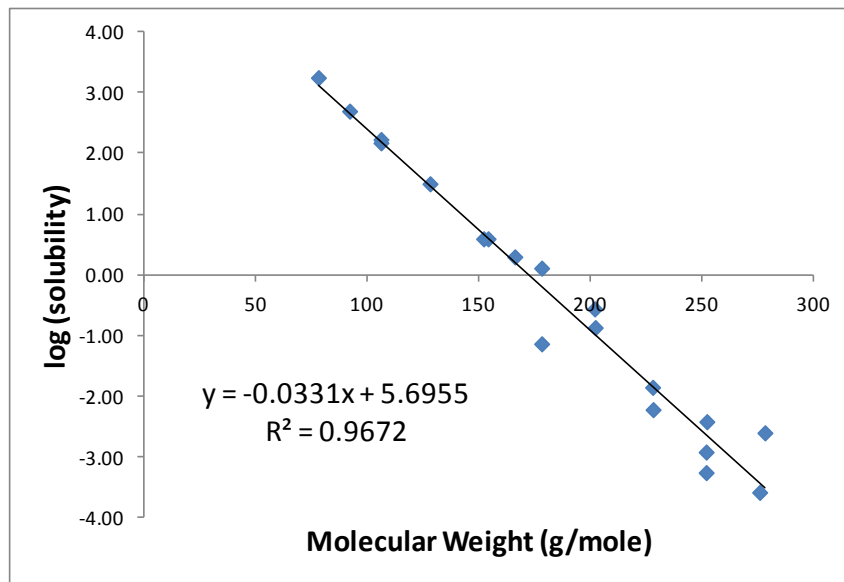
- 6 Review the data shown in Table 1.6 that describes several chemical properties of polycyclic aromatic hydrocarbons.
- a. Use the tabulated data to calculate means, standard deviations for molecular weight and solubility, correlation  $r$ , coefficient of determination  $R^2$ , slope  $m$ , intercept  $b$ , and the equation of the least-squares line for this case. Hint: consider plotting molecular weight on the abscissa and the logarithm of solubility on the ordinate.

**Solution:**

	<b>MW (g/mole)</b>	<b>Solubility (mg/L)</b>	<b>Soil-water partition coefficient</b>
Mean =	184.8	139.1	384238.0
Standard Deviation =	63.7	415.2	661477.4

$$\log(\text{solubility}) = (-0.0331 \times \text{MW}) + 5.6955$$

Slope:  $-0.0331$   
 $r = 0.983$   
 $R^2 = 0.967$



- b. Use an internet search engine to define the soil-water partition coefficient. Use the tabulated data to calculate means, standard deviations for solubility and the soil-water partition coefficient, correlation  $r$ , coefficient of determination  $R^2$ , slope  $m$ , intercept  $b$ , and the equation of the least-squares line for this case. Hint: consider plotting the logarithm of solubility on the abscissa and the logarithm of the soil-water partition coefficient on the ordinate.

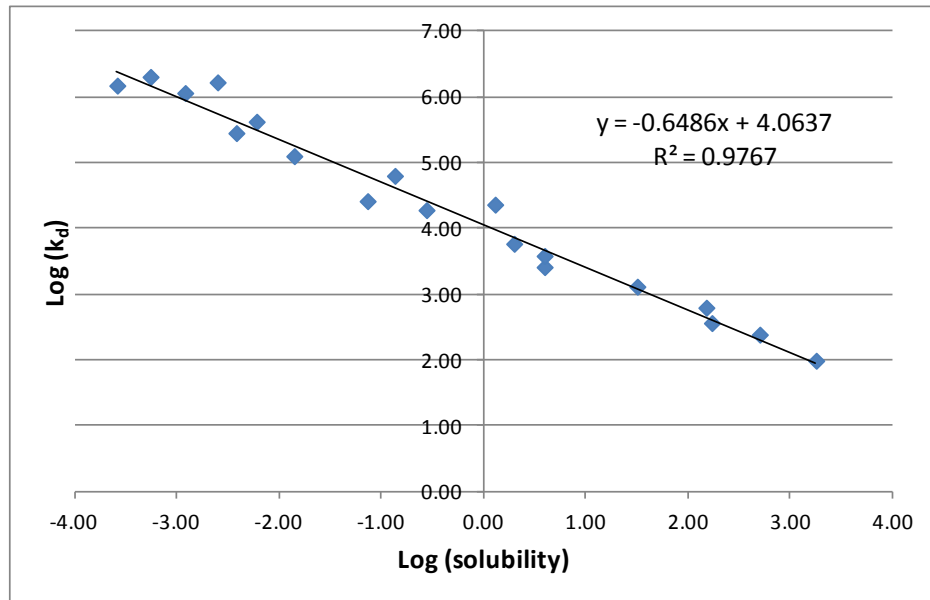
**Solution:**

The soil-water partition coefficient,  $k_d$  is defined as the ratio of the contaminant concentration associated with the solid to the contaminant concentration in the surrounding aqueous solution when the system is at equilibrium.

([http://www.epa.gov/radiation/docs/kdreport/vol2/402-r-99-004b\\_ch1.pdf](http://www.epa.gov/radiation/docs/kdreport/vol2/402-r-99-004b_ch1.pdf))

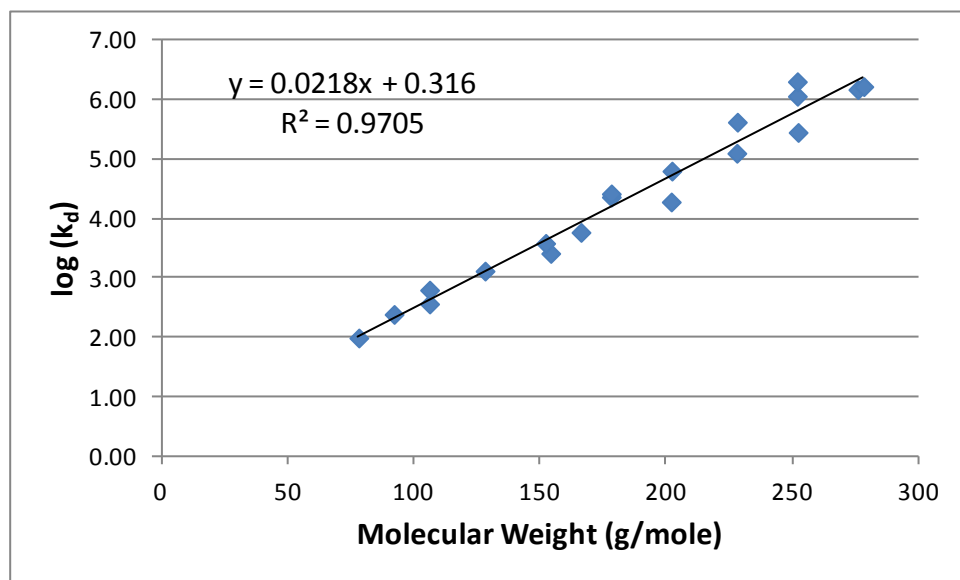
$$\text{Log}(k_d) = -0.6486 \times \log(\text{solubility}) + 4.06$$

$r = 0.988$   
 $R^2 = 0.9767$



- c. Use the tabulated data to calculate means, standard deviations for molecular weight and the soil-water partition coefficient, correlation  $r$ , coefficient of determination  $R^2$ , slope  $m$ , intercept  $b$ , and the equation of the least-squares line for this case. Hint: consider plotting molecular weight on the abscissa and the logarithm of soil-water partition coefficient on the ordinate. It is recommended that a spreadsheet software such as MS *Excel* be used to graph the requested relationships and to perform all calculations.

$r = 0.985$   
 $R^2 = 0.9705$



- d. Use the TINV function in *Excel* to generate a table of critical  $t$  values for 95% confidence level.

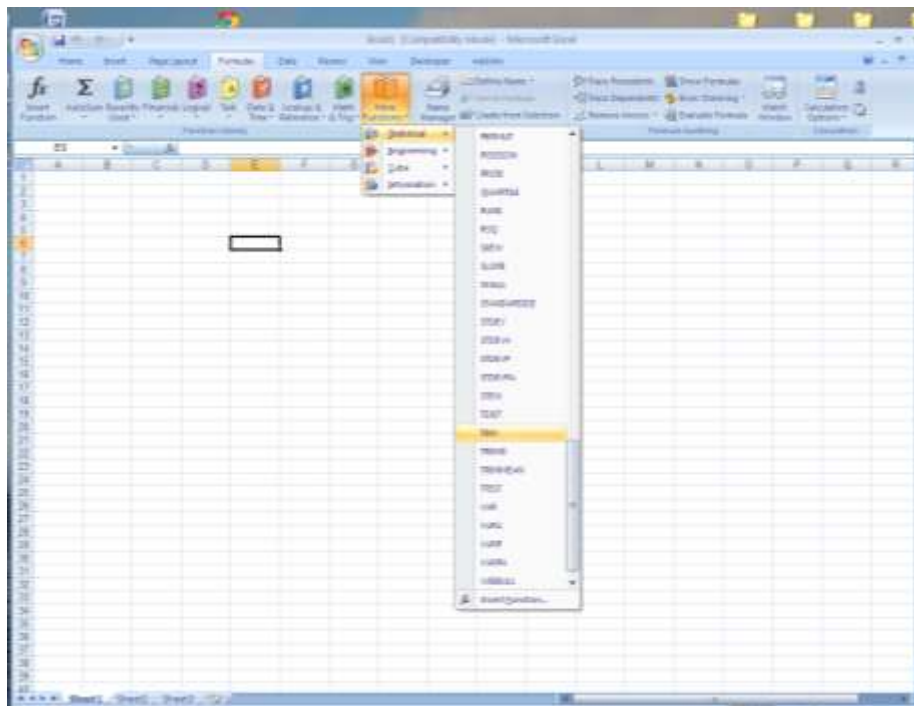
TINV(probability, degrees of freedom) [ $2 \times$  the probability in a single tail]

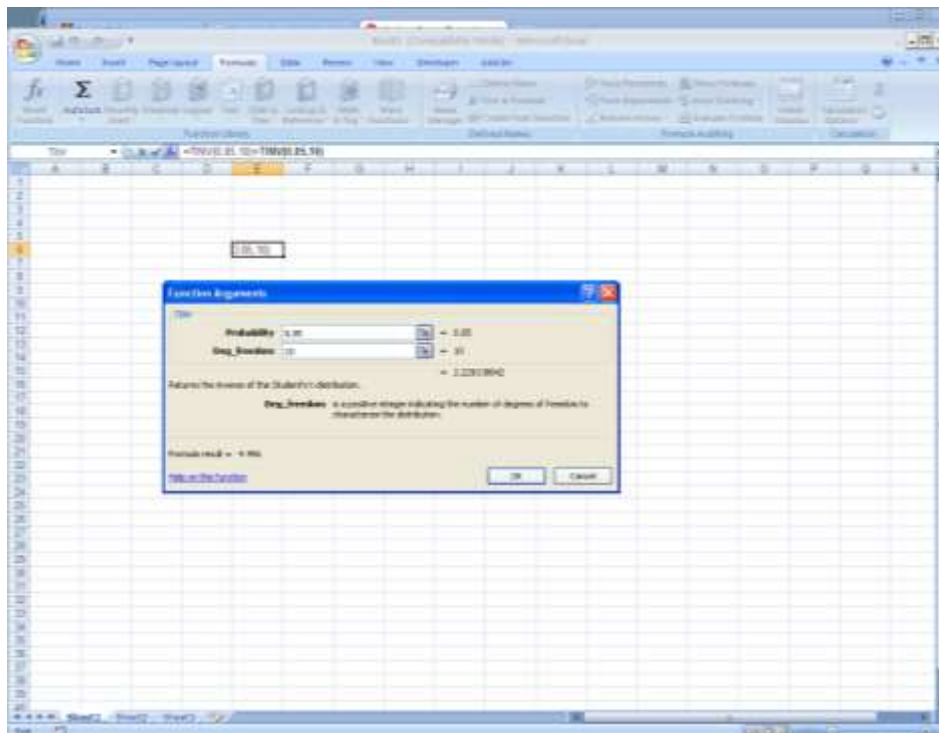
For a two tail test ( $\alpha = 0.05$ ), probability should equal 0.05 [ $=2 \times 0.025$ ]

For a one tail test ( $\alpha = 0.05$ ), double the alpha value (0.05) so that TINV provides the proper t-score. Therefore, enter 0.10 [ $2 \times 0.05$ ; this tells Excel that you want 0.05 in a single tail].

Steps to using the Excel TINV function:

1. Select a cell for TINV's answer
2. Click the Formulas button to open the Formulas dialog box.
3. In the More Functions tab, select Statistic and then TINV to open the Function Arguments dialog box for TINV.
4. In the Probability box, type the result of subtracting your confidence level from 1.00. So for a 95 percent confidence interval, you type 0.05 ( $1 - 0.95 = 0.050$ ).
5. Type the degrees of freedom in the Deg\_freedom box.
6. The answers appear in the dialog box. Enter to put the answers into the selected cell.





Critical t-scores as a function of $\alpha$ level	
d.f.	0.05
1	12.706
2	4.303
3	3.182
4	2.776
5	2.571
6	2.447
7	2.365
8	2.306
9	2.262
10	2.228
11	2.201
12	2.179