# Engineering Innovation Final Exam 2014

## Engineering Innovation: Final Exam Honor Code:

This exam must be worked on by you and you alone. You are welcome to search for any publicly-available materials that might be useful to you. **But, you must not ask anyone else for guidance, help, or information.** This includes TA's, Teaching Fellows, family, friends, and fellow students. It also includes posting questions to ask.com, Yahoo.answers.com, and similar websites. You are permitted to ask your instructor to clarify a problem; but don't ask him or her for advice on how to proceed.

***Failure to comply with this Honor Code will result in a score of zero for the exam.***

Please sign your name to indicate that you understand the rules and the consequences of not abiding by them.

**Print your Name: _____**

**Signature: _____**

## This page including your signature must be returned with your final exam!!!

**Please indicate the problems that you wish for us to grade by circling Y. If you do not wish for us to grade the problem circle N. If you do not circle anything below, the first 5 problems will be graded.**

**Grade? Y / N Problem 1 _____/10 Grader's Initials _____**

**Grade? Y / N Problem 2 _____/10 Grader's Initials _____**

**Grade? Y / N Problem 3 _____/10 Grader's Initials _____**

**Grade? Y / N Problem 4 _____/10 Grader's Initials _____**

**Grade? Y / N Problem 5 _____/10 Grader's Initials _____**

**Grade? Y / N Problem 6 _____/10 Grader's Initials _____**

**TOTAL = _____/50**

1) The city of Amarillo, TX has received a federal grant to repaint the lines on all the streets and highways in the city limits. You have been assigned the task of ordering enough street paint to paint the lines on the sides of all roads, the lane divide markings for all multi-lane roads and the center lines for non-divided highways. How much paint should you order? If the federal grant money must be spent in 60 days, how many paint trucks are needed to complete the project on-time?

To earn full credit you must provide a list of all your assumptions, the justification for each assumption and the url for all websites you used to answer this question.

2) When chemical engineers are working with gas systems that do not follow the behavior predicted by the ideal gas law they may use the Redlich-Kwong equation of state (shown below) to determine properties of the system.

$$P = \frac{nRT}{V - nb} - \frac{an^2}{V^2 - nbV}$$

Where:

P = system pressure (bar)

n = number of moles

R = Ideal gas law constant = R = 83.14472 (bar*cm$^3$)/(mole*K)

T = system temperature (K)

V = system volume (cm$^3$)

$$a = \frac{0.42748R^2T_c^{2.5}}{P_cT^{0.5}}$$

$$b = \frac{0.08664RT_c}{P_c}$$

$T_c$ = Critical Temperature (K)

$P_c$ = Critical Pressure (bar)

You are able to measure the temperature of the system with a thermometer that reads ±2°C, the mass of the system to ±0.04g and the volume to ±75cm$^3$.

a) Use the Redlich-Kwong equation of state to calculate the pressure of a system that is measured to contain 45.82 grams of methanol gas at a temperature measured to be 412K in a container with a measured volume of 2.255 L. The literature values for the $T_c$ and $P_c$ of methanol are 512.64K and 80.9bar respectively.

b) What is the uncertainty in your calculated value for P?

c) Your boss needs more confidence in your calculated value for P, but will only allow you to spend time or money to reduce the uncertainty in one of your measured values. Should you concentrate on the mass, the temperature or the volume? Fully explain your answer.

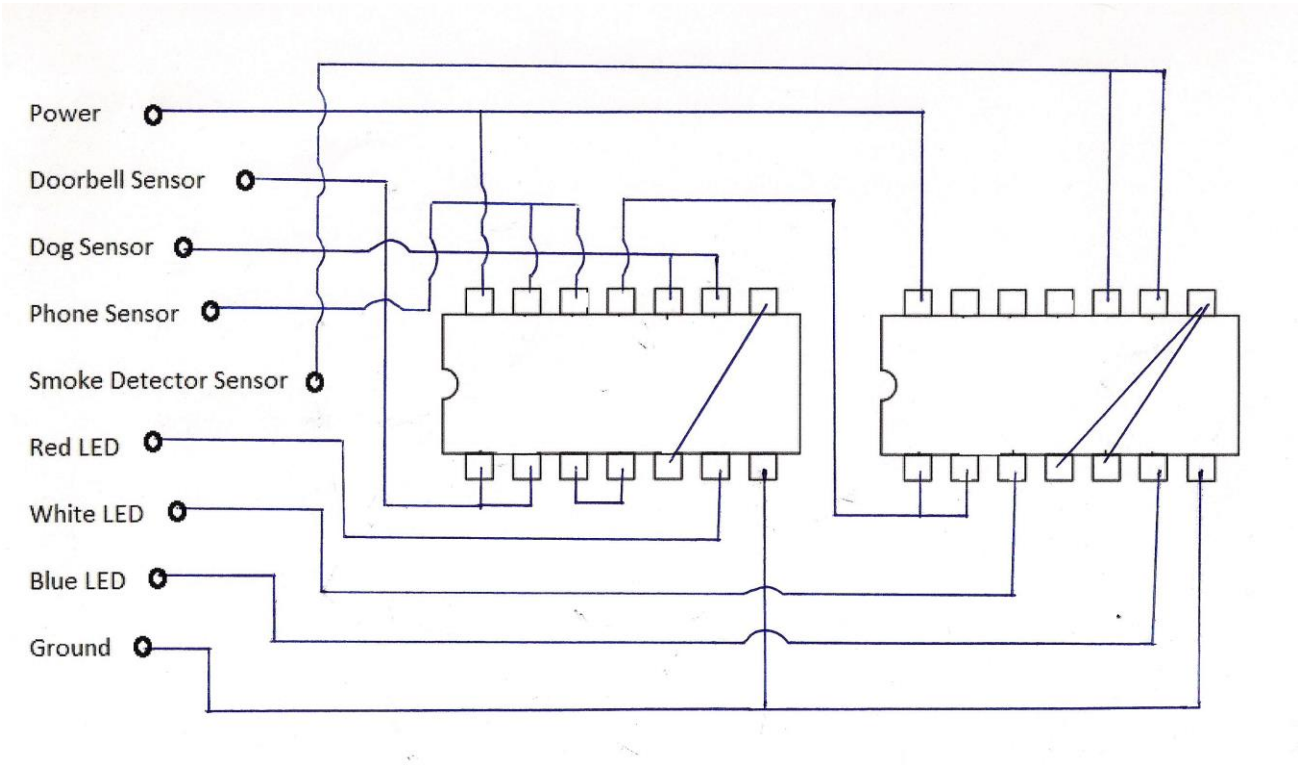
3) Emily's grandmother has moved into Emily's home. The grandmother is deaf and there are times when she will be in the house alone. Fortunately, Emily took Engineering Innovation in 2013 and has developed a circuit to aid her grandmother. The circuit includes four sensors, one each to detect the doorbell, the dog barking, the phone ringing and the smoke detector chirping. She has wired these sensors to activate three LED lights, one red, white and blue. Below you will find Emily's hand drawn wiring key. Use this to complete the following:

a) reverse engineer the circuit

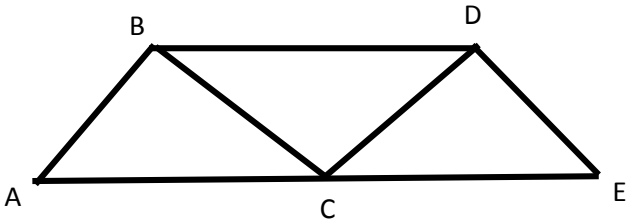
b) input the result into the Circuit Builder program and print out the truth table. **To earn full credit, you must include a printout of the truth table.**

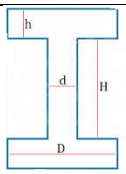
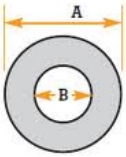
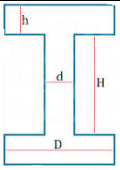
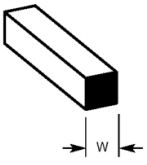
c) write a paragraph for Emily's grandmother that explains how the system works.

A 9-wire ribbon cable is needed to connect the circuit to the sensor inputs, LED outputs, the power and ground. The circuit includes two TI SN 7400N 14-pin CMOS chips containing four NAND gates each (the same chips that were used in the robotic car lab).



4) Below is a sketch **(not to scale)** of a bridge truss that was built from a variety of materials by an Engineering Innovation student who was tired of working with spaghetti. The truss is exactly symmetric. The length and geometry of each section of the truss are given in the table below. The material properties are given in the second table.




| SECTION | LENGTH | CROSS-SECTION | MATERIAL |
|---|---|---|---|
| AB | 15.0 cm |  | Solid rod of balsa wood with a diameter of 1.2 cm. |
| BD | 15.0 cm |   | I-Beam of aluminum<br>D = 0.8 cm; d= 0.2 cm;<br>H = 1.0 cm; h = 0.25 cm |
| DE | 15.0 cm |   | Hollow tube of polystyrene<br>A = 1.5 cm; B = 0.25 cm |
| AC | 15.0 cm |   | I-Beam of borosilicate glass<br>D = 0.5 cm; d= 0.1 cm;<br>H = 0.8 cm; h = 0.15 cm |
| CE | 15.0 cm |   | Rod of concrete with a square cross section<br>W = 1.3 cm |
| BC | 15.0 cm |  | 3 rods of zirconia glued together<br><br>Each piece of zirconia has a diameter of 2.00mm |
| DC | 15.0 cm |  | rod of cast iron<br>diameter of 1.2 cm |

**PROPERTIES OF CONSTRUCTION MATERIALS**

| | Aluminum | Balsa Wood | Cast Iron | Concrete | Borosilicate Glass | Polystyrene | Zirconia |
|---|---|---|---|---|---|---|---|
| **Yield Strength** | 9 MPa | 20 MPa | 600 MPa | 3.5 MPa | 68 MPa | 53 MPa | $5.80 \times 10^4$ psi |
| **Young's Modulus** | 70 GPa | 3565 MPa | 121 GPa | 27500 MPa | 65 GPa | 3300 MPa | 175 GPa |
| **Density** | 2.70 $g/cm^3$ | 163 $kg/m^3$ | 7.1 $g/cm^3$ | 145 $lb/ft^3$ | 2.2 $g/cm^3$ | 1.01 $g/cm^3$ | 5.6 $Mg/m^3$ |
| **Specific Heat** | 24.20 J/(mol*K) | 2.9 kJ/(kg*K) | 0.11 $BTU/(lb_m*°F)$ | 0.75 kJ/(kg*K) | 50 J/(kg*K) | 2.9 kJ/(kg*K) | 480 J/(kg*K) |

a) Assume that all the joints are pin joints and that the truss was well constructed. Once construction was complete the student loaded the truss from joint C. Complete the table below and include this with your calculations when you turn in the final exam.

| **Section** | **Is this section in tension or compression when the truss is loaded from joint C?** | **Maximum load this section can hold when the truss is loaded from joint C.** |
|---|---|---|
| AB | | |
| BD | | |
| DE | | |
| AC | | |
| CE | | |
| BC | | |
| DC | | |

b) When the bridge was loaded from joint C which section of the bridge failed first?

To earn any credit you must show all of your calculations and provide the urls of any websites you consulted.

5) Although he died in 1989, Abel Wolman, a Johns Hopkins engineering school graduate and faculty member (1937 – 1962), continues to be credited with saving millions of lives every year. His groundbreaking research focused upon using chlorine to kill life-threatening protozoa, bacteria and viruses present in bodies of water. This treatment made water safe to drink and his data tables gave cities the information needed to ensure treated water was indeed potable. His chlorination research was first published in 1918 and chlorination remains the most common method for treating water in the United States.

When environmental engineers design chlorination systems they must consider the concentration of chlorine and amount of time the chlorine is in contact with the water being treated. The US EPA has published tables of CT Values (CT = Concentration of Chlorine x Time of Contact) for a variety of pathogens. CT values are dependent upon the pathogen, temperature, pH and chlorine concentration.

Below are several tables of CT values that must be met to reach 99.9% inactivation of *Giardia* cysts. If water containing *Giardia* is not treated, individuals who drink the water will experience extreme gastrointestinal discomfort including violent diarrhea, excess gas, stomach or abdominal cramps, upset stomach, and nausea.

a) Calculate the CT value for a system with:

Chlorine Concentration = 1.4 mg/L  Temperature = 20°C  pH = 7.8

b) How many minutes does the treatment need to last to reach 99.9% inactivation of *Giardia* for the conditions in part (a)?

c) What is the pH necessary to achieve a CT value of 128 min-mg/L at Temperature = 10°C and chlorine concentration = 1.0 mg/L?

d) Calculate the CT value for a system with:

Chlorine Concentration = 1.4 mg/L  Temperature = 8.5°C  pH = 8.2

**CT Values for 99.9% Inactivation of *Giardia* Cysts by Free Chlorine (min*mg/L)**

Condensed from *Guidance Manual LTIESWTR Disinfection Profiling and Benchmarking, U.S*. Environmental Protection Agency, 2003

| Chlorine Concentration (mg/L) | Temperature = 5.0°C | | | | | | |
|---|---|---|---|---|---|---|---|
| | pH | | | | | | |
| | ≤6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 |
| ≤0.4 | 97 | 117 | 139 | 166 | 198 | 236 | 279 |
| 0.6 | 100 | 120 | 143 | 171 | 204 | 244 | 291 |
| 0.8 | 103 | 122 | 146 | 175 | 210 | 252 | 301 |
| 1.0 | 105 | 125 | 149 | 179 | 216 | 260 | 312 |
| 1.2 | 107 | 127 | 152 | 183 | 221 | 267 | 320 |
| 1.4 | 109 | 130 | 155 | 187 | 227 | 274 | 329 |
| 1.6 | 111 | 132 | 158 | 192 | 232 | 281 | 337 |
| 1.8 | 114 | 135 | 162 | 196 | 238 | 287 | 345 |
| 2.0 | 116 | 138 | 165 | 200 | 243 | 294 | 353 |

| Chlorine Concentration (mg/L) | Temperature = 10.0°C | | | | | | |
|---|---|---|---|---|---|---|---|
| | pH | | | | | | |
| | ≤6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 |
| ≤0.4 | 73 | 88 | 104 | 125 | 149 | 177 | 209 |
| 0.6 | 75 | 90 | 107 | 128 | 153 | 183 | 218 |
| 0.8 | 78 | 92 | 110 | 131 | 158 | 189 | 226 |
| 1.0 | 79 | 94 | 112 | 134 | 162 | 195 | 234 |
| 1.2 | 80 | 95 | 114 | 137 | 166 | 200 | 240 |
| 1.4 | 82 | 98 | 116 | 140 | 170 | 206 | 247 |
| 1.6 | 83 | 99 | 119 | 144 | 174 | 211 | 253 |
| 1.8 | 86 | 101 | 122 | 147 | 179 | 215 | 259 |
| 2.0 | 87 | 104 | 124 | 150 | 182 | 221 | 265 |

| Chlorine Concentration (mg/L) | Temperature = 20.0°C | | | | | | |
|---|---|---|---|---|---|---|---|
| | pH | | | | | | |
| | ≤6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 |
| ≤0.4 | 36 | 44 | 52 | 62 | 74 | 89 | 105 |
| 0.6 | 38 | 45 | 54 | 64 | 77 | 92 | 109 |
| 0.8 | 39 | 46 | 55 | 66 | 79 | 95 | 113 |
| 1.0 | 39 | 47 | 56 | 67 | 81 | 98 | 117 |
| 1.2 | 40 | 48 | 57 | 69 | 83 | 100 | 120 |
| 1.4 | 41 | 49 | 58 | 70 | 85 | 103 | 123 |
| 1.6 | 42 | 50 | 59 | 72 | 87 | 105 | 126 |
| 1.8 | 43 | 51 | 61 | 74 | 89 | 106 | 129 |
| 2.0 | 44 | 52 | 62 | 75 | 91 | 110 | 132 |

6) A few quickies:

a) How much money do you need to put into a savings account each month if you need $15,000 in five years? The savings account balance is compounded monthly with an annual rate of 0.6%.

b) Explain the similarities and differences between a fixed node and a rolling node. Why are these important when building a bridge?

c) You have a water heating system that is operating at 43% efficiency. How much energy would you need to add to the system to heat 6.8kg of water from 18°C to 63°C?

d) Have you ever noticed that vibration sets up a set of concentric waves on the surface of your cup of coffee? The wavelength, $\lambda$, of those waves depends on three variables: surface tension of the coffee, $\sigma$, coffee density, $\rho$, and frequency of vibration, $f$. Deduce the relationship of these three variables to the wavelength, i.e. deduce the form of $\lambda = \lambda(\sigma,\rho,f)$.

e) What is a McCabe-Thiele diagram? How can we use it to determine how many distillation stages are necessary to purify a system from an initial concentration to a final concentration?