1. **QUESTION 1** **25 pts**

Data is collected according to a randomized block design with five blocks and three treatment levels. The treatment averages were 45.2, 39.0, and 44.2 for the three treatment groups. A partial ANOVA table for this data is provided below.

Source	Degrees of Freedom	Sum of Squares	Mean Squares
block		47.7	
treatment		110.8	
residual		51.9	
Total	14		

Use Tukey's method to compare the three treatment means simultaneously at level 0.01. Which pairs are significantly different?

You are given the following *R* output:

```
> qtukey(0.99, 3, dfe)
[1] 5.635393
> qtukey(0.99, 2, dfe)
[1] 4.745234
> qtukey(0.99, 5, dfe)
[1] 6.624813
> qtukey(0.99, 4, dfe)
[1] 6.203835
```

2. **QUESTION 2** **25 pts**

Consider an experiment to study the breaking strength (y) in grams of two types of starch film. The breaking strength is also known to depend on the thickness of the film (x) and therefore is recorded and treated as a covariate. The experimental data is shown.

(a) (10 points) Write down an equal slopes ANCOVA model for this data explaining all terms in your model.

(b) (15 points) Suppose we wish to test the null hypothesis of no difference between the treatments (i.e. types of starch film). Write down the appropriate null and alternative hypotheses using the correct notation based on your answer above. Describe briefly how you would perform the test if you are given data from this experiment.

3. **QUESTION 3** **35 pts**

An experiment was conducted to determine whether either furnace position (factor A) or firing temperature (factor B) affects the baked density of a carbon anode. The data are shown below:

	Temperature (°C)		
Position	**800**	**825**	**850**
	570	1063	565
1	565	1080	510
	583	1043	590
	528	988	526
2	547	1026	538
	521	1004	532

Analysis of Variance

Source	DF	SS	MS	F-Value
Position		7160		
Temperature		945342		
Position*Temperature		818		
Error		5371		
Total		958691		

Analyze this data using the two-way ANOVA model:

$$Y_{ijk} = \mu_{..} + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{ijk}$$

where ϵ_{ijk}'s are iid $N(0, \sigma^2)$ by answering the following questions:

(a) (15 points) Suppose we wish to test whether or not the two factors interact using $\alpha = 0.01$. State the alternatives, and the decision rule. Compute the test statistic.

(b) (5 points) If the p-value for the test above equals 0.427, is it meaningful to test for main factor effects? Explain.

(c) (15 points) Suppose we wish to perform a hypothesis test for significance of the following contrast

$$L = \frac{\mu_{.1} + \mu_{.2}}{2} - \mu_{.3}$$

using the Scheffe procedure with a family error rate of 0.05. Compute the test statistic and state the decision rule.

4. **QUESTION 4** **15 pts**

A chemical reaction experiment was carried out with the objective of comparing if a new catalyst B would give higher yields than the old catalyst A. The experiment was run on six different batches of raw material which were known to be quite different from one another. Each batch was divided into two portions to which A or B was applied at random.

(a) (10 points) State two good features of this experimental design from a statistical point of view.

(b) (5 points) Write down an ANOVA table with the sources of variation and their corresponding degrees of freedom.