LAB 7 – KIRCHHOFF'S LAW (TPL2)

Objectives
- Compare the internal resistances of a "dead" battery to a "live" battery
- Calculate currents in a Kirchhoff's Law circuit
- Measure currents in a Kirchhoff's Law circuit

It would be very helpful to look at the online help page for this lab.

Comment about the Multimeter. We will be using the multimeter to measure the voltages and currents in the resistors, as well as the resistance of the different resistors. Be VERY sure that you are on the right meter setting, and you have it connected the correct way – so we can protect the meters!

Basic connections/modes for the multimeter:
- Ammeter – should be "IN" the circuit (i.e., current has to flow through the meter – if the meter would not be there, the circuit would be open) – **best way to use it is to "break" the circuit and use the ammeter to patch the two open ends**
- Voltmeter – should be "ACROSS" an element (i.e., the current should be flowing in the circuit, the meter is not repairing a break – it is reaching across an element)
- Ohm-meter – just connect it across the leads of the resistor - with no power supply connected – the resistor to be measured should be separate from any circuit … (with only the meter connected to it).

Part 1 – Internal Resistance of a power source

A battery has an internal chemical potential (known as the **emf** or electromotive force) that creates the current when you put a resistance (a "load") across it. This emf does not change (for example, in a battery, the two chemicals that create the potential are unchanged as the battery discharges) – yet, over time and usage, the battery will "die" – it can't produce a current any longer.

The reason for this lies in the internal resistance of the battery. As the internal resistance rises (a chemical process that makes it harder for charges to move from one chemical plate to another), the current produced by the emf creates an increasing voltage drop across the internal resistance, and thus a decreasing voltage available to the outside circuit.

A multimeter can measure this emf since it has very little internal resistance inside the multimeter (thus, no "load"). But, if we try to measure the voltage produced by the "dying" battery with a load – we'll find a much smaller reading (and, the two readings can allow us to calculate the internal resistance).

Look at the circuits indicated below:

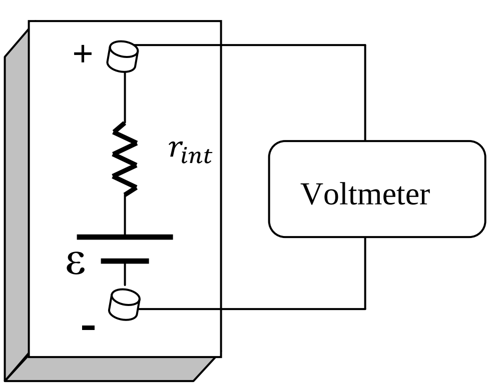


Figure 1A

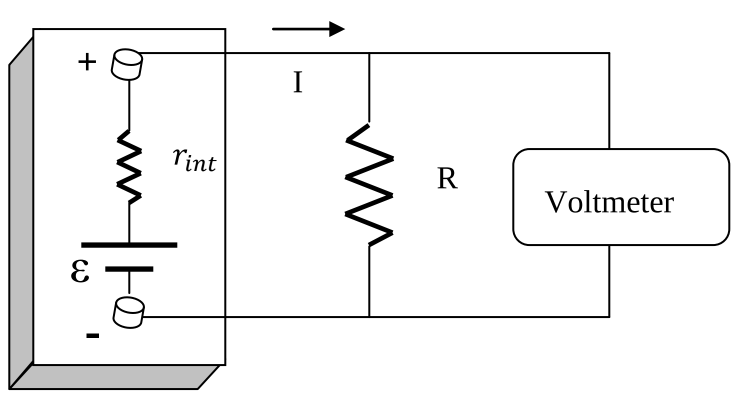
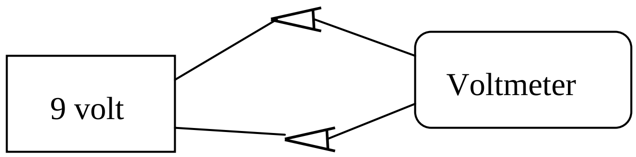


Figure 1B

A) In Figure 1A, the battery is shown with the internal emf (ε) and the internal resistance (r_{int}). Measuring the voltage across the battery with the sensitive multimeters should give us a reading of the emf alone (that is, the multimeter does not need to draw current to make its reading). In Figure 1B above, the battery now has a load resistor (R) across it, and then the multimeter in parallel with R. This voltage reading should show a much smaller value, since some current is produced in the circuit which creates a voltage drop across the internal resistance – thus there is not much "available voltage" to the outside circuit (the load resistance R). If we can't measure the full amount of voltage across the battery, we say that it is "dying/dead". Technically, there is still the emf inside .. we just can't access it with a load circuit!

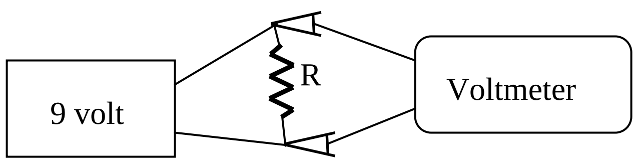
1. Connect the 9-volt "dead" battery to the battery holder.

2. Circuit connections for Figure 1A (measuring ε). Use the DC-Voltage setting for the multimeter. Connect the alligator clips to the leads of the 9-volt "connector" and measure the emf of the battery as illustrated below – record on the Data/Question sheets.



 = Alligator clip

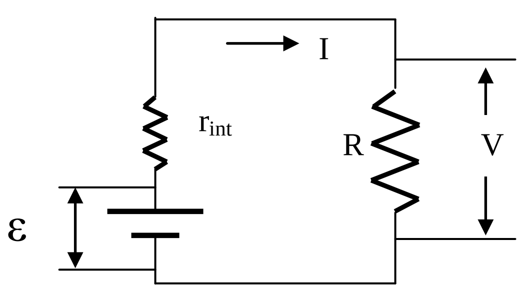
3. Circuit connections for Figure 1B (measuring V). Connect the 220 ohm resistor across the leads of the 9-volt connector (that is, use the alligator clips to connect the leads to each end of the resistor). Measure the voltage of the battery as illustrated below and record it on the Data/Question sheets.



4. Measure the resistance of the resistor. **Disconnect** the 9-volt battery from the resistor. Switch the multimeter to read ohms and switch the banana plug wires to the appropriate ports. Connect the multimeter, via the alligator clips, to the resistor (without the battery in the circuit). Measure the resistance of the resistor and record it on the Data/Question sheets (for both the "live" battery and the "dead" battery).

5. Calculate the current in the loaded circuit. Using the previous two measurements, calculate the current in the circuit (in amps) on the Data/Question sheets.

6. Calculate the internal resistance. Consider the circuit diagram and the calculations below – use the final calculation to determine the internal resistance of the battery on the Data/Questions sheets.



$$\varepsilon = I(r_{int} + R) = Ir_{int} + IR \qquad I = V/R \qquad V = IR$$

$$Ir_{int} = \varepsilon - IR \qquad r_{int} = \frac{\varepsilon - IR}{I}$$

$$r_{int} = \frac{\varepsilon - V}{I} = \_\_\_\_\_\_ \ ohms$$

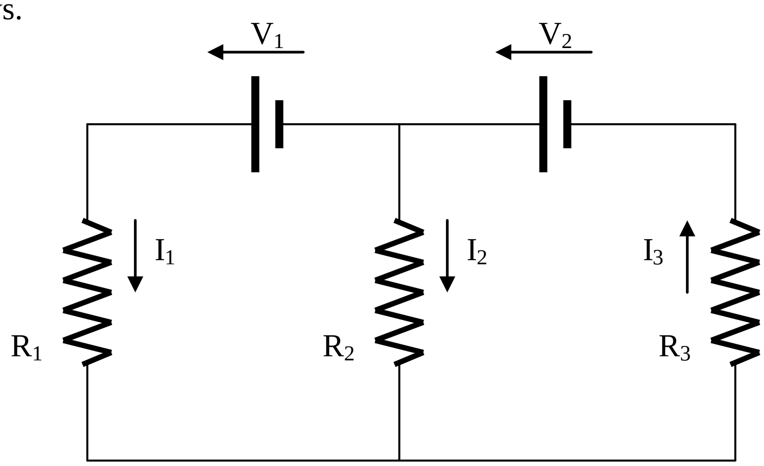
B) Take the "dead" battery out of the holder and connect the "live" battery in to it.

Repeat steps 2,3,5, and 6 from A). Record your data on the DATA/QUESTION Sheet

Answer the Question on the Data/Question sheet.

Part 2 – Kirchhoff's Loop rules - Introduction

Consider the following circuit showing two power supplies and three resistors. We will assume that the internal resistance of the power supplies will be negligible. There are current and voltage rules known as Kirchhoff's Laws.



Based on the above circuit, we could construct several voltage loops – we'll choose the left loop and the right loop and circle the around the loops counter-clockwise. To this, we will add a current rule. The combined set of equations look like this:

$$I_3 = I_1 + I_2$$

$$V_1 = I_1R_1 - I_2R_2$$

$$V_2 = I_2R_2 + I_3R_3$$

Note: the following conventions were followed:

- Traveling in the **same** direction as the current through a resistor, there is a voltage drop (IR).
- Traveling in the **opposite** direction as the current through a resistor, there is a voltage rise (-IR).
- Traveling from the - *terminal* to the + *terminal* across the power supply, there is a voltage rise (+V).
- Traveling from the +*terminal* to the - *terminal* across the power supply, there is a voltage drop (-V).
- The currents coming into a junction must add up to the currents going out of a junction.

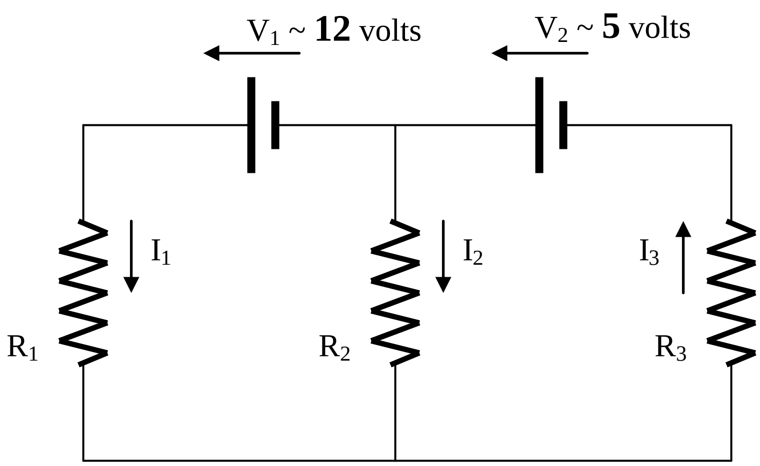
There are three equations above, and three unknowns (I_1, I_2, I_3). While they can be solved using the variables above, it is usually easier to solve them when the numerical values are inserted.

1. Measuring resistances. Switch the multimeter to read resistance (ohms). Measure each of the three resistors (R_1, R_2, and R_3) at the end of the resistor box and record the values on the Data/Question sheets:

2. Measuring voltages of the power supplies. There are two power supplies at your station. The internal circuitry won't allow us to use the 5 V and the 12 V connectors from the same power supply in the same circuit, so we will use one from each power supply. With the multimeter set to the DC-Voltage setting, connect the plugs in the appropriate ports. Turn the power supplies on, and using the designation of the top power supply as V_1 and the bottom one as V_2 – measure the voltages across the 5 volt outputs and the 12 volt outputs and record them on the Data/Question sheets.

Part 3 – Kirchhoff's Circuit A

1. Setting up circuit A. Using the two power supplies and the resistor box, set up the following circuit. Notice that the directions of V_1 and V_2 are very important – the green (positive) terminal of the 12V power supply (V_1) should be connected to one of the leads of the R_1 resistor – the black (negative) terminal of the 12V power supply (V_1) should be connected to the similar socket on the R_2 resistor, and so forth. Use two short wires to connect the lower sockets of R_1 and R_2 and to connect R_2 and R_3 to complete the circuit.



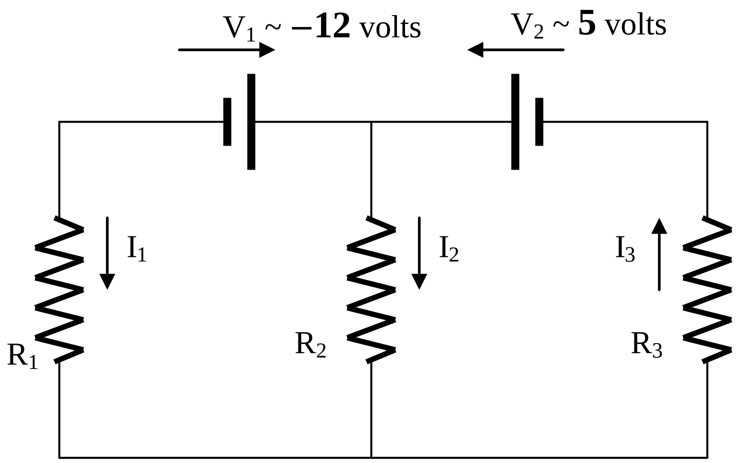
2. Measuring currents. Set the multimeter to read DC-current, and use the appropriate ports. Measure the three currents (I_1, I_2, I_3) by breaking the circuit at the lower ends of the three resistors and "repairing the circuit with the multimeter. The descriptions of how to do this are as follows:

- For $\mathbf{I_1}$: disconnect from R_1 the short wire that goes to R_2 {but leave it connected to R_2} – connect the multimeter between the two open parts {the end of R_1 and the lead to R_2}. The wire from R_2 to the **COM** of the multimeter and a second, new lead, from **A** of the meter back to R_1.
- For $\mathbf{I_3}$, disconnect from R_3 the short wire that comes from R_2 {but leave it connected to R_2} – connect the multimeter between the two open parts {the lead from R_2 and the end of R_3}. The wire from R_2 to the **A** of the multimeter and a second, new lead from the **COM** of the meter back to R_3.
- For $\mathbf{I_2}$: this is a little trickier – there are two wires coming together at the lower part of R_2 – coming from R1and R_3 – disconnect that combination (but leave the two wires connected to themselves) – connect the multimeter between the two open parts {the end of R_2 and the combined leads from $R_1$and R_3}. Connect the combined leads to **A** of the meter and a new wire from R_2 to the **COM** of multimeter.

It is important to keep track of the direction of the currents – so to be consistent, use the RED lead closest to the resistor and the black lead for the other connection. If you get a positive value, then the current direction is from top to bottom through the resistor in the images – a negative value means the other direction. [These "directions" will be indicated by the signs of the currents in the later calculations.] Record your currents (with signs) on the Data/Question sheet.

Part 4 – Kirchhoff’s Circuit B

1. Setting up circuit B. Switch the leads on your 12V power supply so that you create the following circuit:



Notice that the current directions (vectors) are left the same in the diagram {even though the final current directions might be different} … in this case, we can use the same equations as Part 2, **just make sure you switch the sign of the V_1 voltage to negative, -**. If the current values switch sign as well as magnitude in our measurements or calculations, it just means the actual currents are flowing differently than depicted above (but the measurements will still match the calculations as long as we keep track of the new directions). Record your currents (with signs) on the Data/Question sheets.

<u>DATA/QUESTION SHEET FOR LAB 7 KIRCHHOFF'S LAWS</u>

<u>Part 1 – Internal Resistance of a power source</u>

A) "Dead" Battery

<u>2. Circuit connections for Figure 1A (measuring ε).</u> Measure the emf of the battery and record it below:

Emf = ε = __________ volts

<u>3. Circuit connections for Figure 1B (measuring V).</u> Measure the voltage of the battery and record it below:

Voltage with load resistor = **V** = __________ volts

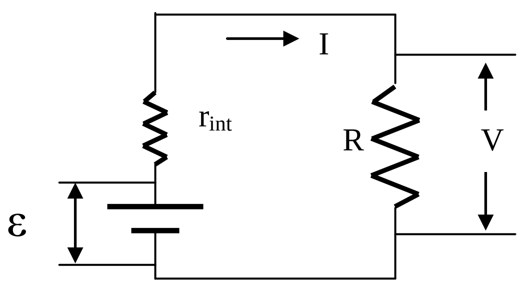
<u>4. Measure the resistance of the resistor.</u> Measure the resistance of the resistor and record it below:

Resistance of the load resistor = **R** = __________ ohms (Copy to B4)

<u>5. Calculate the current in the loaded circuit.</u> Using the previous two measurements, calculate the current in the circuit (in amps) :

Current in the loaded circuit = **I** = **V**/**R** = __________ amps

<u>6. Calculate the internal resistance.</u> Consider the circuit diagram and the calculations below – use the final calculation to determine the internal resistance of the battery.



$$\varepsilon = I(r_{\text{int}} + R) = Ir_{\text{int}} + IR \qquad I = V/R \qquad V = IR$$

$$Ir_{\text{int}} = \varepsilon - IR \qquad r_{\text{int}} = \frac{\varepsilon - IR}{I}$$

$$r_{\text{int}} = \frac{\varepsilon - V}{I} = \_\_\_\_\_\_ \ ohms$$

B) "Live" Battery

<u>2. Circuit connections for Figure 1A (measuring ε).</u> Measure the emf of the battery and record it below:

Emf = ε = __________ volts

<u>3. Circuit connections for Figure 1B (measuring V).</u> Measure the voltage of the battery and record it below:

Voltage with load resistor = **V** = __________ volts

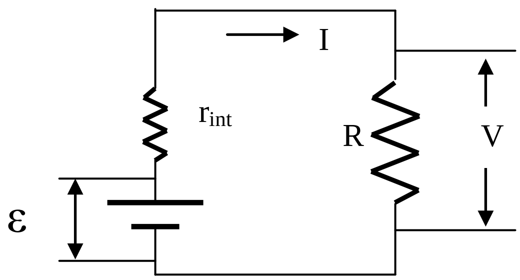
4. Resistance of the resistor. Record below the resistance of the resistor from A 4):

Resistance of the load resistor = **R** = __________ ohms

5. Calculate the current in the loaded circuit. Using the previous two measurements, calculate the current in the circuit (in amps) :

Current in the loaded circuit = **I** = **V**/**R** = __________ amps

6. Calculate the internal resistance. Consider the circuit diagram and the calculations below – use the final calculation to determine the internal resistance of the battery.



$$\varepsilon = I(r_{int} + R) = Ir_{int} + IR \qquad I = V/R \qquad V = IR$$

$$Ir_{int} = \varepsilon - IR \qquad r_{int} = \frac{\varepsilon - IR}{I}$$

$$r_{int} = \frac{\varepsilon - V}{I} = \_\_\_\_\_\_ \ ohms$$

Question Answer this question below:
If your emf reading and your voltage reading were similar (ε~V), you should find the internal resistance to be relatively small – if ε>V, then you should find a higher internal resistance (a measure of how "dead" the battery is). Based on your numbers, how "dead" do you think your battery is – explain?

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Part 2 – Kirchhoff's Loop rules - Introduction

1. Measuring resistances. Measure each of the three resistors (R_1, R_2, and R_3) at the end of the resistor box and record the values below:

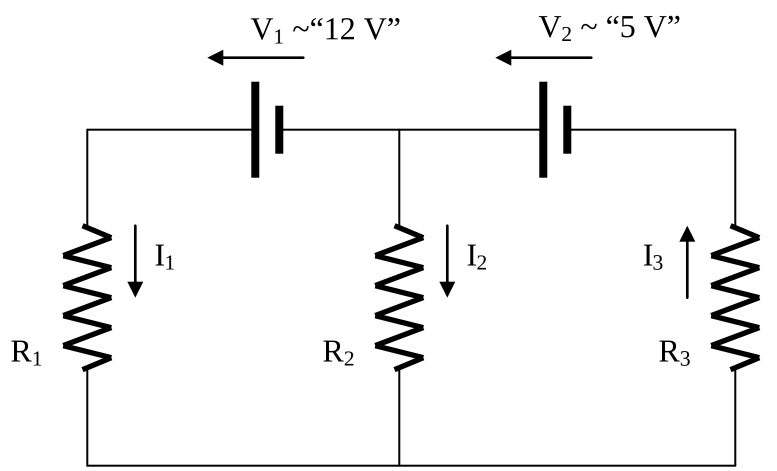
$\mathbf{R_1}$ = __________ ohms $\mathbf{R_2}$ = __________ ohms $\mathbf{R_3}$ = __________ ohms

2. Measuring voltages of the power supplies. Turn the power supplies on, and using the designation of the top power supply as V_1 and the bottom one as V_2 – measure the voltages across the 5 volt outputs and the 12 volt outputs and record below:

Top power supply ($\mathbf{V_1}$) : "5 volts" = _________ volts "12 volts" = ________ volts

Bottom power supply ($\mathbf{V_2}$) : "5 volts" = _________ volts "12 volts" = ________ volts

Part 3 – Kirchhoff's Circuit A



Circuit A – Measurements:

Actual voltages (From Part 2.2)

$V_1 =$ _______V, $V_2 =$ ______V

Resistances (From Part 2.2)

$R_1 =$ ______Ω , $R_2 =$ _______Ω , $R_3 =$ _______Ω

Actual Currents using the ammeter (Remember to include the sign)

$I_{1(meas)}$=______A, $I_{2(meas)}$=_______A, $I_{3(meas)}$=________A

Circuit A – Calculations:

Using the circuit equations below and the values for V_1, V_2, R_1, R_2, and R_3 from above , calculate the values for $I_{1(cal)}$, $I_{2(cal)}$, and $I_{3(cal)}$ (on the next page).

$$I_3 = I_1 + I_2$$

$$V_1 = I_1R_1 - I_2R_2$$

$$V_2 = I_2R_2 + I_3R_3$$

This space is for the loop calculations: (Hint: round the resistance values to a whole number)

Circuit A – Calculated Currents:

$\mathbf{I_{1(cal)}}$ = ___________ A $\mathbf{I_{2(cal)}}$ = ___________ A $\mathbf{I_{3(cal)}}$ = ___________ A

How well did your calculated current values match up with your measured current values? How well did your signs/directions match? [If there are strong differences, you might need to either re-measure or re-calculate.] (Remember – if the sign only is different either the meter is in backwards or we guessed wrong on the current direction.)

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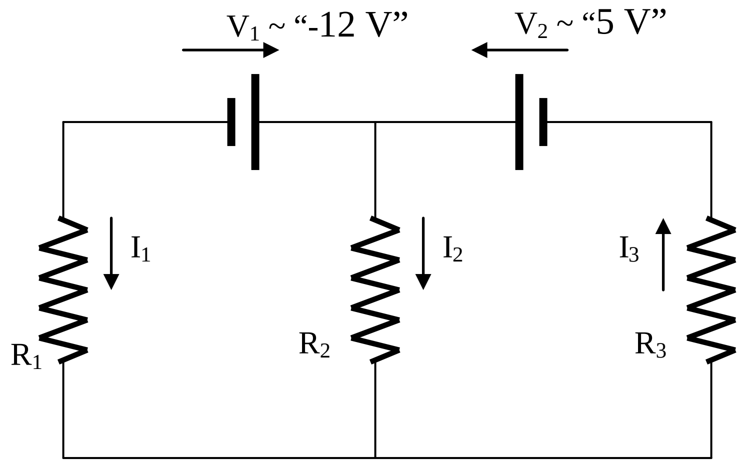
Part 4 – Kirchhoff's Circuit B



Circuit A – Measurements:

Actual voltages (From Part 2.2)

V_1 = ________V, V_2 = ______V

Resistances (From Part 2.2)

R_1 = ______Ω , R_2 = _______Ω , R_3 = _______Ω

Actual Currents using the ammeter (Remember to include the sign)

$I_{1(meas)}$=______A, $I_{2(meas)}$=_______A $I_{3(meas)}$=________A

Circuit B – Calculations:

Using the circuit equations below and the values for V_1, V_2, R_1, R_2, and R_3 from above , calculate the values for $I_{1(cal)}$, $I_{2(cal)}$, and $I_{3(cal)}$ on the next page.

$$I_3 = I_1 + I_2$$

$$V_1 = I_1R_1 - I_2R_2$$

$$V_2 = I_2R_2 + I_3R_3$$

This space is for the loop calculations (Hint: round the resistance values to a whole number)

Circuit B – Calculated Currents:

$\mathbf{I_{1(cal)}}$ = ___________ A $\mathbf{I_{2(cal)}}$ = ___________ A $\mathbf{I_{3(cal)}}$ = ___________ A

How well did your calculated current values match up with your measured current values? How well did your signs/directions match? [If there are strong differences, you might need to either re-measure or re-calculate.] (Remember – if the sign only is different either the meter is in backwards or we guessed wrong on the current direction.)

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Questions/Suggestions → James Nolta - jnolta@LTU.EDU