Circuit Theory Review
4190.309
2008 Fall Semester

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Voltage, current and resistance

- Resistance limits the current
- Electric circuit consists of a source, a load and a current path
- An ammeter is connected in line with the current path
- An voltmeter is connected across the current path
- An ohmmeter is connected across the resistor
- Coulomb
  - 1 coulomb = 6.25×10^{18} electrons
- Volt
  - One volt is the potential difference between two points when one joule of energy is used to move one coulomb
- Ampere
  - One ampere is the amount of current that exists when one coulomb of charge moves though a given cross-sectional area of a material in one second
- Ohm
  - One ohm is the resistance when there is one ampere of current in a material with one volt applied across the material

Ohm's law

- Relationship of voltage, current and resistance
  - Voltage and current are linearly proportional
- Resistor
  - Resistor color codes
    - Four band code
    - Five band code
  - Resistor specification
    - Tolerance
    - Power
    - Frequency range
  - Types and structures

Power and energy

- Definition
  - Energy
    - Ability to work
  - Power
    - How fast energy is used
    - Heat dissipation
  - Watt and Watt hour
    - Energy = Power × time
  - Power in an electric circuit
    - Question: calculate the power consumption of the circuit
    - Heat dissipation

Series circuits

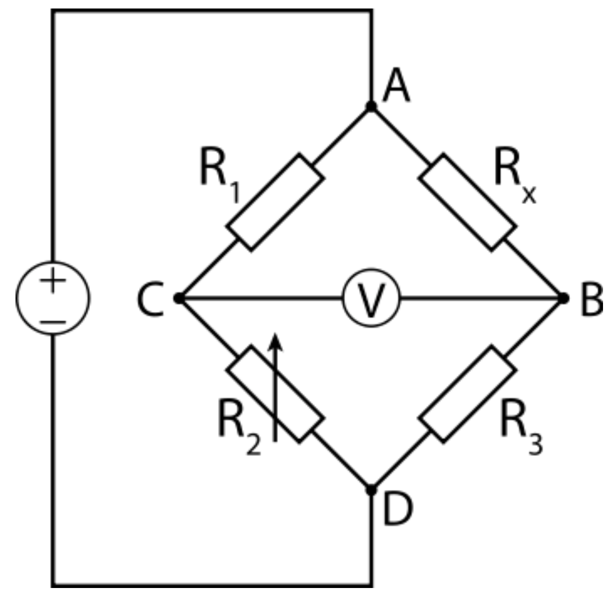
- Series resistors
- Kirchhoff's voltage law for lumped circuits
  - The sum of all the voltages drops around a single closed loop in a circuit is equal to the total source voltage in that loop
  - $V_S = V_1 + V_2 + V_3 + \cdots + V_n$
- Voltage dividers
  - Adjustable voltage dividers
  - Applications of voltage dividers
    - Audio volume control and tank level gauge
- Power in a series circuit
- Circuit ground
  - Zero volts with respect to all points referenced to it in the circuit

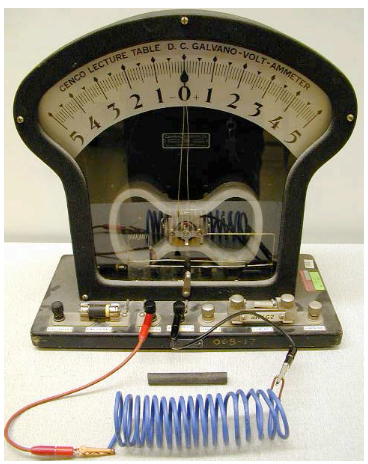
Parallel circuits

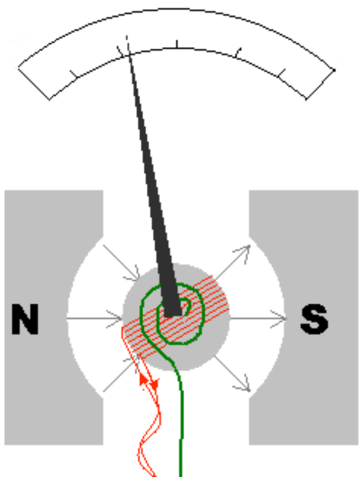
- Resistors in parallel
- Kirchhoff's current law for lumped circuits
  - The sum of the current into a junction is equal to the sum of the current out of that junction
  - $I_S = I_1 = I_2 = I_3 + \cdots + I_n$
  - The algebraic sum of all the currents entering and leaving a junction is equal to zero
- Total parallel resistance
- Current source in parallel
- Power in a parallel circuit
- Examples of parallel circuits
  - ammeters

Series-parallel circuits

- Ladder networks
- The R/2R ladder network
- The Wheatstone bridge
  - Galvanometer
  - Balanced Wheatstone bridge







Circuit theorems and conversions

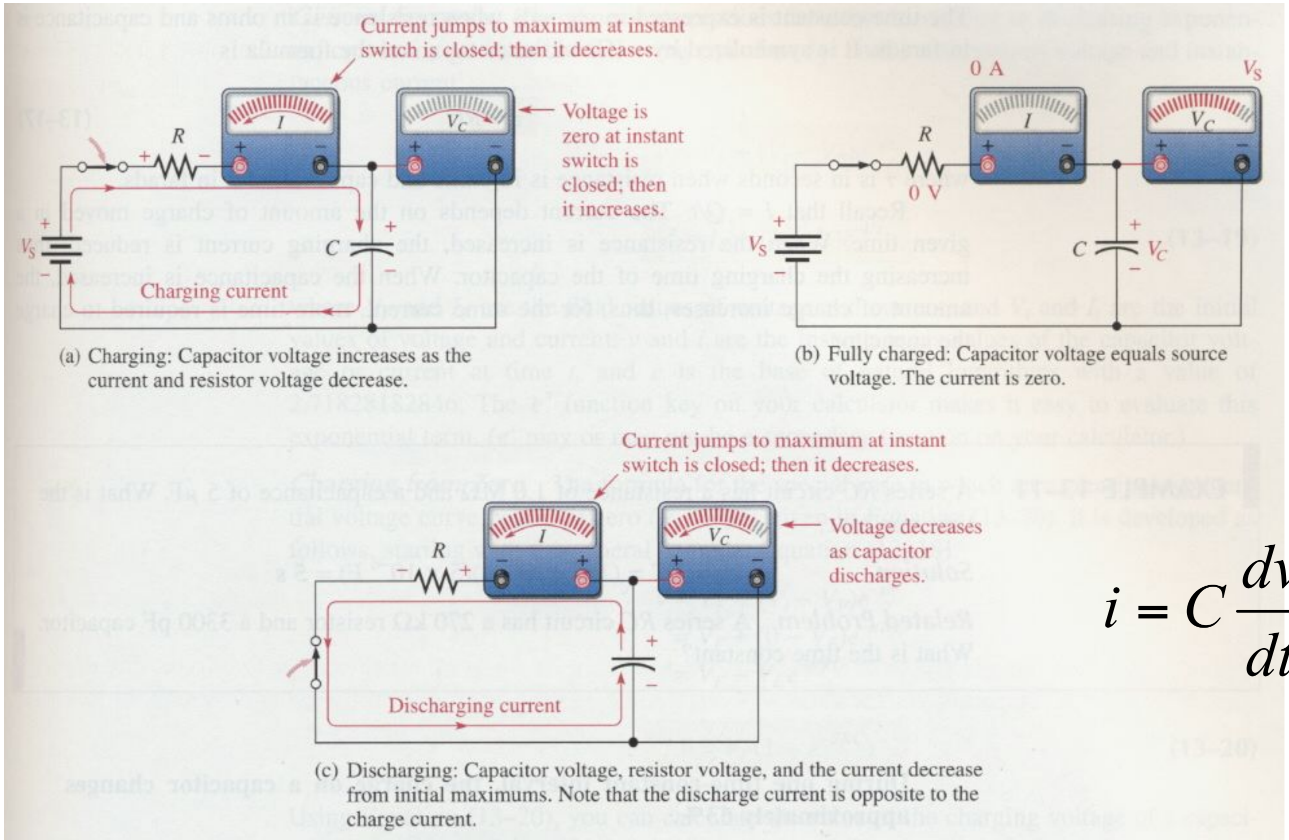
- Voltage source
- Current source
- Internal source resistance
  - Internal source impedance
- The superposition theorem
  - Thevenin's theorem
    - Thevenin equivalent voltage source
    - Thevenin equivalent resitance
  - Thevenin equivalency and viewpoint
  - Thevenizing a portion of a circuit
- Norton's theorem
  - Norton's equivalent current and equivalent resistance
- Maximum power transfer theorem

Branch, mesh and node analysis

- Loops, nodes and branches
- Mesh current method
  - Assign loop currents
  - Apply Kirchhoff's voltage law around each loop
  - Develop the loop (mesh) equations
  - Solve the loop equations
- Loop voltage method
  - Select the nodes at which the voltage is known and assign current
  - Apply Kirchhoff's current law at each node
  - Develop the node equations
  - Solve the node equations

Capacitors

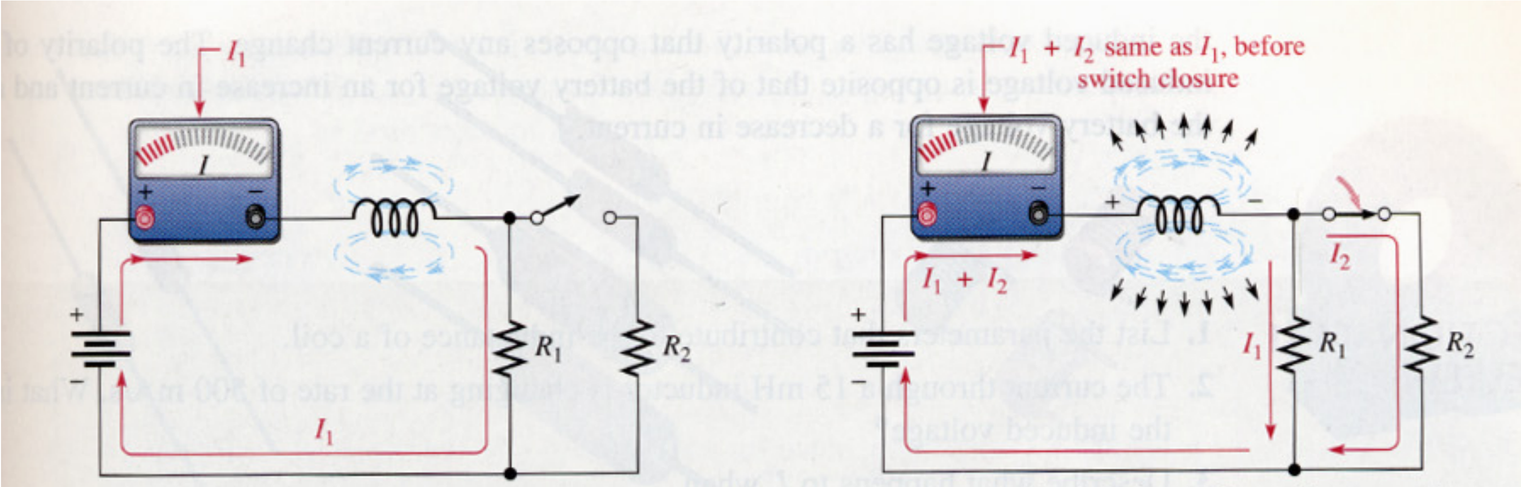
- Charging and discharging



$$i = C\frac{dv}{dt}$$

Inductors

- Lenz's law

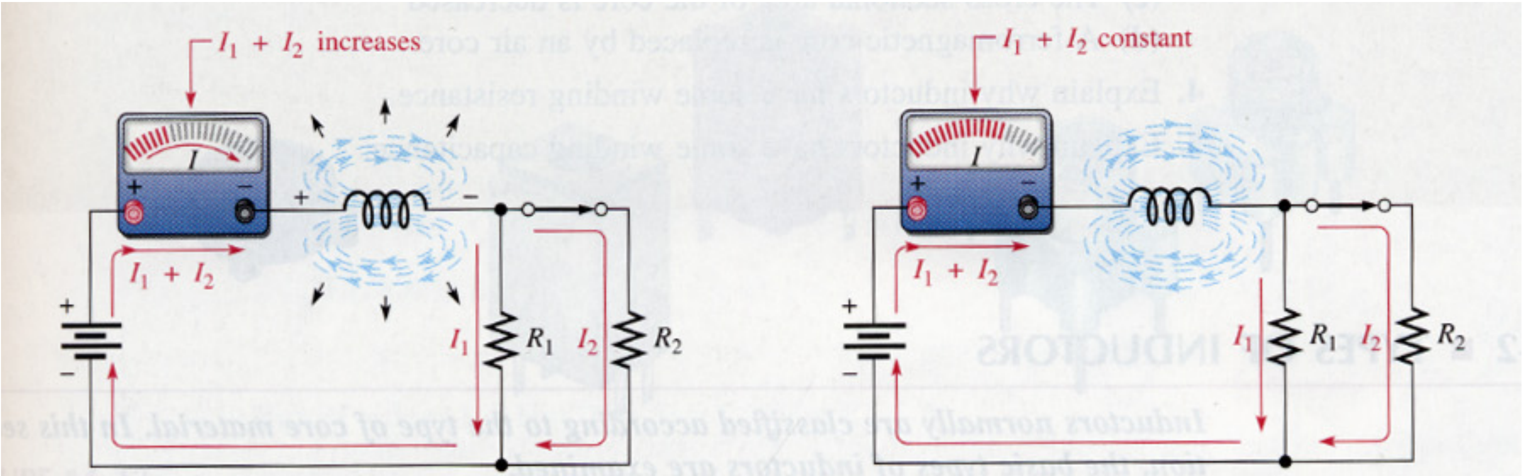


(a) Switch open: Constant current and constant magnetic field; no induced voltage.

(b) At instant of switch closure: Expanding magnetic field induces voltage, which opposes increase in total current. The total current remains the same at this instant.

Inductors

- Lenz's law

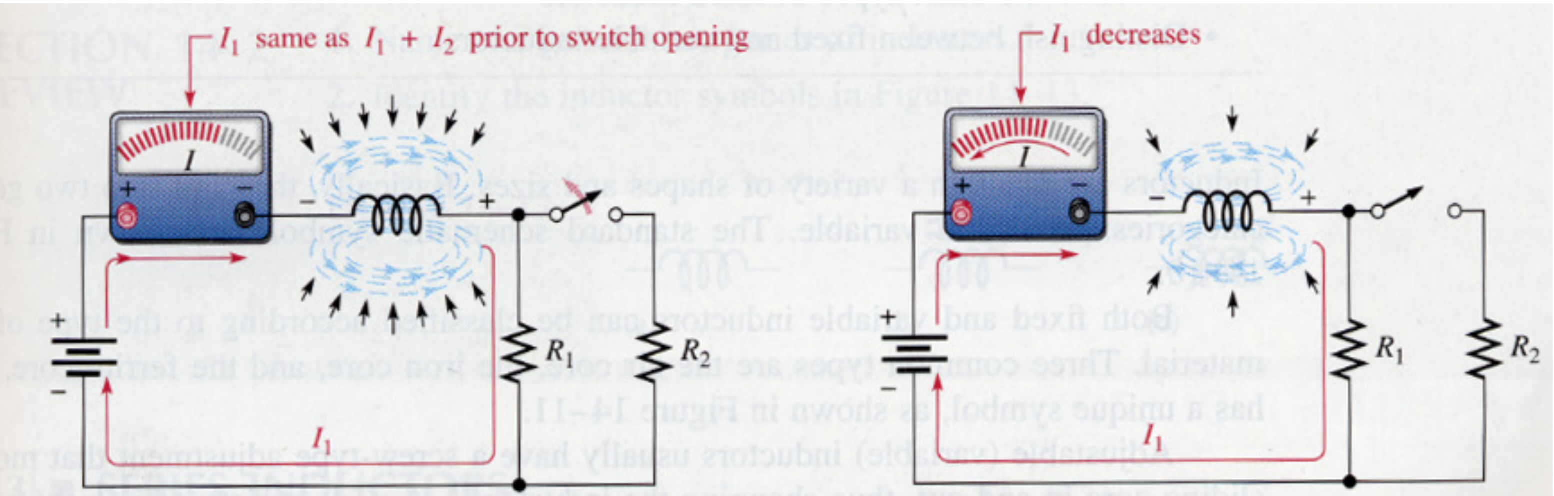


(c) Right after switch closure: The rate of expansion of the magnetic field decreases, allowing the current to increase exponentially as induced voltage decreases.

(d) Switch remains closed: Current and magnetic field reach constant value.

Inductors

- Lenz's law



(e) At instant of switch opening: Magnetic field begins to collapse, creating an induced voltage, which opposes decrease in current.

(f) After switch opening: Rate of collapse of magnetic field decreases, allowing current to decrease exponentially back to original value.

Capacitors

- Control integral of current

$$i = C\frac{dv}{dt}$$

- Impedance
  - Resistance for the sinusoid
- Capacitors are characterized by:
  - Maximum voltage (V)
  - Tolerance (%) (temperature)
  - Frequency range (Hz)
- Type of capacitors
  - Ceramic
  - Film (Polyester, Polypropylene and metalized)
  - Electrolytic (aluminum and tantalum)
  - Chip (C0G and X7R)

Inductors

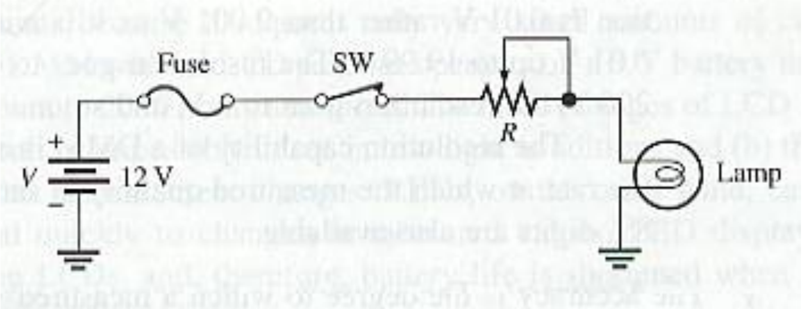
- Control derivative of current

$$v = L\frac{di}{dt}$$

- Impedance
  - Resistance for the sinusoid
- Inductors are characterized by:
  - Maximum current (A)
  - Tolerance (%)
  - Frequency range (Hz)
- Type of inductors
  - Air
  - Ferrate
  - Iron

Theory in practice

- Circuit example
  - Functions?



- Turn on and turn off the lamp
- Dim the illumination
- Add a safety feature

Circuit analysis

- Transient analysis
  - Pulse response of reactive circuits
  - Time domain analysis
- Steady-state analysis
  - Sinusoidal input
  - Fourier series
  - Frequency domain analysis

Illumination circuit of an instrument panel of a car

Linear Circuit Theory
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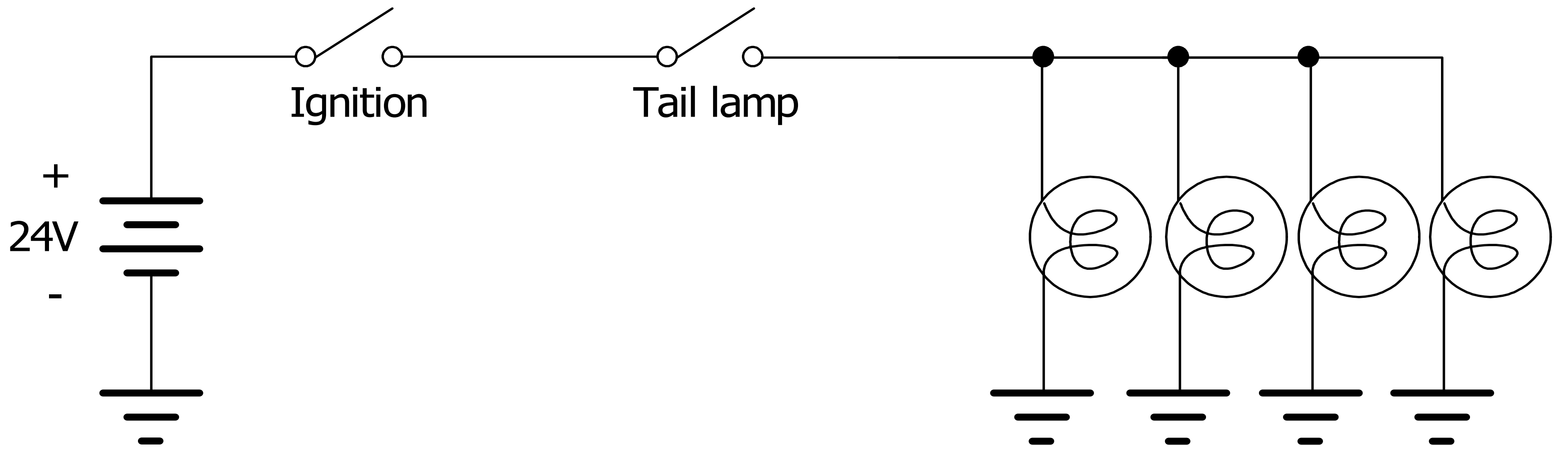
Theories in practice

Simple illumination circuit

- A lightweight truck has illumination lamps in the instrument panel. The main switch is the ignition switch that masters the whole vehicle power. When a driver turns on the tail lamp switch, the instrument panel illuminates so that the driver may recognize vehicle speed, water temperature, engine RPM, etc, in the dark.

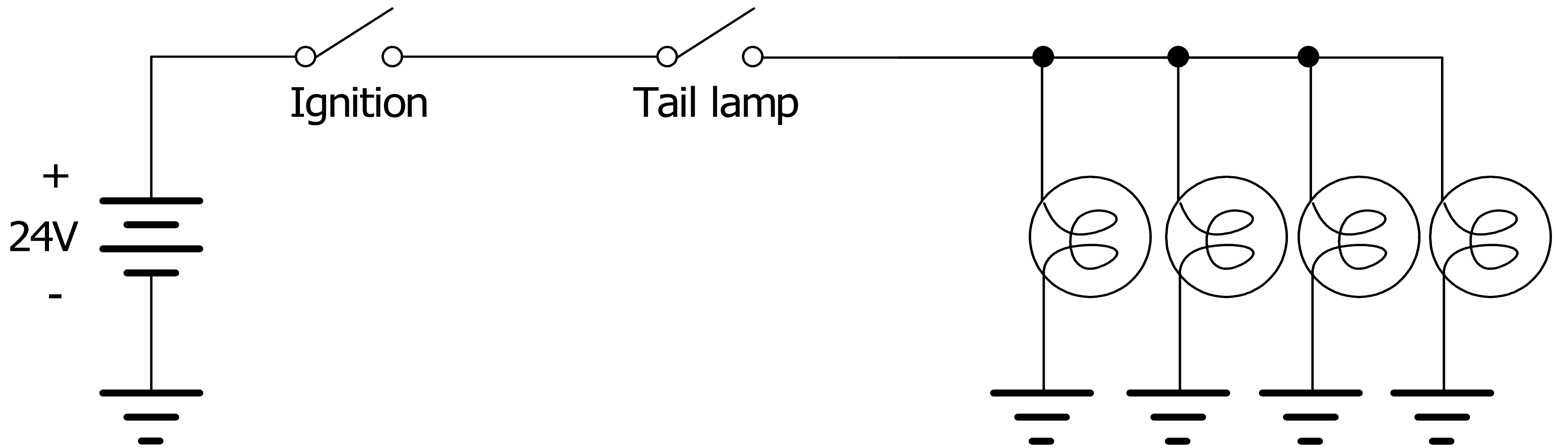


Modify the illumination circuit

- Add a safety feature
  - Add a fuse
- Add a dimming feature
  - Add an adjustable knob to control the luminance of the lamp
- Steps for modification
  - Analyze the circuit
  - Add a fuse
  - Add a potentiometer
  - Verification of the modification

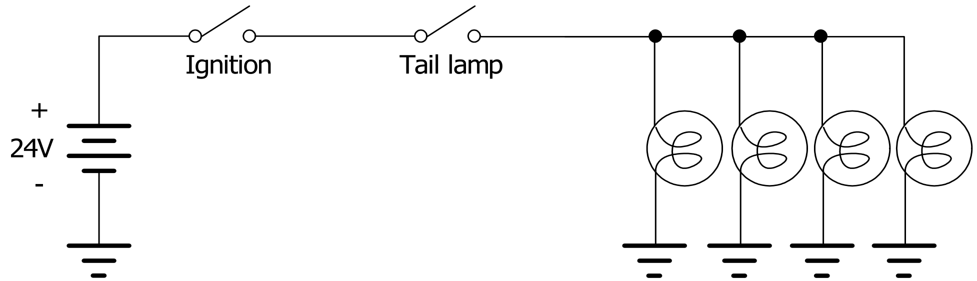
Step 1: Analysis

- We want to figure out that how much power is dissipated. Draw a schematic diagram to measure the power consumption



Step 1: Analysis

- If the lamps draw 2A current in total, calculate the resistance of the lamp. Note that, all the lamps are identical.



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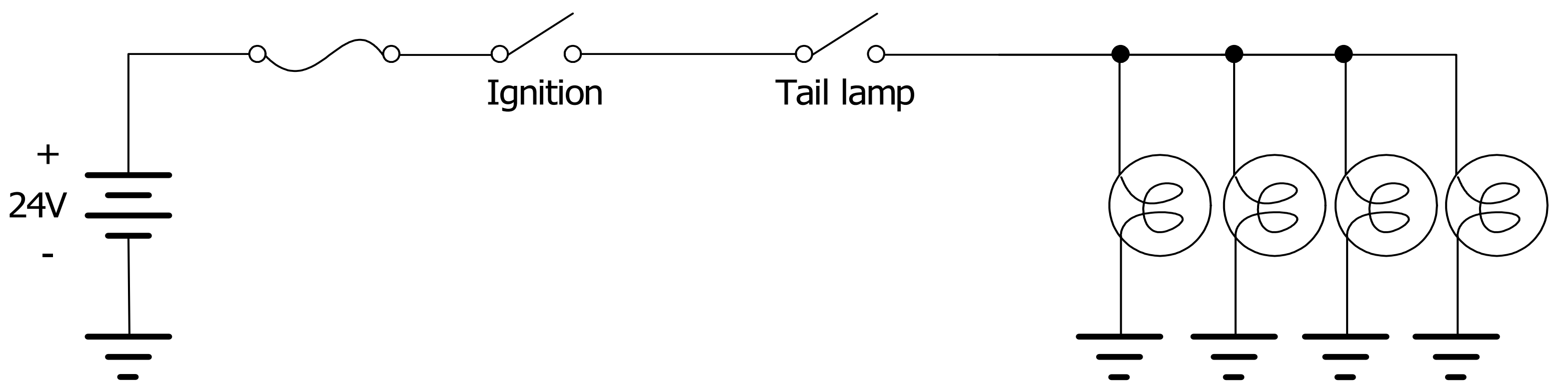
Step 2: Add a fuse

- Sometimes, the lamp and the wire may short to the body frame (ground). So, we want to add a safety feature. Calculate proper rating of the fuse.

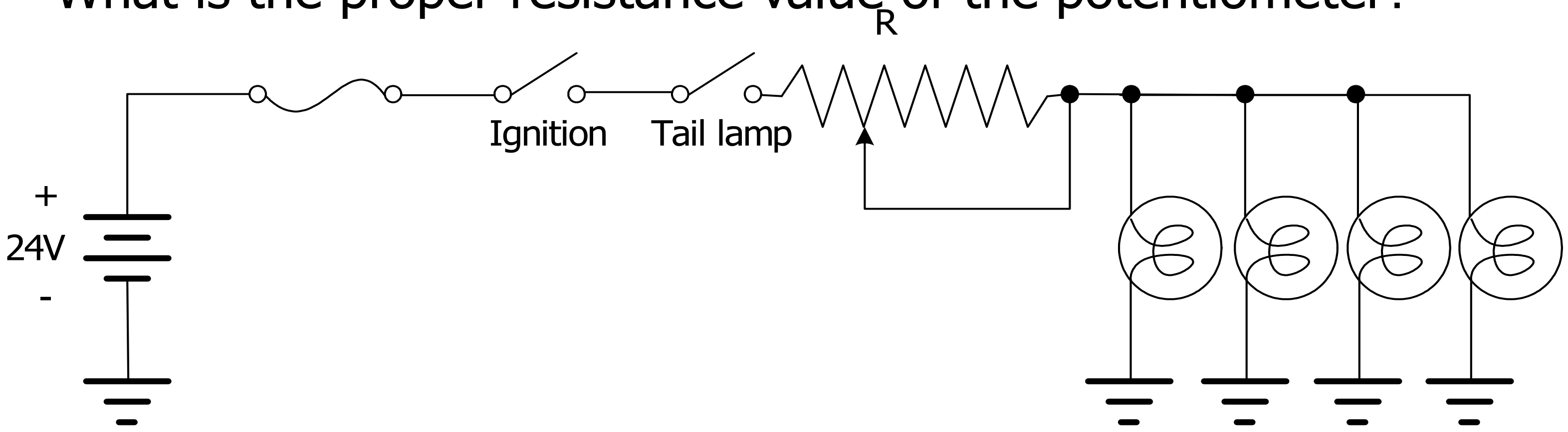


Step 3: Add a potentiometer

- We want to change the luminance of the instrument panel by adjusting a knob. We want to adjust the luminance from 1/10 to full brightness. Determine the value of the potentiometer, R .
- Question
  - What's the relationship between the power consumption of the lamp and its luminance?
  - What's the relationship between the power consumption of the lamp and the current?
- How to control the luminance of the lamp?
- How to control the current?

Step 3: Add a potentiometer

- Add a potentiometer
  - What is the proper resistance value of the potentiometer?

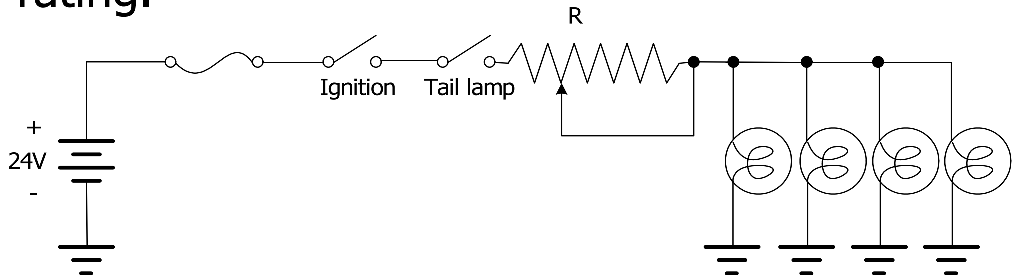


Step 3: Add a potentiometer

- Use a potentiometer as a rheostat

Step 3: Add a potentiometer

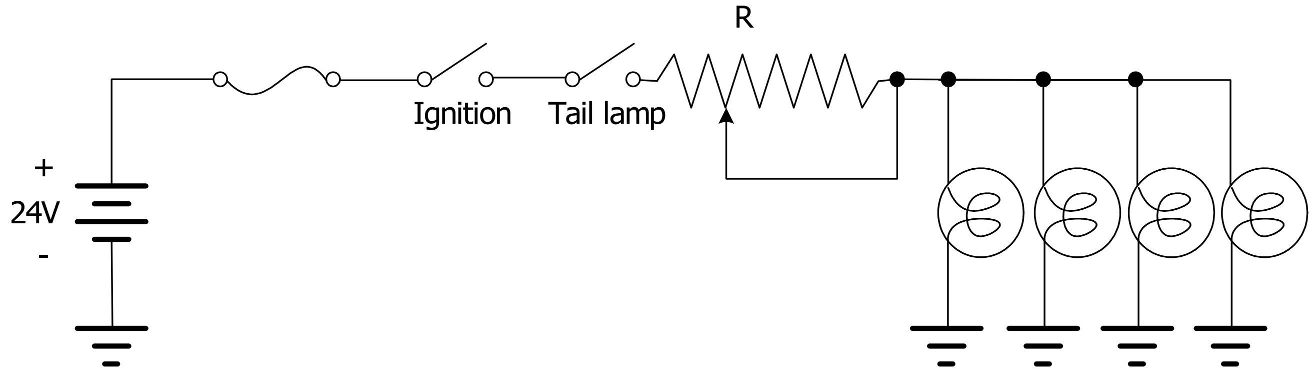
- Selection of a potentiometer?
  - What else do we need to determine?
    - Power rating.



  - Power consumption of the potentiometer
    - Is is variable or fixed?
    - How do we calculate?

Step 4: Verification

- Determine the minimum power consumption of the illumination circuit



Step toward a real-world case

- Assume that the resistance of lamp at the ambient temperature is 1/10 of the steady-state resistance. Calculate again a proper tolerance of the switches, the potentiometer and the fuse.