

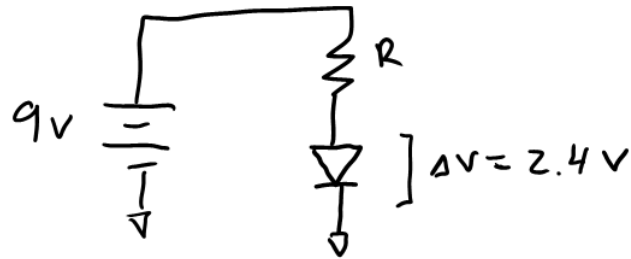
## **Circuits**

### **– Models of Motion 2015 –**

Sample problems from previous years.

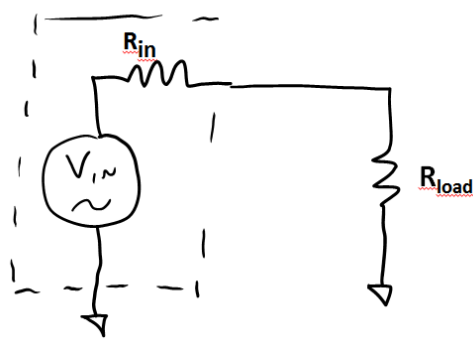
NOTE: this circuits class is different, and covering different material, so these problems are not exact examples of what you might see. They are intended to be representative of my question style, and of circuit-type questions I have asked before.

1. (5 points) An LED requires 10mA of current to light up properly. When it is lit, it has 2.4V across it. You use a 9V battery to power it; what resistor should you use in series with the LED to get the right current?



2. (10 points) Extra Credit: You have a function generator putting out some voltage, and the generator has an internal resistance  $R_{in}$ . For radio-frequency circuits, it is important to maximize the power absorbed in the load (the other system) you connect to the signal generator – anything not absorbed will reflect, making a big mess and possibly damaging things.

Signal Generator



- a. Assuming  $V_{in}$  is steady and constant, and  $R_{in}$  is a constant, find an expression for the power dissipated in  $R_{load}$ .
- b. Find the value of  $R_{load}$  for which the power transmitted to the load (i.e., dissipated in  $R_{load}$ ) will be a maximum.
- SHOW YOUR WORK – no work, no credit.

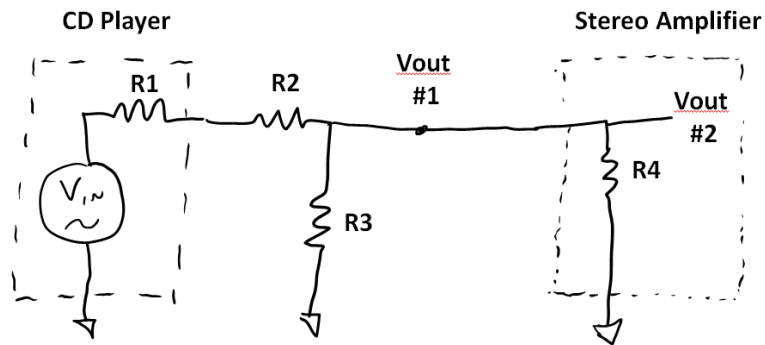
1. Fill in the following formulas (25 points / 5 points each):

<p><b><u>Two</u> formulas for the power dissipated in a resistor: First formula:</b></p>	
<p><b><u>Two</u> formulas for the power dissipated in a resistor: Second formula:</b></p>	
<p><b>Formula for the total resistance of two resistors in parallel:</b></p>	
<p><b>Kirchoff's voltage law:</b></p>	
<p><b>Krichoff's current law:</b></p>	

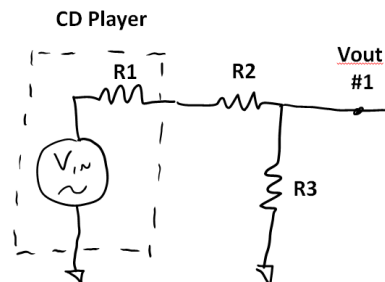
2. (25 points total) Volume control for a stereo: you have a CD player and an amplifier with no volume control (called a “power amplifier”), as shown in the figure below.  $R_1$  is the output resistance of the CD player, and  $R_4$  is the input resistance of the amplifier:



You want to make a volume control with some resistors, so you build a circuit like the one shown below:



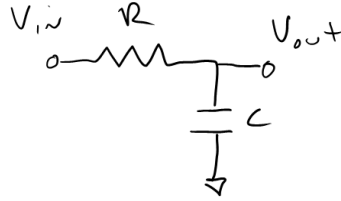
- a. (15 points) Write down the formula for the volume ( $V_{out\#2}$ ) based on  $V_{in}$  and  $R_1, R_2, R_3, R_4$ . Please include drawings of any ways in which you simplify the circuit, so I can give partial credit/see what you are doing. Simply writing the answer with no explanation is no credit.
- b. (10 points) For your CD player and amplifier,  $R_1 = 100\Omega$  and  $R_4 = 50k$ . Choose values of  $R_2$  and  $R_3$  that give  $V_{out\#1} = 0.5 * V_{in}$  when the amplifier is NOT connected, and still give at least 45% of  $V_{in}$  when the amplifier IS connected. Example of amplifier NOT connected:





4. Extra credit (10 points): You manage a large factory, which has equipment that acts like a large capacitor, of value  $C = 10 \text{ F}$ .
- (3 points) What current does your factory draw from the power lines?  
[Nb: lines supply  $V = 120\text{V} * \sin(2\pi * 60 \text{ Hz} * t)$ ]
  - (5 points) If the power lines run 100m to the power substation, at  $0.03\Omega/\text{km}$ , how much power is dissipated in the power lines?
  - (1 point) From Question #3 (above), how much power is dissipated in your factory?
  - (1 point) How much power should the power company bill you for? Note: this is called billing according to the “power factor”, and there is a way to vastly reduce the problem.

1. (20 points): Low-pass filter:



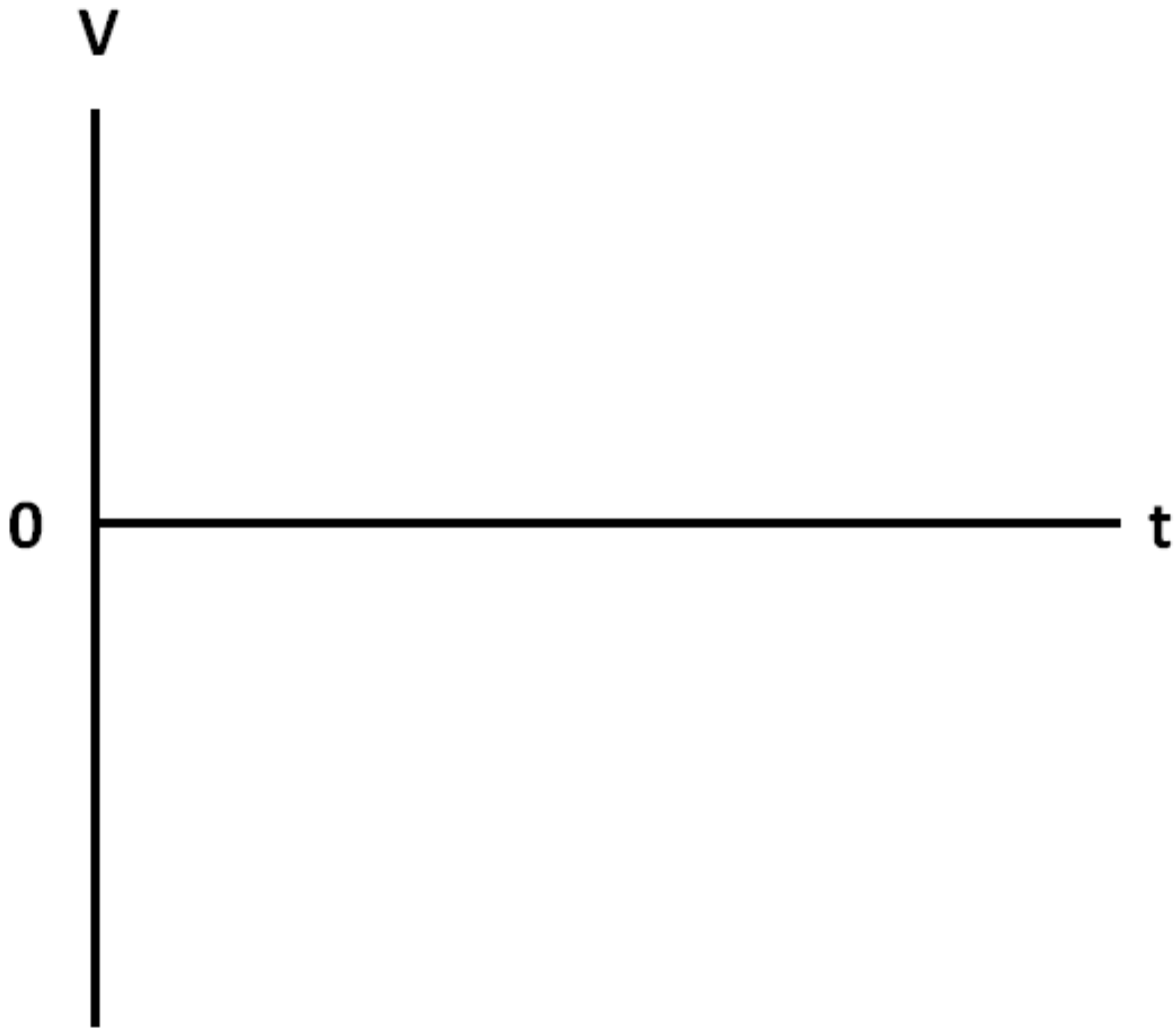
The filter above works as follows: The current through the resistor  $R$  is  $I = (V_{in} - V_{out}) / R$ . The voltage across the capacitor varies as  $I = C \, d/dt \, V_{out}$ . Combining these gives the equation:

$$\left[ \frac{(V_{in} - V_{out})}{R} \right] = C \frac{dV_{out}}{dt}$$

Assume that  $V_{in} = \text{constant} > 0$ , and  $V_{out} = 0$  at time  $t = 0$ . Show EVERY STEP in the derivation of the final formula for  $V_{out}$ ,

$$V_{out} = V_{in} * \left( 1 - e^{-\frac{t}{RC}} \right)$$

2. (5 points extra credit): Graph  $V * \left(1 - e^{-\frac{t}{RC}}\right)$ . Label the maximum and minimum of the function, if any, and (at least) indicate the y-axis values at  $t = 0, RC, \infty$ .



1. (20 points) Many physical processes obey the formula of the form:

$$\frac{dV}{dt} = -\alpha V$$

Where  $V$  is a function of time, i.e. is  $V(t)$ , and  $\alpha$  is a constant (e.g., maybe  $\alpha = 1 / RC$  for an RC circuit.)

Assuming that  $V$  has the value  $V_0$  at time  $t = 0$ , derive the FULL solution to the equation above.

SHOW EVERY STEP. Be very clear.

If you are in any doubt as to whether I want to see a step, include it.