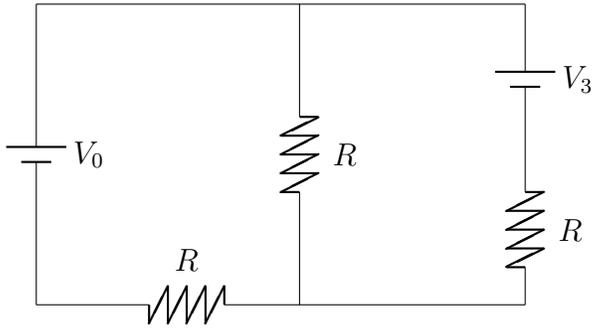


**Note:** As I walk around, you can ask me for help; for example, to supply an equation or a number you have forgotten down, or to give you algebra aid. If you do, however, I will write down what help I provided on your exam, and grade your answer accordingly.

**1. (30 points)** A friend of yours hears that “space and time are curved” on a science fiction show, and decides to ask you to explain that statement, since you’re taking a physics course. How would you explain it? What examples would you use?

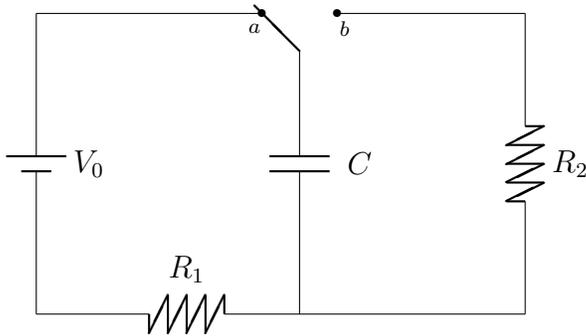
2. (40 points) You have the following circuit with three identical resistances  $R$  and two batteries with voltage  $V_0$  and  $V_3$ .



(a) Solve for  $I_3$ , the current through the battery with  $V_3$ , in terms of  $R$ ,  $V_0$ , and  $V_3$ .

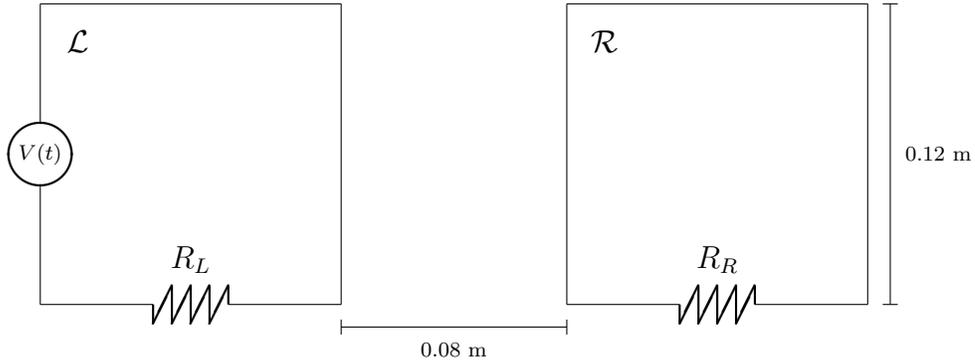
- (b) You can use a second battery like  $V_3$  in this circuit to control the power dissipated by the resistor in series with  $V_3$ . Say you knew the power dissipated by this resistor had to be  $V_0^2/36R$ . What would  $V_3$  then have to be?

**3. (40 points)** Here is a simplified (oversimplified) model of a circuit for a camera flash. The resistance  $R_1$  is considerably larger than  $R_2$ . When the switch is at  $a$ , the capacitor  $C$  slowly recharges. When the switch is at  $b$ ,  $C$  rapidly discharges.

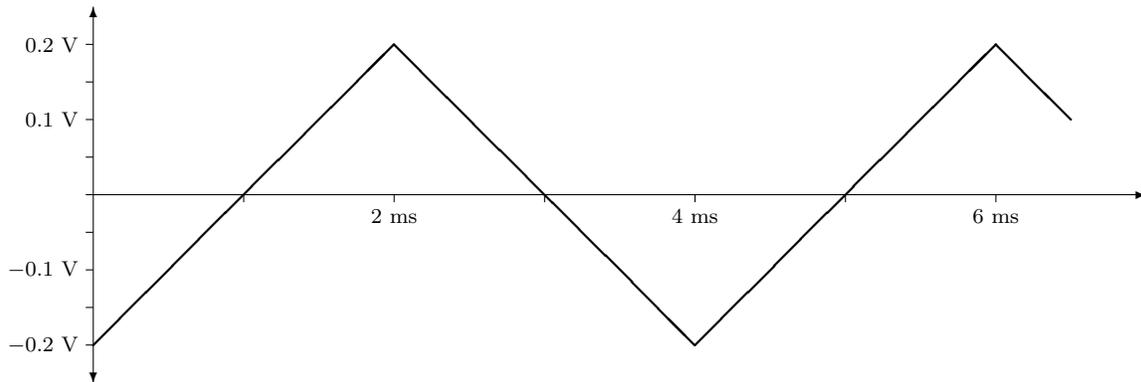


- (a) Say the switch remains at  $a$  for a long time in order to fully charge up the capacitor. This is a “long time” compared to what?
- (b) What is the power dissipated by  $R_2$  immediately after the switch is flipped to  $b$ ? Explain, using this, why a flash requires a small value for  $R_2$ .
- (c) Say  $C = 12 \mu\text{F}$ , and  $R_2 = 0.21 \Omega$ . How long will it take for the capacitor to discharge 90% of its starting charge?

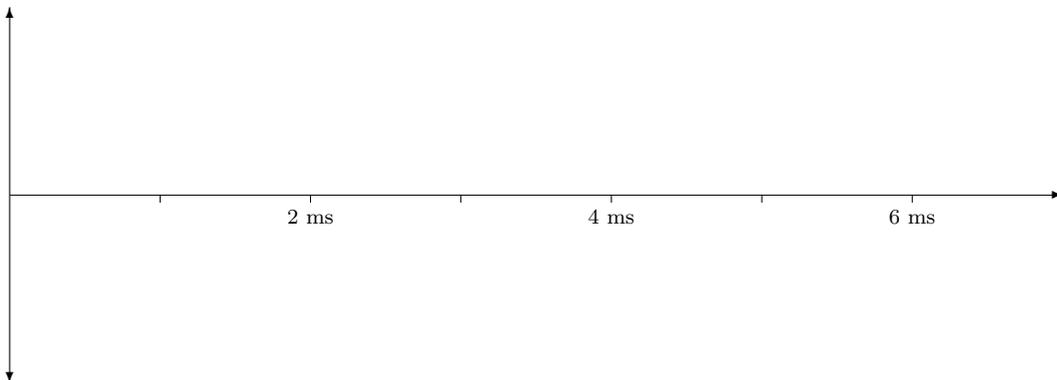
4. (50 points) You have two circuits next to each other:



Each circuit is square with  $0.12\text{ m}$  sides, and  $0.080\text{ m}$  separates the right edge of the left circuit ( $\mathcal{L}$ ) from the left edge of the right circuit ( $\mathcal{R}$ ). Both have the same resistance values  $R_L = R_R = 0.50\ \Omega$ , and  $\mathcal{L}$  has a voltage source which produces a sawtooth waveform  $V(t)$ , which looks like the following on an oscilloscope:



(a) Sketch the shape of the waveform you will see if you measure the voltage across  $R_R$  with an oscilloscope. Don't put in any voltage numbers—just sketch the waveform.



- (b) Now let's make some approximations to estimate the amplitude of the voltage waveform induced in  $\mathcal{R}$ . There are four wire segments in  $\mathcal{L}$ : the left, top, right, and bottom on the diagram. The current in each wire produces a magnetic field through  $\mathcal{R}$ . Only one of the following makes the largest contribution to the magnetic flux through  $\mathcal{R}$ —we will just take that and ignore the rest. Circle your answer:

The right wire      The top and bottom wires      The left wire

*Brief explanation:*

The magnetic field produced by the wire segment you picked will not be uniform through  $\mathcal{R}$ . But we are looking for a rough estimate, so we will assume that it is uniform. The magnitude of  $B$  at what part of  $\mathcal{R}$  will be a representative value to use in this uniform approximation?

The right edge      The center      The left edge

*Brief explanation:*

Now we need an equation that will help us get the magnetic flux:

$$\text{Loop: } B = \frac{\mu_0 I}{2r} \quad \text{Long wire: } B = \frac{\mu_0 I}{2\pi r} \quad \text{Wire: } F = ILB$$

*Brief explanation:*

Finally, use all this and estimate the *amplitude* of the waveform sketched in part (a).

5. (40 points) You have a proton and an antiproton at rest on Earth. They annihilate to produce a muon-antimuon pair:  $p + \bar{p} \rightarrow \mu^- + \mu^+$ . The muon heads toward the Moon,  $3.8 \times 10^8$  m away, and the antimuon is captured by a detector here on Earth. The typical lifetime of a muon is  $2.2 \times 10^{-6}$  s. Will the muon make it to the Moon to be captured by a detector there? A muon's mass is  $m_\mu = 1.9 \times 10^{-28}$  kg, or  $110 \text{ MeV}/c^2$ . A proton's mass is  $m_p = 1.7 \times 10^{-27}$  kg or  $940 \text{ MeV}/c^2$ . The speed of light is  $3.0 \times 10^8$  m/s. Note:

- Relativistic energy ( $\gamma mc^2$ ) and momentum ( $\gamma m\vec{v}$ ) are both conserved in this reaction. Show how you use both.
- You'll get a **bonus +5 points** if you solve this using the masses given in  $\text{MeV}/c^2$ .